



*NAVAL RESEARCH PROGRAM
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NAVAL POSTGRADUATE SCHOOL*



2017 ANNUAL REPORT



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NAVAL RESEARCH PROGRAM

NAVAL POSTGRADUATE SCHOOL

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MESSAGE FROM THE DEAN OF RESEARCH

I am pleased to support the Naval Postgraduate School (NPS) Naval Research Program (NRP) in the fourth complete fiscal year of the program. NRP is an official Navy and Marine Corps program, having had its charter signed jointly by the Chief of Naval Research and Commander, Marine Corps Warfighting Laboratory in August of 2015. The studies sponsored within FY17 have made significant contributions to the Department of the Navy (DoN) by providing insights to key operational decision-makers along with recommendations to support cost savings in a fiscally constrained environment. The NRP's funding and program goals are 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 results from the spectrum of NPS NRP research activities conducted on behalf of both Navy and Marine Corps Topic Sponsors during the 2017 fiscal year. Executive summaries from each of the 96 research projects are included in the report. While most of those summaries detail final results, some projects have multi-year project lengths. In those cases, progress-to-date is reported.

NRP is one critical component of the overall NPS research portfolio. Under the stewardship of the NPS president, it utilizes a dedicated block of research funding to assist the operational naval community with timely studies while also informing NPS students and faculty about the latest operational priorities. As such, NRP projects are excellent complements to the other faculty-driven research projects, which tend toward the basic research program areas.

Looking forward to FY18, NRP management will transition from founding manager Dr. Rodman Abbott to a new NPS staff member being recruited through a national search. We all thank Dr. Abbott for his leadership and insights as the program was stood up and we wish him well back in his permanent position at the Lawrence Livermore National Laboratory. In addition, the program itself is slated to become a component of the newly formed Navy Analytic Office (NAO), which will place it squarely within the Navy's data gathering and decision informing processes.

Finally, the many benefits that accrue through the NPS NRP depend on the wholehearted participation of the NPS faculty, the NPS students, and the many Topic Sponsors from across the OPNAV and Marine Corps headquarters commands. My thanks to all who have participated during this program year.

Sincerely,



Dr. Jeffrey Paduan NPS Dean of Research

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NAVAL RESEARCH PROGRAM OVERVIEW

The Naval Postgraduate School (NPS) Naval Research Program (NRP) is funded by the Chief of Naval Operations, 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 Department of the Navy (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 DoN 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 United States Marine Corps (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 2,000 potential and current research topics through NRWG events, while funding over 300 research projects.

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 the NRP’s operations, NPS research is more directly aligned with the naval community than in prior years:

- In FY17, NPS received \$12.8M, which it translated into over 96 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 FY17 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 300 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 over 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 newfound knowledge from graduate studies. There were over 234 United States and foreign thesis students collaborating with faculty on 73 of the 96 projects.

FY17 Research Highlights

The FY17 research aligns with the recently released NPS Strategic Plan and the 2018 National Defense Strategy. The FY17 ERB and TRB implemented a business rule to encourage collaboration across both Navy and Marine Corps Topic Sponsors. That decision recognized that the NRP should address broader naval issues. The NPS Strategic Plan signed in April 2018 recognizes that the most impactful research areas are those that address the core challenges facing both the Navy and the Marine Corps. Accordingly, the research highlights are grouped by topic area.

Data Science and Machine Learning

The Naval Research Program funded 25 studies related to data science and machine learning. Some studies, such as NPS-17-N279-A: Reinforcement Learning for Modeling Large-Scale Cognitive Reasoning and NPS-N16-M163-A: Exploring Potential Alternatives Using Simulation and Evolutionary Algorithms, focused on the algorithms and logic behind machine learning. Other studies, such as NPS-17-N185-B: Big Data Strategy Plan for Combat ID and NPS-17-N088-A: Scaled Approach to Open Sourcing Department of the Navy Produced Software were focused on the adoption of big data and machine learning into the Navy. The breadth of topics leveraging big data and machine learning span all of the warfare domains from air to cyber to undersea. The studies also highlight the impact data science and machine learning will have on challenges such as insider threat, additive manufacturing, and sonar detection. Individually, the studies provide answers to the specific questions or the Topic Sponsors. In aggregate, they are building the capacity of NPS to respond to the challenges of adopting artificial intelligence across the Department of Navy.

Innovation

In line with the broader focus on innovation, the Naval Research Program delivered in key areas. Innovation is the adoption of a new practice within a community. Several studies focused on understanding innovation within specific communities in the Navy and best practices for adopting innovations in those communities. Three studies that highlight that theme include: NPS-17-N097-A: Analysis of Navy Innovation Network; NPS-17-N125-A: Analysis of Innovation Communities of Interest for Technology Transfer and Development; and NPS-17-N353-A: Fostering Innovation in the Naval Research and Development Establishment. Other studies looked at the adoption of key technologies across the Navy such as additive manufacturing, manpower analysis, and learning centered technologies. Three studies that highlight this theme include: NPS-17-N236-A: Additive Manufacturing: Technical Issues and Test of Large Scale Adoption in Naval Domain; NPS-17-M360-A: Variable Flow Model (VFM) for USMC Manpower Analysis; and NPS-17-N159-A: The Role of Navy Processes in Enabling and Constraining the Adoption and use Of Learning Centered Technologies.

Cyber

In Cyber, the studies provided tailored answers to the challenges facing the naval service from operations afloat (NPS-17-N221-A: Afloat Network Defense Cyber Operations with CDOSS and MAST) to developing core capabilities (NPS-17-M156-B: Developing, Simulating, and Training for Cyber Attacks on Adversary Networks). Research in the Cyber domain highlights the linkage to other concerns such as the Insider Threat (represented by NPS-17-N342-A: Lexical Link Analysis of Insider Threats Using Digital Forensics) and self-induced challenges such as updates to the Marine Corps Enterprise Network (represented by NPS-17-M190-A: Automated Testing of Virtualized MCEN). More broadly, the FY17 research projects underscore that Cyber is the critical enabler for all of the other systems in other domains to operate effectively.

Talent Management

Talent management was an area of research that highlighted the common concerns of the Navy and the Marine Corps where the solutions are tailored to the specific requirements of the service. Both the Navy and Marine Corps were concerned about talent management, but each approached the topic differently. For the Navy, the issue was captured in the study NPS-17-N191-B: Improving Navy Talent Management with Model-Driven Big Data. For the Marine Corps, NPS-17-M001-A: Issues in Marine Corps Talent Management approached the talent management question from a more qualitative perspective. The studies are complementary and can provide the basis for future research by the sister service. Likewise, both services are interested in non-cognitive measures and retention analysis models as represented by: NPS-17-N181-A: Utilizing Non-Cognitive Measures for Navy Selection and Classification; and NPS-17-N358-A: Retention Analysis Model (RAM) for Navy Manpower Analysis. The Marine Corps leveraged Navy-supported research in applying sleep study research to the Marine Corps Aviation community in NPS-17-M014-A: The Effects of Crew Rest on Performance in Marine Corps Aviation. The ongoing work in sleep research and its application to the Navy and Marine Corps are critical components to force preservation efforts by both services.

Acquisition and Logistics

The NRP supports the core service function of equipping the force. In acquisitions, this is highlighted by the research into full ship shock testing in NPS-17-N382-A: Investigation into the True Systemic Benefits of Full Ship Shock Trials. Other studies investigated the opportunities offered by emerging technologies such as NPS-17-N089-B: ASW Continuous Trail Unmanned Vessel (ACTUV) Operational Vignettes Study and NPS-17-N101-A: The Role of Raw Powder Characteristics in Additive Manufacturing (AM) of Metals and Alloys for Naval Applications. Much of the research for naval logistics focused on fuel consumption, planning, and resource allocation. This research is best represented by NPS-17-N129-A: Reducing Transit Fuel Consumption and Enabling Additional Time on Station with an Improved Transit Fuel Planner (TFP); NPS-17-N130-A: Measure the Potential Impact of Fuel Planner Systems on Surface Fleet Time on Station; and NPS-17-M005-A: Simulation System for Optimal Solutions for Resource Organization and Allocation for the MEB LCE in Support of Operation Assured Resolve. NRP studies provided the basis for decisionmakers and planners to optimize what is acquired and how it is supported.

Global Strategy

The National Defense Strategy signed in 2018 focuses on the return of strategic competition and its impact on U.S. strategy. The FY17 research aligned with the National Defense Strategy even though it had not been signed when the projects were prioritized. NRP projects such as NPS-N16-N422-A: China's "New Asian Security Concept" and US Maritime Interests in East Asia focused on the role of China as a strategic competitor, while NPS-17-N111-A: NATO Resilience and Nuclear Deterrence focused on the threat from Russia. Other studies focused on broader themes such as strategic stability, represented by NPS-17-N112-A: New Directions in Arms Control and Strategic Stability, and where the strategic competition might manifest as represented by NPS-17-N306-A: The Navy's Role in Potential Regional Conflicts. Several studies highlighted courses of action to mitigate the concerns of strategic competition including: NPS-17-N297-A: Creating Unclassified SE Asia Maritime Domain Awareness; NPS-17-N186-B: Employing Distributed Low Cost Sensors ISO C7F Operations; and NPS-17-N086-A: Mapping Dark Maritime Networks. The studies are focused on naval responses in support of the National Defense Strategy.

UNITED STATES NAVY (USN)

N1: PERSONNEL, TRAINING AND EDUCATION

NPS-17-N039-A: Using Eye Tracking to Improve Intelligent Tutoring

Researcher(s): Mr. Perry McDowell, Dr. Quinn Kennedy, Dr. Rudy Yoshida, and Ms. Rabia Khan
Student Participation: Sqn Ldr Salman Aleem PAF

Project Summary

Objective: The purpose of this study was to determine if the incorporation of eye gaze information into the Conning Officer Virtual Environment intelligent tutoring system (COVE-ITS) would provide more targeted feedback to student shiphandlers.

Background: An intelligent tutoring system (ITS) is paired with a U.S. Navy immersive virtual trainer for shiphandling called Conning Officer Virtual Environment (COVE) to monitor students' performance and provide spoken feedback. The feedback can be improved by incorporating the cognitive state of shiphandlers through analysis of their attention allocation patterns from eye tracking data.

Method: This pilot study analyzed the eye tracking data of three expert and five student shiphandlers as they completed a simulated shiphandling scenario. We examined the relationship between shiphandlers' experience level, attention allocation patterns, and performance during a simulated shiphandling exercise.

Results: Results indicate expertise differences in shiphandling performance, general eye tracking measures, scan transitions, as well as time distribution between different areas of interest. The experts' superior shiphandling performance was linked with having targeted and tight attention allocation patterns that focused only on the relevant areas of interest. Students' attention allocation patterns were highly scattered and irregular.

Conclusion: Results suggest that incorporating the "ideal" attention allocation patterns of experts into the ITS could improve its feedback to student shiphandlers by telling students where they should look and when.

Application: Eye tracking data may provide insights into the mental model of a student shiphandler. It can be used by the ITS to provide more appropriate and precise feedback to the trainee, improving performance more rapidly.

Keywords: *training, eye tracking, cognitive state, simulation*

Background

For nearly 16 years, Surface Warfare Officer School (SWOS) has been using COVE to train Surface Warfare Officers in shiphandling. Although originally it was very successful, it required an instructor to observe the trainee throughout the entire training event in order to provide performance feedback. In an attempt to alleviate this burden, the Office of Naval Research (ONR) funded development of an intelligent tutoring system (ITS) which would provide feedback to the trainee during and after the training event. The resulting system is referred to as COVE-ITS.

Human tutors can often use a trainee's actions and behaviors to determine his mental state before or at the time he makes an error. Sometimes, the clues provided by the trainee are very subtle, and it is only the tutor's long experience which allows her to correctly interpret mental model the trainee was using at the time. However, doing so gives the tutor an insight as to the likely underlying cause of the trainee's error, which allows the tutor to give specific advice or remediation to improve the trainee's future performance.

The current ITS portion of COVE-ITS does not evaluate these behavioral clues into the trainee's mental state. Instead, when an error is committed, the ITS gives feedback based upon the most likely cause of that error across the field of all trainees rather than interpreting the trainee's actions in the context of his mental state to deliver more specific feedback.

Vision is the primary sensory input for most human tasks, and what objects a trainee looks at can give significant clues about his mental model. Eye tracking has been shown to predict a trainee's level of task experience as well as underlying cognitive strategies by examining attention allocation patterns: which information the trainee attends to, for how long, and at what point(s) in the training scenario. (Sarter et al, 2007; Schriver et al, 2008; Sullivan, et al, 2011; Yang et al, 2013). These insights are extremely useful for tutors, either human or computer, while creating a mental model of the trainee in order to provide feedback tailored to the specific misconception of the trainee which lead to the error.

Findings and Conclusions

Overview: The purpose of this pilot study was to determine whether the addition of eye tracking to ITS could provide more targeted feedback to instructors. We employed network and timeline graphs to examine attention allocation patterns and performance data of eight shiphandlers who ranged in their shiphandling experience levels from two to 30 years while they completed a COVE scenario. This study also extended previous findings by examining attention allocation patterns in a new population (shiphandlers) and incorporating novel statistical and visualization methods in the eye tracking data. We addressed three research questions: (1) What is the relationship between shiphandlers' experience level and scan techniques? (2) Is the expert's attention allocation pattern associated with better performance? (3) When errors occur, does eye tracking data provide insights into how and when the trainee's attention allocation pattern deviated from the experts' attention allocation pattern? Due to the small sample size, no specific hypotheses were tested. This research was approved by the Institutional Review Board at the Naval Postgraduate School. Informed consent was obtained from each participant.

Shiphandling scenario: The scenario selected for the study in consultation with the sponsor was an Advanced Division Officer Course (ADOC) course capstone assessment exercise that entails mooring a DDG-51-class ship at Mina Salman, Bahrain as a conning officer, who gives orders to control the ship's motion (see Figure 1). This exercise demands skillful navigation and control of the ship as the channel is

narrow and the pier is usually busy with other ships. For analysis purposes, the simulation exercise is divided into four segments.

Eye tracking measures: We extracted the following eye tracking metrics in each area of interest (AOI) during each segment of the shiphandling exercise: AOI fixation count, AOI total fixation duration, and AOI average fixation durations. Because each participant took a different length of time to complete the segments, the absolute counts and total fixation durations were converted into percentage count/duration for each AOI. Two visualization methods were employed with the eye tracking measures: network graphs and timeline charts. We used network graphs to visualize the eye scan fixation transitions between AOIs. Eye scan fixation transitions inform which combination of visual cues a person is using. Timeline charts indicate the timing in the use of visual cues.

Results: Prior to examining whether certain attention allocation patterns were associated with better shiphandling performance, we first confirmed that the experts did in fact perform better on the simulation exercise in both the accuracy of the ship's navigational path and time to complete the exercise.

Eye tracking results highlight the differences between the expert and novice shiphandlers. For example, the experts looked at the stern of their ship far more than the novices, because they couldn't begin moving closer to the pier (i.e., transition to segment 4) until they passed the stern of the Guided Missile Destroyer (DDG). Additionally, their goal was placing the bridge next to the "Bridge Here" sign, so that object's position and relative motion occupied a great deal of their attention. Network graphs and timeline charts revealed obvious differences, not only in which visual cues the expert and novice shiphandlers used, but also in the timing of utilizing visual cues. The expert shiphandlers use a streamlined and strategic visual scan pattern in which they fixated on the key areas at the right time. In contrast, the novice shiphandlers' showed scattered scan patterns in which no clear visual strategies are evident.

Finally, we asked our subjects what objects they thought were important to focus on while conning the ship. An interesting result was that there was significant disagreement between which objects participants reported they focused upon and which objects the eye-tracking system recorded them focusing upon. This is important because often even experts may know what need to do intuitively, but they may not be aware of this explicitly. Recording what cues experts actually use facilitates transferring that knowledge to novices and allows them to progress towards expertise faster.

Student participation: Squadron Leader Salman Aleem completed the extensive data preparation, all data analyses, and visualization graphs. For his superb work and innovative application of visualization techniques, he earned the Surface Navy Association Award for Excellence in Surface Warfare Research, The Military Operations Research Society's Tisdale Prize, and The NPS Operations Research Department award for outstanding thesis. The thesis was presented at the 2017 Applied Human Factors and Ergonomics conference.

Recommendations for Further Research

The results obtained in our study can have important implications towards the development of the ITS system and also in enhancing the training value of shiphandling. For example, information from the network and timeline graphs can be used in teaching optimal attention allocation techniques to the student shiphandlers during various phases of mooring exercises. We found that the experts focused on specific controls—the rudder and the engines, along with the tug boat—during the last phases of the

exercise. These results can be used to better teach student shiphandlers when and how to employ these controls and their impact on lateral movement of a ship.

Secondly, results can be used to update the expert model in the ITS. ITS has two components: an intelligent tutor and an expert model (Kirschenbaum et al., 2010). The latter component is a cognitive model that represents an expert's performance for various shiphandling tasks. Currently, the visual cues used by experts are established through interviews with subject matter experts and head-tracking while conducting simulation exercises. Both techniques have limitations. Regarding subject matter expert interviews, due to automaticity, experts often aren't aware of all of the strategies and visual cues they use, and thus some key information may not be communicated in the interview (Dror, 2011). Head-tracking only tracks the direction of the head and therefore can only provide gross estimates at what the person is actually looking. In contrast, eye tracking provides more accurate quantitative data on the AOIs fixated by experts in time and space. The scan patterns and gaze shifts also can be determined from the raw eye tracking data. The expert model in ITS can thus be updated with more accurate information that may result in better feedback to students from ITS.

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NPS-17-N159-A: The Role of Navy Processes in Enabling and Constraining the Adoption and Use Of Learning Centered Technologies

Researcher(s): Kathryn Aten, Marco DiRenzo, and Anita Salem

Student Participation: LT Jessica Hall USN, and LTJG Jessica O'Connor USN

Project Summary

This research examined the influence of organizational and individual barriers, with specific respect to mobile learning technology (MLT) and developed recommendations to support acceptance and a model of organizational and individual level drivers of *technology acceptance*. As opposed to traditional face-to-face classroom training, MLT entails utilizing smartphones or tablets (iPhone, Android, iPod, etc.) to access training courses, modules, and additional resource materials. This technology enables individuals to undergo training remotely while either on- or off duty, instead of traveling to training sites and physical schoolhouse locations. The findings of this research provide insights to alleviate potential resistance and facilitate greater acceptance of *learning technologies* and *technology-mediated learning*.

Keywords: *learning technology, technology acceptance, mobil learning technology, technology-mediated learning*

Background

Achieving high velocity learning at every level in the Navy is a core and essential effort in the execution of the Chief of Naval Operation (CNO)'s Design for Maintaining Maritime Superiority. Emerging technologies enable decentralized learning and often generate greater learner control, volition, and engagement. These capabilities have been shown to improve learning outcomes, in particular when the subject matter is complicated or involves the transfer of tacit knowledge. Improving agility, creativity, and insight will require competence in such subject matter.

Despite the potential benefits, however, there are many barriers to the adoption and implementation of learning technologies. These barriers can derive from the organizational level (e.g., from culture, leadership, and policy) and the individual level (e.g., from user resistance, dispositional opposition to change, and habit).

Technology-mediated learning, using computers and other information technologies as a key part of the learning process, can provide alternatives to traditional face-to-face classroom learning with individual and organizational benefits (Aten & DiRenzo, 2014; Piccoli, Ahmad, & Ives, 2001). Benefits include enhanced speed to capability resulting in lowered training time and cost (Pantazis, 2002); increased learner control, academic performance, and satisfaction; and improved collaborative learning capability, which makes individuals more interested in learning (Alavi & Leidner, 2001). Learning technologies also offer customization capabilities, allowing tailoring of programs to meet the needs of different types of learners, which can further increase interest (Pantazis, 2002; Ruiz et al., 2006). Finally, students value the readily available nature of technology-mediated learning (Aten & DiRenzo, 2014; Karoly & Constantijn, 2004).

Findings and Conclusions

The research team included two students who explored the research questions through interviews and a survey of NPS students (Hall & O'Connor, 2018). NPS faculty conducted a literature review, stakeholder interviews, and a user survey to address the following questions:

- What behaviors are enabled by new learning technologies?
- What has existing research found regarding the learning and job performance outcome effects of new learning technologies?
- How are Navy processes likely to influence the adoption and use of new learning technologies?
- What unique technological and/or organizational barriers must be addressed to mitigate friction between new learning technologies and Navy processes, structure, and culture?

The researchers collected qualitative data through in-depth, semi-structured interviews. Interview questions focused on general themes and specific examples of implementing training technologies. The research team conducted fifteen semi-structured interviews at the Naval Postgraduate School in Monterey, CA, at NETC in Dam Neck, VA, and by phone with the Submarine Learning Center in Norfolk, VA. The interviews lasted approximately 45 minutes each. Participants were selected using purposeful sampling and reflect a variety of roles, ages, and communities. Demographic information was collected prior to the interview. The interviews were recorded and transcribed. Questions centered on the impact of Navy processes, policies, culture, physical environment, and technologies on the adoption of new learning technologies and ready, relevant learning. Interviewees used critical incidents of successes and failures to focus on these areas. Interviewees were also asked to identify key stakeholders and make recommendations for improvement. Researchers then analyzed the interview transcripts using thematic analysis.

The researchers conducted a survey of a sample of new Navy enlistees who recently completed A-school training at the Training Support Center (TSC) in Great Lakes, Illinois. Surveys were conducted on-site and focused on individuals' experiences using various forms of mobile technology, their perceptions about MLT, their beliefs regarding their immediate leadership's and the Navy's support for MLT, their preferences for using MLT, and their expected desire to use MLT going forward in their careers. Initially, 143 surveys were collected, but four were deemed unusable, resulting in a final sample of 139 participants. The average age of respondents was 21-43 years, with 14% being married/living with a partner and 4.4% having children. The initial analysis resulted in a model of direct and mediating effects that influence acceptance and resistance to MLT. Additional analysis explored the role of dispositional factors and moderating effects.

All variables exhibited strong internal reliability having Cronbach alphas greater than .70. Additional tests for measurement reliability were done using confirmatory factor analysis (CFA), with the measurement model exhibiting a CFA above .90 and root mean square error of approximation (RMSEA) below .08. As such, the measures were deemed reliable, and further analysis to construct a predictive model followed.

Despite the fairly small sample size, a $p < .05$ level of significance was used throughout all phases which provides strong support for the reported findings. Correlation analysis was used to develop the process model shown in Figure 1. Hierarchical regression analysis was then conducted using SPSS 23 in phase 2 to test the model and mediation effects. This provided added support for the model's validity as the overall structure of the model was confirmed and nearly all mediating relationships being supported. Structural Equation Modeling was then conducted in AMOS 23 using bootstrap analysis to further confirm the

model's structure and the direction of the causal paths. Finally, the supplemental analysis was conducted using hierarchical regression and moderation analysis to test for direct and moderating/interaction effects related to three dispositional trait-like variables.

Recommendations

Organizational Level: Current organizational processes for developing learning technologies will likely affect the implementation of learning technologies and new approaches such as Ready, Relevant, Learning (RRL). RRL offers the opportunity to improve the Navy's training readiness, but current practices present a number of risks. Following is a list of high-level recommendations:

1. Develop a **learning strategy** that provides standardization of learning outcomes, supports agile development, and utilizes an iterative development process that is learner-centered.
2. Create a **management strategy** that coordinates activities across stakeholders and the learning life cycle, provides strong leadership and political position, and includes standard change management activities.
3. Provide a **system strategy** that focuses on mission effectiveness measures and provides a master plan for aligning technology and learning outcomes and integrating RRL into manning and ship processes.
4. Improve the **implementation** of learning technologies by increasing collaboration, communication, and requirements development and tracking across the Enterprise.
5. Remove **technical barriers to adoption** by improving the reliability and capacity of IT networks and the usability of individual systems.

Individual Level: A key finding is that if individuals believe that the Navy and immediate supervisors support the change to MLT by advocating for it and providing resources, they will be more likely to accept MLT. Additionally, exposing students to MLT in traditional classrooms could ease the transition to MLT in the same way that experience utilizing online demonstrations (such as via YouTube) positively affected acceptance and minimized resistance. Finally, brief priming activities can be very effective at eliciting promotion regulatory focus and learning goal orientation (for example, sharing stories of previous students' success). This priming will reduce potential resistance to MLT and ultimately serve to help individuals become more engaged in their learning.

The following actions are recommended.

1. Widely publicize Navy's and leadership's support for MLT, communicate its value, and research and provide the resources necessary for successful implementation.
2. Combine online how-to demonstrations with in-person instructor support at early career training sessions.
3. Investigate best methods to prime students with high promotion focus and learning orientation at the outset of MLT training modules.

Recommendations for Further Research

Future Research: Future surveys to replicate these findings on other populations will expand consideration of the types of costs of benefits. For example, very few survey participants were married or had children, but family-role costs and benefits may be important to these populations. The ability to train at home or on-duty, rather than travel distances to off-site locations, may be an important benefit to Navy personnel with growing families.

Additionally, researchers should undertake comparative analysis of traditional face-to-face versus MLT-based training. This would enable an in-depth assessment of the learning processes in each context. Researchers should conduct studies that analyze both contexts simultaneously on distinct groups, as well as longitudinal studies of students who attend face-to-face training and then are exposed to MLT training. Finally, researchers should investigate the best methods to prime promotion regulatory focus and learning goal orientation prior to training as well as seek to confirm their beneficial effects.

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NPS-17-N181-A: Utilizing Non-Cognitive Measures for Navy Selection and Classification

Researcher(s): Elda Pema

Student Participation: No students participated in this research project.

Project Summary

Approximately 35,000 recruits access into the U.S. Navy annually; however, a staggering 15 percent of those recruits may attrite before reaching fleet service, costing the Navy over 100 million dollars. The Tailored Adaptive Personality Assessment System (TAPAS) is a computer adaptive test measuring non-cognitive traits. This assessment may provide Navy leadership with an additional screening tool for selecting recruits more likely to make it from “street to fleet”, and, therefore, reduce the costs associated with recruit attrition. Prior studies have shown that TAPAS scores are statistically significant in predicting the probability of enlistment and Delayed Entry Program (DEP) attrition (Pema et al 2015). Prior research also shows that TAPAS scores help predict whether a recruit will graduate from the Navy's Recruit Training Course (RTC) and “A”/Apprentice Schools (Pema et al 2016).

Using data on 13,443 recruits enlisted between April 2011 and March 2013 research finds that TAPAS scores can provide new information regarding recruits' training capabilities, beyond those offered by the

traditional, cognitive screening tools alone (Armed Forces Qualification Test (AFQT) and schooling level). The findings show that, while controlling for demographic and cognitive factors, TAPAS facets Physical, Optimism/Wellbeing, Non-delinquency and Selflessness/Generosity are significant predictors of RTC graduation. The findings also suggest that the TAPAS composite Will-do, and the TAPAS facets Physical, Achievement, and Tolerance are significant predictors of recruit graduation from the Navy's "A"/Apprentice Schools.

This study summarizes all prior research on Navy attrition and reenlistment, with special attention to the dynamics of attrition over the first term. The study also collects all prior findings on TAPAS effects on various measures of performance and analyzes the implications of the results to date.

Keywords: *TAPAS, non-cognitive measures, recruit classification, attrition, reenlistment*

Background

The Tailored Adaptive Personality Assessment System (TAPAS) is a non-cognitive assessment instrument designed to measure personality traits and temperament among U.S. Navy applicants. Prior research on TAPAS finds that several TAPAS scales are significant accession predictors. Several TAPAS facets, namely Achievement, Dominance, Intellectual Efficiency, Non-Delinquency, Order, and Selflessness/Generosity are significant predictors of applicant enlistment regardless whether or not cognitive tests are controlled for.

Prior research also indicates that TAPAS scores predict recruit attrition in the Delayed Entry Program (DEP), above and beyond schooling, AFQT scores, and demographics. Individual TAPAS facets, namely Dominance, Intellectual Efficiency, and Order were consistently found to be significant predictors of DEP attrition for Navy recruits.

More recently, research shows that TAPAS scores are significant predictors of A-school performance and graduation from RTC. Using TAPAS as an additional personnel selection tool may contribute to a more comprehensive assessment of individual recruits.

Findings and Conclusions

Identifying applicants who will perform successfully in the military depends in part on predicting their ability to adapt to the unique military lifestyle. Not all youth who are interested in military careers can meet the organization's demanding requirements or adapt to these many life changes. The armed forces apply several criteria to determine the suitability of applicants for the military, including aptitude, physical fitness, and moral background. While the current screening process relies heavily on cognitive ability, there is growing interest in supplementing aptitude tests with additional, non-cognitive, factors. Non-cognitive tests incorporate constructs that make up an individual's behavior, attitude, and interests.

Prior studies in several academic fields have identified consistent statistical relationships between non-cognitive factors and the success of employees in the civilian labor market. The strength of this evidence suggests that non-cognitive factors may assist military recruiters in identifying applicants who will successfully adapt to the military workplace. Combined with aptitude measures, non-cognitive tests could be an important component of a "whole-person" assessment.

This study uses data derived from the TAPAS test administered to Navy recruits between April 2011 and March 2013.

We report on several statistical analyses using the TAPAS data. First, we summarize the relationship between TAPAS test scores and demographic characteristics of applicants, including gender, educational attainment, marital status, age, number of dependents, race/ethnicity, and waiver status. Second, we evaluate the relationship between TAPAS test scores and scores on Armed Services Vocational Aptitude Battery (ASVAB) subtests and on the AFQT. Next, we use TAPAS data to explore the effect of personality characteristics of Navy applicants on their decision to enlist on active duty. By understanding the factors that influence the propensity of applicants to complete the enlistment process, manpower planners may be able to develop policies that utilize non-cognitive measures in the recruitment process.

The analysis of the relationships between TAPAS and demographic variables reveals several patterns. The TAPAS composite scores are negatively associated with various race/ethnic categories. The Will-Do composite score, designed to predict commitment, motivation, and attrition, is negatively correlated with the Asian, Black/African American, Hispanic, and Native Hawaiian/Pacific Islander demographic groups. The Can-Do composite score, designed to predict job knowledge and training graduation rates is negatively correlated with the Asian, Native Hawaiian/Pacific Islander, and Hispanic groups. Among educational credentials, not having a high school diploma is negatively correlated with both TAPAS composite scores.

Next, we summarize the correlation between TAPAS scores and conduct waivers. Minor non-traffic waivers are negatively correlated with Non-Delinquency and Self-Control, whereas minor traffic waivers were positively related to the Excitement scale.

Overall, it appears that TAPAS scores reveal new information not already captured by the current cognitive tests the military administers. If TAPAS does obtain new information that is both valid and reliable, then the test offers potential to establish criteria for better assessing the “whole-person” when selecting among military applicants.

In this study we summarize the TAPAS scales that are significant accession predictors and DEP attrition. Of the TAPAS facets, Achievement, Dominance, Intellectual Efficiency, Non-Delinquency, Order, and Selflessness/Generosity are all significant predictors of applicant enlistment regardless whether or not cognitive tests are controlled for. Individual TAPAS facets, namely Dominance, Intellectual Efficiency, and Order were consistently found to be significant predictors of DEP attrition for Navy recruits.

Next, the study provides a comprehensive summary of all recent research on Navy retention. The intention is to lay down the groundwork for the comparison of retention results with the addition of TAPAS scores. While retention analysis was intended to be a large part of this research, it became apparent during the course of work that the data delivered had multiple inaccuracies. Our efforts are ongoing in putting together a more accurate dataset to investigate the link between TAPAS and first term retention.

Finding the right person for the right job is important in the Navy. Using TAPAS as an additional personnel selection tool may contribute to a more comprehensive assessment of individual recruits. Considering the high cost of attrition, it would be beneficial to follow the cohorts used in this study and

examine the relationships between attrition behavior and associated TAPAS scores. As the cohorts age, researchers can follow attrition patterns in the Recruit Training Command and the first-term of service to discover the predictive effects of TAPAS on recruit behavior. Non-cognitive skills are complex to measure. Only with continued assessment developments, validity tests, and re-standardizations, will the growing literature satisfy public concerns for accurate non-cognitive measures.

Recommendations for Further Research

The findings of this study highlight the potential for improving early attrition prediction models by incorporating TAPAS scores. The analysis results in the following recommendations.

First, due to limitations in the data collection, this study only used demographic variables that accounted for gender, race, and age. Previous research suggests that incorporating variables for marital status, dependents, immigration status, state economic factors, and the use of recruit waivers may produce better models. Without these additional variables, the findings could potentially be impacted by omitted variable bias.

The most significant suggestion for future research includes utilizing TAPAS scores to better match recruits to occupational ratings. More efficient job matching may help the Navy improve retention by assigning recruits to occupational ratings that are better suited to their cognitive and non-cognitive abilities.

Finally, we recommend re-introducing TAPAS as one of the pre-enlistment tests alongside the ASVAB. In the civilian sector, increasingly more companies are employing personality tests to select workers from their applicant pool. A recent survey of the Society for Human Resource Management finds that 22% of firms employ personality tests to select applicants. In contrast, only 16% of the firms in the sample employ cognitive skills testing. The survey was conducted in 2014 and included 344 companies in various sectors (private, government, non-profit). Given that the Navy engages in relatively more intensive and more expensive training than civilian firms, it is even more imperative to employ all known tools for selection of applicants to minimize attrition from the force.

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NPS-17-N191-B: Improving Navy Talent Management with Model-Driven Big Data

Researcher(s): Thomas W. Lucas and Susan M. Sanchez

Student Participation: LT Allison Hogarth 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 Sailor. 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 and the Navy Total Force Strength Model (NTFSM). During this research period, Lieutenant Allison Hogarth built, tested, and demonstrated a user interface in Excel that enables users of the Production Resource Optimization (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 (PROM-WED) (Hogarth 2017a). In addition to working with thesis students, the faculty supporting this project advanced methods that enable N1 analysts to efficiently explore numerous factors simultaneously and fit complicated response surfaces to a breadth of diverse responses; thereby, improving their ability to quickly glean comprehensive insight from their computational models (Erickson, Ankenman, and Sanchez, 2018).

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. One such model is the Production Resource Optimization (PRO) model. PRO is used to assist in determining how the Navy will annually allocate hundreds of millions of dollars to recruit Sailors. PRO, and other models used at N1, have many input variables and generate multiple outputs of interest.

Such models are more useful to N1 analysts if they are embedded in an environment that allows analysts to quickly and efficiently obtain experiment-based information.

Findings and Conclusions

The U.S. Navy recruits approximately 40,000 new Sailors each year. Given an annual budget of about \$300 million for recruitment, how best should the Navy allocate those resources? To help inform on recruiting choices, N1 uses the Planned Resources Optimization (PRO) model. PRO is a deterministic, non-linear optimization model that provides users with recommendations on how to use recruiting resources to most efficiently accomplish recruiting missions. Many factors affect the Navy's ability to recruit; hence, PRO has many input variables. The analysis is complicated by the fact that inputs to PRO include many uncertain factors, such as future unemployment rates, enlistment bonuses, and elasticities of multiple responses.

Given a set of inputs, PRO provides a recommended allocation of resources for advertisements, recruiters, enlistment bonuses, and education incentives. This recommended allocation is optimal (that is, the most effective use of the recruiting resources) if the model inputs correctly capture the recruiting environment. However, one limitation of the PRO model is its deterministic nature; inputs to the model reflect conditions of the recruiting environment that are, in reality, uncertain and fluctuate over time. A second limitation is that extensive experimentation with model inputs is manually intensive and cumbersome. This makes it difficult for analysts to gain general insights about how changes to model inputs influence the recruiting environment, and ultimately affect the recommended recruiting resource allocation.

To address these limitations, this research developed, tested, and provided training on Planned Resource Optimization Model with Experimental Design (PROM-WED), a software tool that "alleviates the limitations and enhances the analytic utility of the legacy PRO model" (Hogarth 2017a). PROM-WED augments the existing Excel-based PRO model with Visual Basic for Applications (VBA) code and additional worksheets that enable users to readily run multiple PRO experiments using a sophisticated design of experiments and view numerous summary graphs and tables. PROM-WED's more extensive outputs are available for analysis using more sophisticated statistical software. This provides N1 analysts with previously unobtainable insights on the robustness of their recruiting resource recommendations.

To transfer these new capabilities to N1 analysts, the Simulation, Experiments and Efficient Design (SEED) Center for Data farming at NPS provided a general one-day short course at N1 on the design and analysis of simulation experiments. In addition, PROM-WED's primary developer, Lieutenant Hogarth, provided detailed documentation on the software (Hogarth 2017b) and gave a hands-on tutorial of its use.

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. This past year we continued performing 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 2018). 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

N1 analysts use models to inform senior leaders on actions and policies that influence the Navy's ability to recruit, manage, and maintain its talent. These models will continue to grow in complexity in order to meet future Navy talent management objectives. The above capabilities provided to Navy manpower analysts, while substantial, are only scratching the surface of what could be useful. Thus, the Navy should continue to improve upon its ability to design, execute, and analyze experiments involving MPTE models.

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NPS-17-N198-A: A Follow-On Study on Identifying and Retaining Quality Navy Officers

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Project Summary

Under the "Sailor 2025" initiative, one of the Navy's priorities is to increase its efforts to better identify, promote, and retain the most talented, highest quality personnel. Identifying and measuring talent is a challenge. This project integrates qualitative and quantitative approaches to bring insights into the definition and identification of talent and high-quality job fit. The qualitative part of the study employs very well-established, grounded theory building methods to identify and understand the Navy Surface Warfare Officer (SWO) talent. Results suggest that the SWO community is working very well overall, that its recently implemented changes are serving their intended purposes, and that many talented people are being identified, recognized, promoted and retained as desired. Nonetheless, this community is no exception to having room for improvement. The most "talented" officers appear to be those receiving the highest rankings and strongest endorsements on their fitness reports (FITREPs). A key problem is that FITREPs are subject to increasing criticism regarding bias, subjectivity, and focus on tenure over merit, and current performance over future potential. Indeed, the Navy is in the process of reevaluating its performance evaluation process now. The quantitative part of the study uses a large officer data set and multivariate statistical analysis to test feasible ways to use legacy FITREP measures of officer talent and job fit. The results validate these alternate performance measures, and also find that the lateral-transfer

mechanism, a way the Navy provides career choice flexibility, contributes to improving job fit and retention of top-performing officers.

Keywords: *identifying talent and high quality in the Navy, retention of high -quality officers, talented and diverse manpower, integrated qualitative and quantitative analysis*

Background

The Sailor 2025 initiative is aimed at modernizing the personnel management system to more effectively recruit, train, and incentivize the most talented personnel to meet the current and future manpower needs of the U.S. Navy. Implementing these changes requires the ability to identify and measure talent. The construct “talent” remains somewhat ambiguous. The results from our previous research suggest strongly that talent is a highly situated and nuanced concept, with key characteristics likely to differ with rank, role, job, and other factors that vary over time. Hence it remains uncertain whether the talent we retain currently is the best to meet our present, much less our future, needs. This study addresses the issue directly through its integrated qualitative and quantitative approach.

Findings and Conclusions

To support of the Navy leadership decision-makers’ efforts to identify and measure talent, our study uses an integrated quantitative and qualitative approach.

The qualitative part of the study focused on the Navy surface warfare community, which provides a vital, sophisticated capability to address increasingly dynamic and unpredictable threats around the world. Many SWOs find life at sea to be fun and exciting, filled with challenging jobs and camaraderie, and a balance that makes the hard work and long hours worthwhile and rewarding. Alternatively, for others the sacrifice seems unsustainable, and the SWO community has battled mid- and junior-level officer attrition for many years. To help combat such attrition, community leaders have devised and implemented a number of progressive changes to enhance the SWO profession and to help retain talent. For several instances, it has recently increased its Department Head Retention Bonus, increased compensation to officers selected early for Department Head, and organized a number of alternate, parallel career tracks to expand flexibility and options regarding sea-shore rotation, education, specialization, and other decisions affecting retention. Nonetheless, it remains unclear whether the talent we retain currently is the best to meet our present, much less our future, needs.

Three research questions are addressed by the qualitative part of the study: 1) What constitutes talent in the SWO community? 2) Why do some talented people choose to leave the Navy while others choose to stay in? 3) How can we retain talent in the Navy? Eschewing the idea of using deduction and quantitative analysis through one or more top-down theoretic models of talent—approaches that presume a detailed understanding of what talent is and how to measure it—we choose instead to employ qualitative methods inductively and to build up a grounded understanding of SWO talent. We employ very well established, grounded theory building methods, which provide a systematic, scientific process to develop an understanding inductively, from the data themselves. Moreover, we focus specifically on people who have been identified as “talented” beyond the current fitness report (FITREP) process.

Three techniques are utilized for qualitative study data collection: 1) document review, 2) strategic contact, and 3) interview. All study participants are assigned currently (or were assigned recently) to NPS

for graduate education, and all have been identified as “talented” beyond the current FITREP process. All study participants are relatively junior officers (O3).

Results suggest that the SWO community is working very well overall; that its recently implemented changes are serving their intended purposes; and that many talented people are being identified, recognized, promoted and retained as desired. Nonetheless, this community is no exception to having room for improvement, and through their grounded, independent study, the NPS researchers identified seven significant retention risks: 1) talented people not being assigned to challenging jobs, 2) unfavorable interaction with Chiefs, 3) unfavorable interaction with Detailers, 4) unfavorable commanding officer/executive officer (CO/XO) interaction, 5) lack of command opportunities, 6) difficult family planning, and 7) dissatisfaction with sea life. Each of these retention risks offers potential for mitigation, and the researchers offer a set of nine recommendations to help address such risks and to retain talent.

The construct “talent” remains somewhat ambiguous, and the most “talented” officers appear to be those receiving the highest rankings and strongest endorsements on their fitness reports (FITREPs). A key problem is that FITREPs are subject to increasing criticism regarding bias, subjectivity, and foci on tenure over merit, and current performance over future potential. Indeed, the Navy is in the process of reevaluating its performance evaluation process now. We complement our approach with a large-scale quantitative study. Using a detailed data set on naval officers commissioned between 1999 and 2003 and followed annually until promotion to O4 or until separation, the quantitative study examines alternative measures of junior officer performance from their FITREPs that can be used to track officer performance and measure job fit, whether in an officer’s original job assignment, or following lateral transfer to a new designator.

The questions addressed in the quantitative study are: 1) What alternative quantitative measures, including fitness report marks, are available as reliable predictors of officer performance and potential? 2) What professional and pre-accession attributes of officers can be used as markers of talent to predict performance? 3) How do warfare-qualified officers who lateral transfer perform in their new communities? Using our detailed data set and multivariate regression analysis, the study recommends alternative measures of junior officer performance that can be used to track officer performance and measure job fit, whether in an officer’s original job assignment, or following lateral transfer to a new designator. The findings demonstrate the feasibility of using legacy FITREP measures of officer performance and potential with the proposal measures of performance. Another component of the Navy’s strategy is the *Talent Management* program with one of the core goals emphasizing greater career choice and flexibility. The lateral transfers mechanism is one way the Navy provides career choice flexibility, and which contributes to improving job fit and retention of top-performing officers. This study addresses some of the issues associated with identifying talent and generating quality by assigning the right officers to the right jobs. They show that the Navy’s lateral transfer process tends to select officers who have above-average performance and retention outcomes.

Recommendations for Further Research

As the Navy increases its efforts to implement Talent Management initiatives, our integrated qualitative and quantitative study approach brings support of the Navy’s efforts to identify and measure talent and job fit. The qualitative study focuses on the Navy Surface Warfare Officer (SWO) community. Results suggest that the SWO community is working very well overall; yet, this community is no exception to having room for improvement. Each of the seven significant retention risks identified offers potential for

mitigation. A set of nine recommendations is proposed to help address such risks and to retain talent: 1) work to assess talent in advance of JOs' sea tours, 2) set and enforce expectations of mutual cooperation and respect between junior officers (Jos) and chiefs, 3) set and enforce expectations of responsive interaction between JOs and detailers, 4) set and enforce expectations of increased mentoring and coaching by COs and XO's, 5) reevaluate the performance evaluation process, 6) continue to offer the recently expanded number of career tracks, 7) work to support pregnant officers, 8) think creatively of ways to lessen the loss of time with friends and families while at sea, and, finally, 9) train JOs more thoroughly in advance of their sea tours. In addition, based on the findings from the quantitative study, we recommend the Navy investigate the costs and benefits of expanding lateral transfer approval rates. The benefits appear to be improved job fit, productivity, retention, and overall readiness. The cost is faced by the supplying community; however, this cost may be low since disapproved applicants are four times more likely to leave the Navy. We also recommend using legacy FITREP measures proposed and tested in this study to use as an indicator of officer potential.

The Navy is currently undergoing a performance evaluation transformation (PET), which aims to address some of the shortcomings of the current FITREP evaluation system. Specifically, the PET is aimed at tracking performance and professional development on a standard-based scale to effectively contribute to identifying and developing talented personnel and to improve job fit of sailors. Future studies can support the efforts to validate the traits identified by the PET working group for use as signals of talent and predictors of high performers.

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NPS-17-N208-A: Returns to Navy-funded Graduate Education: A Baseline Capture for CIVINS and an Examination of Service Obligation Requirements

Researcher(s): Dr. Simona Tick, CDR William Hatch USN Ret., and Dr. Gail F. Thomas

Student Participation: LT Kimberly M. Fowler USN and LT Benjamin F. Pitzel USN

Project Summary

Under the Design to Maintain Maritime Superiority and Sailor 2025 initiatives, the Navy is increasing its efforts to manage its talent through a diverse set of policies. These policies include the use of Navy-funded graduate education as a strategic human capital investment to recruit, promote and retain the most talented and diverse personnel. The Navy invests time and money into graduate education for service members in order to compete for talent and meet its current and future manpower needs. Opportunities exist both in military and civilian educational institutions (CIVINS). How can the Navy improve its return to investment? Using an integrated qualitative and quantitative approach, this study examines the returns from Navy-funded graduate education received from military and civilian institutions. The findings from a large data-based multivariate analysis provide a baseline for the expected returns from recent increases in the quota for funded graduate degrees from high-ranking civilian institutions. The study also examines the likely effect of an increase in service requirements to increase returns to Navy-funded graduate education, using qualitative research methods.

Keywords: *Navy-funded graduate education, minimum service obligation, returns from fully funded graduate education, retention and promotion of officers with graduate degrees from military and civilian institutions*

Background

The Navy provides its officers the opportunity to pursue funded graduate education. This strategic investment in human capital allows the Navy to compete for talent and to meet its current and future manpower needs. Officers with graduate education can then fill positions whose duties require specific expertise and critical thinking skills acquired in graduate school. Sending officers to graduate education institutions is costly to the Navy, both in terms of pay and allowances, but also in terms of opportunity cost incurred: the officer's services during graduate education are lost to the operational billets, and no experience is acquired for the duration of the graduate studies. Naval officers who receive fully or partially funded graduate education, whether from a civilian or military institution, are required to serve payback tours in their graduate education sub-specialty, to ensure that the Navy receives a return to its investment. The payback tours are determined by the Navy's service obligations requirement policy. To improve the Navy's returns from funded graduate education, should the Navy adjust the current service obligation requirements policy? What are the current returns to Navy-funded graduate education? How do they differ by type of educational institution, i.e., civilian versus military?

Findings and Conclusions

One of the two goals of this study was to examine the current service obligation requirements policy for all funded graduate education programs with the goal to identify the policy changes most likely to generate improvements in the Navy's returns from funded graduate education. Using a qualitative

approach of focus groups and one-on-one interviews with thirty-five Naval Postgraduate (NPS) resident students, this study builds a pilot methodology that can be further expanded to the entire junior officer fleet. It identifies the primary factors Navy officers consider when deciding to attend fully funded graduate education at NPS, how these factors vary by communities and years of commissioned service, and how the decision to attend NPS might be impacted by a change in service requirements. The study finds that an increase in obligated service by more than six months might be a deterrent to attending funded graduate degrees. The depth of answers from the study participants provides valuable feedback about the officers' perception of value and costs related to Navy funded graduate education and highlights the differences in these perceptions among officer communities. The findings of the qualitative part of the study may be used by policy makers to make more informed decisions on how to fund and obligate service members who choose to pursue fully funded graduate education. Although the scope of this qualitative part of the study is limited to the NPS resident students, the findings of this study can be used to design a larger-scoped survey aimed at junior naval officers across the fleet in order to assess the likely impact of adjusting the obligated service length on the officers' willingness to pursue funded graduate education. Improving utilization of sub-specialty degrees may have a larger potential to improve returns to Navy-funded graduate education.

The second goal of this study was to examine the returns from Navy-funded graduate education received from military and civilian institutions. This quantitative part of the study uses a multivariate analysis approach and a large longitudinal data set on Navy officers commissioned from 1997 to 2002, followed annually until O5 promotion, or until separation. Multivariate analysis findings show that twelve, and fifteen-year retention, and O4 and O5 promotion rates do not differ significantly among Navy funded graduate education degree recipients from military or civilian educational institutions, after controlling for demographic characteristics, community, and cohort year. The only significant differences are found for Unrestricted Line (URL) officers with funded CIVINS graduate degrees who are found to have about seven percentage lower twelve-year retention rates than officers with military-funded graduate degrees. In addition, Restricted Line (RL)/Staff O-4 promotion rates are about eight percent lower than those of RL/Staff officers with military funded graduate attainment. These findings can be used to formulate a baseline expectation regarding the recent expansion of the CIVINS quota.

Recommendations for Further Research

The findings from the quantitative part of the study are not causal. As discussed in previous work (Bowman & Mehay, 1999), an analysis of the effect of graduate education on retention and promotion needs to account for the selection bias that may be present in the estimates. Selection to funded graduate education is based on established criteria, and not the result of a random assignment process. There is potential selection bias when attempting to estimate the effects of funded graduate education on retention and promotion rates of naval officers. Officers who obtained graduate degrees may have characteristics (observed and unobserved, such as ability and motivation) that set them apart from officers without graduate education. This study did not have access to detailed data that could be used to address the selection bias and provide more accurate estimators of causal effect of funded graduate education on retention and promotion rates. Future research should obtain such data and attempt to estimate a causal effect of graduate education on retention and promotion outcomes.

The scope of this qualitative part of the study is limited to the NPS resident students. The intent was to develop a pilot survey tool that can form the foundation for a larger-scoped survey. Future research can develop the large-scale survey and administer it to junior naval officers across the fleet in order to assess

the likely impact of adjusting the obligated service length on the officers' willingness to pursue funded graduate education. Future research can further explore which policy changes would have the most potential for improving the returns to funded graduate education.

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NPS-17-N245-A: Business Case Analysis for Objective Based Cost Impact Scenarios Applying the I-TRAIN Cost Model

Researcher(s): Dr. Robert J. Eger III and Dr. Thomas Albright

Student Participation: LCDR Victor Lange USN, LCDR Thomas Radich USN, LT Joseph Minnich USN, and LT William Szczepanik USN

Project Summary

The Installation-Training Readiness Aligned Investments (I-TRAIN) model provides detailed cost information for all aspects in the training path of a Sailor. Resultant information from the model facilitates objective and cost-effective decision-making when changing the training path of a Sailor. As I-TRAIN is still in development, we begin validating the practicality and efficacy of the model. This project utilized the I-TRAIN model to produce a cost estimate of training an Operation Specialist in the legacy training pipeline as well as the block learning (BL) structure. To show how decisions regarding training can be applied, costs not currently recognized in the I-TRAIN model were identified and incorporated into calculations for block learning.

Keywords: *modeling, validating, block learning*

Background

The Navy provides state-of-the-art training to those applicants who have successfully completed the rigorous requirements to be trained to become a USN Sailor. As the Navy transitions the way it provides initial technical job training to its Sailors, some areas of the learning process will remain unchanged, while other areas will be manipulated to deliver training at a more suitable time. The foundation of a Sailor's training will remain the same in legacy and block learning (BL). For example, in both training tracks, a person will be recruited and processed through a Military Entrance Processing Station (MEPS). Next, both tracks will send recruits to basic training. Life skills classes following boot camp will also remain unchanged. At this point, Sailors have received a foundational history, etiquette, and universal skills that are applicable to life in the Navy and are necessary for a successful path during a single enlistment or an entire career. Extensive examination by the Navy concluded that many rates are being trained to a level

beyond what is utilized within the Sailor's first assignment. After curriculum evaluation at Naval Education Training Command (NETC), it was decided that some of the content being taught at A-school was not applicable to the Sailor's duties during first enlistment. The training identified as applicable for usage within the Sailor's first tour would remain in place at A-school. This reduced syllabus of training is now referred to as Block 0. Additionally, the training removed from the legacy syllabus in creating Block 0 would be moved to a later point in the career path of the Sailor. The additional training not completed during Block 0 but deferred to a later time would then be deemed Block 1. The amount of training deferred to a later time will vary with the technical requirements and specifications of the rate.

Findings and Conclusions

The initial objective is to provide validation for the Installation Training Readiness Aligned INvestments (I-TRAIN) model. The I-TRAIN model is a Microsoft Excel and Access-based program that accounts for requirements cost (standard cost) in training of a Sailor from recruitment through first arrival in the fleet. Next, we were tasked with examining the I-TRAIN model and its cost constructs for validation and completeness. The I-TRAIN model extensively details costs for the various steps of training a Sailor. The complexity of the various inputs for the I-TRAIN model were then explained. We then used the model to directly identify legacy costs for an Operational Specialist (OS) rate. To calculate the total incremental costs incurred by the new BL training program, we gathered four significant costs: Transportation (airfare) costs, Transportation Allowances, per diem, and costs associated with an increase in rank of returning students. We were able to determine the cost of training a Sailor for the OS rating in an assumed BL environment.

Recommendations for Further Research

Currently the model utilizes Microsoft Excel as a platform for computing individual component and total costs. Our research leads us to encourage further research to address the value of a web-based program with the ability to control access and updates as required. Our team identified additional costs that will be incurred in BL when the Sailor returns at a later point in his or her career versus continuing with training in the Legacy system. As BL has not yet been implemented, these costs were derived under various assumptions. As BL is implemented, historical costs will assist in providing a more accurate forecast of future cost. For this reason, the team recommends conducting an analysis of costs actually incurred when returning Sailors for Block 1 training throughout the course of a year. Utilizing a retrospective analysis provides the benefit of comparing budgeted information to what is actually expended. An additional benefit of more accurately estimating the cost of a Sailor returning for Block 1 training is the ability to provide decision-makers with better information.

NPS-17-N288-A: Gender and Attrition within Non-traditional Career Fields

Researcher(s): Latika Hartmann

Student Participation: No students participated in this research project.

Project Summary

Combining individual-level data on Navy enlisted and officer populations with logistic regressions, we find that (1) male and female enlistees have higher odds of attriting in the first six months of service from occupations with more than 25% women compared to non-traditional occupations with fewer than 5% women. Here, occupations with fewer than 5% women are interpreted as non-traditional female occupations. Unlike such early-career attrition, we find that (2) females have lower odds of attriting in year three from occupations with more than 25% women compared to women in non-traditional occupations with fewer than 5% women. We also find that (3) female enlistees in occupations with more than 25% women have higher odds of retaining to year five. And, we find (4) males in occupations with more than 25% women have lower odds of retaining to year five. Unlike the enlisted population, we find that (5) both male and female officers have lower odds of retaining till year five in occupations with more than 25% women compared to non-traditional female occupations with fewer than 5% women. This holds true even for retention up to year ten. Taken together, we find female enlistees are less likely to retain and more likely to attrite from non-traditional occupations with fewer than 5% women. But, we do not find similar patterns for female officers where women in non-traditional fields with fewer than 5% women are more likely to retain till year five.

Keywords: *Navy, gender, attrition, retention, female critical mass, occupations*

Background

The share of women serving in the Navy has increased in both the enlisted and officer populations over the last two decades. Between 2000 and 2015, the share of women accessing the enlisted ranks increased from 18% in 2000 to 25% in 2015. Among officers, the share of women increased from 21% to 29% over the same period. Despite this progress, female attrition (i.e., involuntary separation) and loss continue to remain a problem for the Navy. In our sample, female attrition rates for enlistees in the first six months of service average 15.5% compared to 11.2% for men. While attrition is lower in the officer population (under 2% on average in the first two years of service), there are differences in retention by gender. In our sample of officers that joined the Navy between 2000 and 2011, 88% of men retain up to five years compared to 80% of women.

Our study analyzes if there is any correlation between the share of women in an individual's military occupation, and female attrition/retention. A large civilian literature has highlighted the theoretical role of critical mass, a minimum representation of women that can affect change in female outcomes in business, education and political settings. But, the empirical evidence on critical mass is mixed with some studies finding a positive effect of female politicians, but others finding no effects of critical mass on firm and female labor market outcomes. To that end, we compare individuals in military occupations with different shares of women to assess if female attrition

(retention) is higher in occupations with a lower (higher) share of women. In line with the civilian world where the Bureau of Labor Statistics defines occupations with fewer than 25% women as nontraditional, we also use the share of women in an occupational group to define nontraditional occupations. In the military setting, we view occupations with fewer than 5% women as nontraditional, i.e., male dominated. Our comparison across occupations with low and high shares of women thus speaks directly to job outcomes for men and women in nontraditional and traditional female occupations.

Findings and Conclusions

To study the relationship between female attrition/retention and the occupational share of women, we obtained individual-level data on all Navy enlisted and officer accessions between 2000 and 2015 from the Defense Manpower Data Center (DMDC). We also obtained aggregate annual data on the share of women in each DoD occupation group. After cleaning the data and dropping missing information, we conducted regression analysis on enlisted personnel across 96 different occupations and on officers across 22 different occupations. Although the DoD occupation categories do not match one-for-one with Navy specific ratings/designators, there is a significant and logical overlap between the two. (We provide a crosswalk in appendices to our technical report.)

Our main independent variables focus on different levels of female representation. Using information on the share of females in each DoD occupation, we constructed four indicator variables (0/1) – an indicator for occupations with fewer than 5% women, an indicator for occupations with 5-10% women, an indicator for occupations with 10-25% women, and finally an indicator for occupations with more than 25% women. We chose the cut-offs based on the empirical distribution of the share of females across DoD occupations. Since 25% is often used as the cut-off in the Navy for sufficient critical mass, occupations with more than 25% women can be interpreted as having female critical mass. Occupations with fewer than 5% women can be interpreted as non-traditional female occupations. Apart from using the share of women in an occupation, we chose not to categorize each of the 96 enlisted and 22 officer occupations into non-traditional and traditional because any such classification would be arbitrary in the military context where many occupations are inherently nontraditional for women, barring perhaps nursing and support. Such classifications also correlate well with the share of women in the occupation. For example, women account for over 50% of nurses in the Navy compared to less than 5% of fighter and bomber pilots. Thus, we believe the different bins for female representation offer a clean interpretation on whether women are more or less likely to retain in non-traditional occupations with fewer than 5% women.

For the enlisted population we constructed four attrition outcomes and a retention outcome. The four attrition outcomes include an indicator for attrition in the first six months of service, an indicator for attrition in the second six months of service conditional on surviving the first six months of service, an indicator for attrition in year two, and an indicator for attrition in year three, conditional on surviving up to that point. We measured retention as an indicator variable for individuals that were not separated from the Navy at year five in their career. We only measured retention for cohorts that joined between 2000 and 2011 because the later cohorts have not yet hit their five-year milestone. Since attrition rates are low in the officer population, we only studied officer retention at year five with the variable constructed in the same manner as for the enlisted

population. As a robustness check, we also studied officer retention up to year ten for cohorts that joined between 2000 and 2007. Using these variables and other demographic controls such as age, race, education and military rank, we run logistic regressions to test whether female critical mass affects male and female career outcomes.

Our findings on enlisted attrition/retention paint a mixed picture on the performance of women in nontraditional occupations. Both men and women in occupations with more than 25% women have higher odds of attriting in the first six months of service compared to individuals in occupations with fewer than 5% women (nontraditional occupations). Since we find similar patterns for men and women, it seems other factors such as job match and suitability are at play as opposed to just the share of women. In contrast, we find that females in occupations with more than 25% women have lower odds of attriting in year three compared to women in non-traditional occupations with less than 5% women. Females are also more likely to retain in occupations with a larger share of women compared to those with a lower share of women. We find the opposite patterns for enlisted male attrition and retention. Unlike women, men are more likely to attrite in years two and three, and are less likely to retain till year five in occupations with greater than 25% women. While female critical mass in these occupations is more successful in retaining women, it is leading more men to leave compared to occupations with fewer women.

Unlike enlisted attrition/retention, we find female officers have lower odds of retaining to year five in occupations with more than 25% women compared to nontraditional occupations with fewer than 25% women. This is also true for men. Moreover, this pattern holds even within broad occupation categories such as tactical (non-traditional) officers. Finally, we find similar patterns for retention up to year ten.

Recommendations for Further Research

Based on our findings, we believe gender-specific factors play a smaller role in early career enlisted female attrition versus female attrition in year three and retention to year five. Hence, we recommend the Navy look at more general factors such as job skills and suitability to understand early career attrition.

Our findings indicate that late career enlisted female attrition (retention) is lower (higher) in occupations with more women. But these findings are based on personnel data and regression analysis that are not suited to identify which specific characteristics of occupations are responsible for the correlation between the occupational share of women and female attrition/retention. Hence, we recommend the Navy identify key characteristics of occupations (ship/shore duty, mentoring, role models, family-work balance to name a few) and compare the presence/absence of these characteristics across occupations with different shares of women. We also recommend the Navy study in more detail why enlisted men are leaving in larger numbers from occupations with more women.

In terms of Navy officers, our findings suggest both men and women, at least in our sample, are less likely to retain to year five and up to year ten in occupations with more than 25% women. Given these patterns are consistent by gender, we suspect other factors may be responsible for the differences in officer retention. We recommend the Navy look at survey data from mid-career officers to generate other testable predictions that may explain the career trajectory of Navy officers.

NPS-17-N302-A: Predictive Value of the Sailor Evaluation Tool

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Student Participation: LCDR Christine Fletcher USN, CPT Alexandra DeAngelis USA, LCDR Joseph Felix USN, ENS Anthony Baldessari USN, Summer Interns: Mr. Josh Strubel, Mr. Christopher Paghassian, Ms. Katherine Mortimore, and Mr. Alexander Laney

Project Summary

A series of studies at the Naval Postgraduate School has demonstrated that fatigue due to sleep deprivation and circadian misalignment plays an important role in the performance and morale of U.S. Navy crews. In addition, analysis of Defense Equal Opportunity Climate Survey (DEOCS) data indicates a strong negative correlation between amount of sleep and perceived stress levels which may erode resilience over time. This project seeks to determine if there is a relationship between individual resilience (as measured by the Servicemember Evaluation Tool (SET), the work and rest schedules of Sailors during underway operations, and the collective resilience (i.e., sum total of the SETs) of the command. Using a longitudinal study design, we studied the crews of four ships collecting data on the SET, sleep and work schedules, and other occupational stressors at the beginning, and end of underway deployments.

Keywords: *sleep, stress, resilience, work/rest schedules*

Background

A series of studies at the Naval Postgraduate School has demonstrated that fatigue due to sleep deprivation and circadian misalignment play an important role in the performance and morale of U.S. Navy crews (Brown, Matsangas, & Shattuck, 2015; Shattuck & Matsangas, 2014, 2015a, 2015b; Shattuck, Matsangas, & Brown, 2015; Shattuck, Matsangas, Moore, & Wegemann, 2015; Shattuck, Matsangas, & Powley, 2015). In contrast, healthy sleep behaviors are associated with enhanced resilience and the ability to manage current and future stressors. Resilience denotes the ability to respond to and then bounce back from stressors in the environment. The term also includes active resistance as well as recovery. The capacity for resilience in response to stressors is at least partially dependent on a well-functioning circadian system. Research on sleep has begun to shift from a focus on pathology and dysfunction to learning how healthy sleep promotes physical and psychological health and well-being. Sleep impacts overall stress levels and various areas of resilience such as mood (e.g., optimism), coping, cognitive flexibility, frustration tolerance, as well as behavioral and cognitive control (Pedersen et al., 2015). Given the amount of stress experienced by military personnel and the prevalence of sleep problems in the military, critical avenues of inquiry address how sleep impacts operational readiness and performance and how sleep can be maintained and improved in the context of operational demands. This project seeks to determine if there is a relationship between individual resilience (as measured by the Servicemember Evaluation Tool - SET), the work and rest schedules of Sailors during underway operations, and the collective resilience (i.e., sum total of the SETs) for the command.

Findings and Conclusions

This was a naturalistic longitudinal study. Data (N=646) were collected from five United States Navy (USN) ships (two destroyers and two cruisers; three ships provided data twice, at the beginning and before the end of their deployment). Collected data included demographics (age, gender, rate/rank, department, years on active duty, total months deployed), factors affecting sleep, type/frequency of caffeinated beverage use, and sick call visits, sleep and work schedules, psychomotor vigilance performance, other occupational stressors, and the SET. The SET was designed by the US Naval Center for Combat and Operational Stress Control (NCCOSC). The SET is a self-report assessment battery comprised of validated measures that collects information about individual resilience and related outcomes. The self-administered Morningness-Eveningness Questionnaire (MEQ-SA) (Terman, Rifkin, Jacobs, & White, 2001) was used to assess participants' chronotype. Sleep history was assessed with the Pittsburgh Sleep Quality Index (PSQI) (Buysse, Reynolds III, Monk, Berman, & Kupfer, 1989). The Epworth Sleepiness Scale (ESS) was used to assess average daytime sleepiness (Johns, 1991). The Insomnia Severity Index (ISI) was used to assess the severity of insomnia (Bastien, Vallieres, & Morin, 2001). The Fatigue Severity Scale (FSS) was used to assess fatigue (Krupp, LaRocca, Muir-Nash, & Steinberg, 1989). The Profile of Mood State (POMS) questionnaire was used to measure mood states mood (McNair, Lorr, & Droppelman, 1971). The study team also requested sick call information from the ship's medical department and frequency of destructive behaviors (alcohol related incidents, sexual assaults, suicide related behaviors, motor vehicle accidents, other shipboard accidents, etc.). In four ships sleep was assessed for approximately ten days with actigraphy assisted by activity logs. Participants were active duty crewmembers performing their normal daily duties. The study was conducted in two phases.

The results we present are based on the data collected in June 2017 (N=535 participants; 27.3±6.43 years of age, 413 males, 457 enlisted personnel), whereas analysis of the data collected in December 2017 is still ongoing. Approximately 33% of the participating crewmembers reported using nicotine products, ~81% reported drinking caffeinated beverages, and ~72% reported having an exercise routine. The average Epworth Sleepiness Scale (ESS) score was 10.3±4.95 suggesting that 46.9% of the participants had elevated daytime sleepiness. The average Insomnia Severity Index (ISI) score was 10.7±5.29 suggesting that 49.8% of the participants had subthreshold insomnia symptoms, and 22.4% had symptoms of clinical insomnia. The average Pittsburgh Sleep Quality Index (PSQI) score was 8.26±3.36 with 77.3% of the participants classified as poor sleepers.

Approximately 65% of the Sailors had Total Mood Disturbance (TMD) scores worse than the 50th percentile in adult norms (Vigor: 77.6%; Confusion/Bewilderment: 64.1%; Anger/Hostility: 58.0%; Fatigue: 55.9%; Tension/Anxiety: 52.5%; Depression: 50.5%). Sailors slept on average 6.55±0.93 hours/day, with 69.4% sleeping ≤ 7 hours/day. Split sleep was evident with 77.7% of the participants splitting their sleep in more than 1 sleep episode per day.

We calculated the SET score as the average of normalized scores of all 18 tools included in the SET battery. Therefore, the SET score ranged from 0 (worse) to 100 (best). Analysis showed that the average SET score for our sample was 65.1±10.4 ranging from 27.2 to 94.7. Crewmembers with better (higher) SET score had better mood as assessed by POMS TMD (Pearson's $r = -0.307$, $p < 0.001$), had less severe insomnia symptoms as assessed by ISI score ($r = -0.249$, $p < 0.001$), had better sleep quality as assessed by PSQI Global score ($r = -0.246$, $p < 0.001$), were more morning types as assessed by Morningness-Eveningness Questionnaire (ME) score ($r = 0.235$, $p < 0.001$), were older in age ($r = 0.145$, $p < 0.001$), and had less severe symptoms of daytime sleepiness as assessed by their ESS score ($r = -0.103$, $p = 0.018$).

Specifically, regarding POMS subscales, crewmembers scoring higher in resilience (higher SET score) scored higher in POMS Vigor (Pearson's $r = 0.513$, $p < 0.001$), and lower in POMS Depression ($r = -0.269$, $p < 0.001$), Tension-Anxiety ($r = -0.179$, $p = 0.002$), Fatigue ($r = -0.170$, $p = 0.004$), Conscientiousness ($r = -0.167$, $p = 0.004$), and Agreeableness ($r = -0.138$, $p = 0.017$).

Higher SET scores were associated fastest response speed in psychomotor vigilance tests (PVT) (ANOVA, $F(1,82) = 4.96$, $p = 0.029$), and fewer errors (percentage of 355 ms lapses combined with false starts: robust fit, $X^2(1) = 9.92$, $p = 0.002$; percentage of 500 ms lapses combined with false starts: robust fit, $X^2(1) = 5.01$, $p = 0.025$). It should be noted, however, the overall explained variability between PVT metrics and SET was small, less than 5%.

Analysis also showed that the three destroyers had a higher SET score (67.2 ± 9.97) compared to the two cruisers (62.8 ± 10.3 ; Wilcoxon Rank Sum test, $Z = 4.93$, $p < 0.001$; effect size $r = 0.214$).

NCCOSC initially developed the SET battery to evaluate the performance of its internal resilience training programs. One objective of the current research was to evaluate the SET for use in operational settings. We therefore analyzed the psychometric properties of each of the SET's 134 items and 18 scales, as well as the battery as a whole, and compared our findings to those in the published literature. Results were satisfactory, to include normally distributed item responses, acceptable internal consistency estimates, and comparable factor structures to those found in previous studies. However, we observed the time burden for completing the SET to be a limiting factor in the battery's practical utility. On-going content validation efforts have identified 61 items across nine scales as candidates for elimination, which would reduce the overall test time by nearly 50%. The goal of this scale reduction effort is to yield a more efficient SET battery that maintains acceptable psychometric properties, effectively captures the resilience construct, and is ultimately less burdensome in operations.

Recommendations for Further Research

The current study was the first to employ the full SET battery in an operational setting using Sailors in the initial stage of a deployment. As none of the SET scales were developed for use in this context, or normed using military members, our data provide foundation to build a normative database on Sailor resilience in operational settings. Beyond developing norms for deployed Sailors, future research should examine the criterion-related validity of the SET using measures of Sailors' stress, strain, and relevant performance outcomes. Such studies should take into account contextual factors, such as workload, supervisory support, and schedule demands, as well as objective measures of Sailor health, well-being, and behavior. Longitudinal studies (e.g., using the SET throughout a deployment) would also provide insights into the stability of Sailor resilience over time and in different operational settings. Comparisons of these data to those obtained in other contexts (e.g., during shore rotations) and with other populations (e.g., age-matched general population; clinical populations, such as those diagnosed with Post-Traumatic Stress Disorder (PTSD)), will provide insight into Sailors' stress experiences and coping resources while underway. This research can also inform the development of resilience training programs to optimize Sailor readiness and recovery efforts.

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NPS-17-N326-A: Optimal Location of Navy Recruiters

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Student Participation: LTJG Omer Ovenc TNF

Project Summary

This research has developed the Navy Recruiter Prediction and Optimization Model (NRPOM) and implemented it in computer code. NRPOM can assist Navy Recruiting Command (NRC) with the assignment of recruiters to geographical areas across the U.S.. Under given assumptions, NRPOM optimizes: (a) the allocation of a limited number of recruiters to candidate recruiting stations in a region; (b) the assignment of ZIP codes to recruiting stations; and (c) the (fraction of) time recruiters should spend at each ZIP code. The research has also developed a predictive tool that produces input data for NRPOM. Experiments conducted on realistically-sized problems demonstrate that these tools can be used to guide the NRC's decisions. However, NRPOM has only been tested with notional data from the state of California, and for this case some of the required inputs have not been provided by the NRC. Instead, the authors have used estimates that have no guarantee of reflecting actual data. Thus, we believe NRPOM is a starting point by which to approximate a truly optimal solution to the problem, but its development is not finalized yet.

Keywords: *recruiting, forecasting, optimization, facility location, assignment*

Background

Navy Recruiting Command's (NRC's) mission is "to recruit high-quality men and women to meet the Navy's quantitative, qualitative, and program needs as specified by the Bureau of Naval Personnel." NRC's Analytics Division is working on the development of a tool to assist NRC with the optimal location of recruiting stations. Currently, NRC has implemented a heuristic algorithm that assigns recruiting facilities based on several factors such as distance between ZIP code centroids. The current algorithm uses the concept of a "central ZIP" (the first ZIP code chosen for the facility) which is used to gauge which other ZIPs ("core ZIPs") may be added to the facility to ensure that the facility's outer ZIPs do not exceed a certain radius. The proposed research has sought to extend the existing capability by developing the "Predictor" and "Optimizer" tools and, more specifically, by introducing formal optimization in the latter.

Findings and Conclusions

a. Recruiting's Chicken-and-egg Problem

The fundamental problem we face in predicting recruiting is that recruiters almost always produce the number of recruits they are told to produce. This can come at great cost to their quality of living, and it might even in some cases lead to lower-quality recruits. Still, the costs of failure are very high. Conversely, the benefit to producing more recruits than assigned are quite small, so recruiters have an incentive to "game" the system – to delay the induction of some recruits until a later month, for example. So, in areas where there are few available recruits, recruiters work harder, and in areas where there are plenty of recruits, recruiters can work less hard. If all recruiters reach their goals, then there is no obvious way to determine the relative efficacy of recruiters. In such a world, all recruiters seem equally capable, and all regions seem equally productive (in that they produce exactly as many sailors as they are assigned). This has an effect on the Navy's missioning strategy, too, since that strategy arises, at least in part, from the historical levels of recruiting achieved in each area.

b. County-level and Zip Code-level Data

A recruit is “eligible” to join the Navy if he or she is not disqualified. “Propensity” describes the interest a youth shows in joining the military. This is obviously a personal decision for each person, but in aggregate we expect youth in different areas to have different average propensities to join.

In order to determine the best locations for recruiters we need to know where potential recruits can be found. Thus, we need to know about the numbers of young people, and also, to the extent possible, about their eligibility and propensity rates. There have been a number of attempts in the literature to model the number of available recruits by ZIP code. Among these, the recent thesis of Fulton (2016) examines a number of publicly available data sets that can be brought to bear. These include community health status indicators from the Centers for Disease Control, ZIP Code-level income tax data from the Internal Revenue Service, and locations of universities from the National Center for Education Statistics. The Census Bureau maintains a number of potentially valuable databases, including Economic Census and County Business Patterns data, as well as information on the number of veterans residing in each community.

Inevitably a number of issues arise. First, ZIP codes are not quite sufficient; they describe mail-delivery routes, rather than polygonal areas, and change from time to time as the Postal Service’s requirements change. It is common to use Zip Code Tabulation Areas (ZCTAs); these generalized areas, maintained by the Census Bureau, are more stable, and essentially every US household sits in exactly one ZCTA. Second, a lot of data is available only at the county level. For these data sets we distribute county values to ZCTA codes in proportion to the population in each ZCTA (correcting for the ZCTAs that cross county lines where applicable). This has the effect of adding noise to the data and making neighboring areas look more similar than they should.

c. The Problem of Diminishing Marginal Returns

It is important that the model impose a diminishing rate of return as additional recruiters are added to an area. Otherwise, the optimal approach would be to assign all recruiters to the one area with the largest recruitable population – perhaps New York City. We assume that the number of recruits in any area is finite and exhaustible, and that as additional recruiters are added, the number of recruits they are able to secure will eventually decrease. There is little evidence as to the size of the diminishing return associated with adding recruiters. Adding one more recruiter might approximately double the number of recruits – depending on local factors like, for example, economic conditions. On the other hand, after there are too many recruiters in an area, adding yet one more might produce little additional benefit.

We want to be able to model the effect of a partial recruiter as well, so that we can split recruiters across areas – assigning a recruiter to spend half his time in one area and half in another, for example. We implemented a simple formula to describe the diminishing rate of return, as shown here:

$$R(r) = A(1 - e^{-Br}),$$

where r is the number of recruiters, $R(r)$ is the number of recruits expressed as a function of r , and A and B are two numbers (called “parameters”) that will be determined separately for each area. Figure 1 (left) depicts $R(r)$ for several values of A and B .

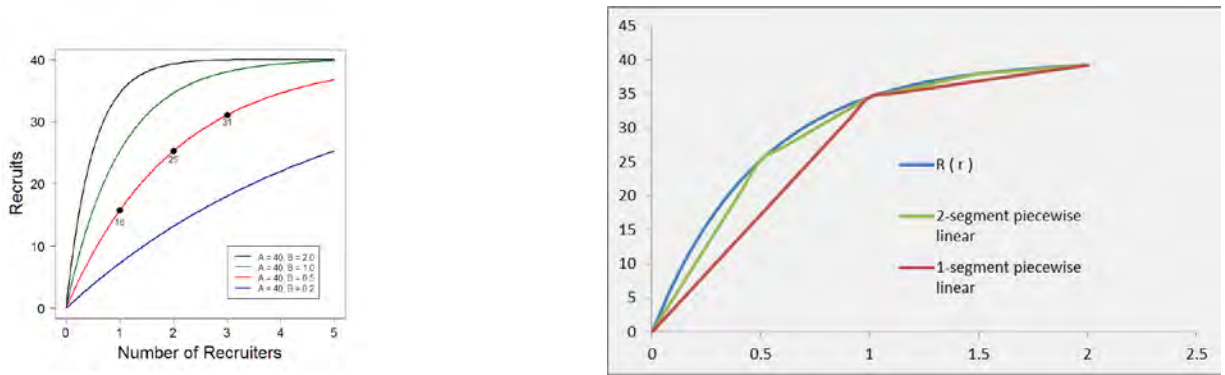


FIGURE 1: EXAMPLES OF DIMINISHING RETURNS CURVES FOR $A=40$ AND DIFFERENT VALUES OF B (LEFT); PIECE-WISE LINEAR APPROXIMATIONS OF A RECRUITING EFFORT CURVE (RIGHT)

The parameter A describes the maximum number of recruits available in an area, while B describes the rate at which the return decreases as more recruiters are added. A little calculus shows that the slope of the line for a particular value of r is given by ABe^{-Br} . When $r = 0$, the slope is the product of A and B ; as r becomes large, the slope tends to 0.

For this work we have constructed a very simple model for the number of recruits available in an area, as a function of the number of recruiters placed there. The model is intended only as a discussion aid and starting point for further research. In the model, each young person in an area is given a number called a “recruitability” score. This number describes the level of effort a recruiter would require to get that young person signed up for the military. We scale the recruitability scores from 0 (meaning that the young person volunteers for the service unasked, with no recruiter effort) to infinity (meaning there are no circumstances under which this young person would join the service, regardless of recruiter effort).

The specific “Recruiter Calculator Algorithm” (RCA) is given in Salmeron and Buttrey (2018). When the RCA completes, we have a number of recruits for each recruiter in the area.

In addition to the shape of the distribution of recruitability scores, a number of elements of this set-up have been chosen heuristically. These include the size of the sample that each recruiter takes and the way the probabilities of selection are computed.

The number of recruits, given by $R(r) = A(1 - e^{-Br})$, needs to be further linearized to become usable in the NRPOM, which is a mixed-integer, linear optimization model. We accomplish this by approximating $R(r)$ between every pair of consecutive integers (e.g., between $r = 0$ and $r = 1$, or between $r = 1$ and $r = 2$) by a piece-wise linear function, as shown in Figure 1 (right) for $A=40.0$ and $B=2.0$. The linearization assumes the marginal recruiting effort is constant between break points. Obviously, the more segments per recruiter, the better the approximation of the intended recruiting function $R(r)$ will be.

d. Mathematical Model

For a given region of interest, the NRPOM seeks to optimally determine: (a) what candidate stations must be operated; (b) how many recruiters must be assigned to each operated station; and (c) what recruiter effort should be assigned from each operated station to each ZIP code. The NRPOM incorporates the following specifications in its mathematical formulation (the full formulation can be seen in Salmeron and Buttrey, 2018):

- Main decision variables following (a)-(c) in the above paragraph: station staffing and effort assigned to each ZIP code.
- An objective function that maximizes the total expected number of recruits as described by the piece-wise linearization of $R(r)$, corrected by the distance between the station and the ZIP code recruited, and also corrected by the distance to the closest Military Entrance Processing Station (MEPS).
- Ensure the following limits are not exceeded from inputs provided by the planner: number of stations opened; number of recruiters assigned to the area; minimum and maximum number of recruiters in each station.
- Ensure each ZIP code is assigned to, at most, one recruiting station.
- Other logical and/or ancillary constraints.

e. Input Files for Optimization

The NRPOM's optimization uses seven input files, all of which must be in .csv format. The files are described in detail in Salmeron and Buttrey (2018). Below is a summary of the information they contain:

Miscellaneous data: multiple inputs in this file include: number of recruiters available; maximum number of stations to operate; maximum distance desired between a station and a ZIP code assigned to the station; weight that distance from ZIP to MEPS has in the penalty function; minimum effort that can be assigned to any ZIP code; number of segments in the piece-wise linear approximating functions of the recruiting effort; and, regression option between two integers (1 for linear, 2 for exponential approximated as piece-wise linear); mean squared error required to accept a ZIP code's exponential approximation of recruiting effort; and maximum time given to the optimization solver.

Station data: list of station names; distance from the station to the closest MEPS; maximum number of recruiters that can be assigned to the station; and the fixed cost of operating the station (not included in the current formulation but intended for future use with a budget).

ZIP data: list of ZIP codes; ZIP-station distance matrix; number of recruits that can be recruited by 0, 1, 2, 3, 4, 5, and 6 recruiters operating full-time in the ZIP code.

f. Example of Optimization Results

We have tested Predictor and NRPOM with notional data to emulate a California-like scenario, although some data has not been drawn from reliable NRC sources. Overall, the CA scenario has 2,156 ZIP codes of which 121 are candidates to host a recruiting station. We do not have enough information to differentiate among the candidate stations in terms of size (how large or small those stations could be) and cost (set up, annual overhead and/or staffing). Thus, we simply assume that each station can host anywhere from 2 to 20 recruiters. We use great-circle ("cosine") Euclidean distances among ZIP code centroids. Nominal recruiting functions $R(r) = A(1 - e^{-Br})$ are fit based on inputs by incremental recruiter for each ZIP code with a candidate station. Then, they are approximated with four-segment piecewise linear functions between each pair of consecutive integers. The maximum desired distance is set to 200 miles, and the relative weight of the distance to closest MEPS is set to 0.2.

We run several scenarios, where "Scenario nr - ns " denotes nr recruiters available and up to ns stations that can be opened. As expected, run time (in seconds) increases with the complexity of the scenario (more stations and/or recruiters to assign), see Figure 2 (left). The most complex case (Scenario 500-80) takes

approximately 1.5h. This time assumes that all regression fits have been performed in advance (this process may take an additional 30 minutes, but it needs to be done only once). All scenarios are solved to a relative error under 1%. The number of recruits (Recruits column) is our final goal. The column labeled Original shows the recruits as assessed by nominal rates approximation. This is just a function of the recruiting efforts (i.e., it disregards the associated recruiting stations). When distance and MEPS weight are factored in, we estimate a reduction (shown in the next column) that produces the final recruit figure. The last column simply displays the number of stations open in the final configuration. In all of our scenarios, opened stations match the maximum available to open. We observe no significant improvement by allowing more than 30 stations if the number of total recruiters remains the same (150).

Scenario	Run time	Recruits	Original	Reduction	Open
150-30	3,397	2,049.2	2,061.4	239	30
150-40	2,087	2,057.2	2,076.6	235	40
150-50	3,297	2,064.6	2,295.1	230	50
500-80	5,359	5,929.1	6,310.6	382	80

station	ZIP	Recruiters	Recruits
92121		6	
	92121	1.25	13.9
	92007	0.5	5.4
	92014	1	11.1
	92075	0.75	8.1
	92129	1.5	16.4
	92130	1	10.8

FIGURE 2: SUMMARY OF TEST CASES AND RESULTS (LEFT) AND DETAILED EXCERPT FOR A ZIP CODE (RIGHT).

In Figure 2 (right) we can see an excerpt from the detailed output for Scenario 500-80. Specifically, we see a ZIP code (92121) that the NRPOM recommends for a recruiting station with six recruiters. These recruiters will share their time among several ZIP codes in fractions that are multiples of 25%. We will have 125% recruiting effort in the same ZIP code where the station is located, 50% effort in ZIP code 92007, and so on. The last column is identical to the one described on the left, but specific to a ZIP.

Recommendations for Further Research

We recommend that NRC compile the data necessary to run the Predictor and Optimizer tools developed in this research. We also recommend NRC begin testing of these tools in order to gain insights into their potential use to guide recruiter assignment decisions. In addition, testing will reveal areas of improvement that can be communicated to the researchers for further enhancement of the models and computational tools.

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NPS-17-N358-A: Retention Analysis Model (RAM) for Navy Manpower Analysis

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Student Participation: LT Peter A. Simerman USN

Project Summary

This project linked two talent management related topics. The first topic area involves designing a model structure to estimate how future retention and force structure are affected by changes in military compensation and to include mechanisms to retain high-quality sailors and integrating both monetary and non-monetary compensation incentives. This is accomplished through two related efforts. The first effort critically assessed the current models used for determining long-term retention and force structure implications of compensation changes and identifying any underlying shortcomings and data biases. We then begin to identify potential alternative modeling or non-modeling approaches to support manpower decision makers. The second related initiative examines three alternative mechanisms for setting retention incentives in the short-run: regression analysis, auctions, and an incentive-compatible menu-of-contracts. These short run initiatives provide the means to influence sailor quality and integrate non-monetary incentives.

The second topic area addressed in this project involves the role of naval officers' college education on retention and performance. This research analyzed undergraduate education as a predictor of retention and performance for a sample of naval officers across a variety of career fields. Separating the sample between URL and RL/STAFF officers, we analyzed the attrition decisions of service members at 6 and 10 years of service. In addition, we studied officers' job productivity using two alternative measures of performance: 1) average FITREP scores during the first 6 years of service, and 2) likelihood of promotion to grade O-4.

Keywords: *retention modeling, variable flow modeling, force structure modeling, retention bonus, reenlistment bonus, logistic regression, retention auction, menu of contracts*

Background

The retention analysis model: As the U.S. military evolves to the new blended retirement system (BRS), there are several important questions that the Navy needs to determine:

- What is the predicted impact of the BRS on near-term and long-term reenlistment rates?
- How can the Navy tailor retention incentives to individual sub-groups or service members?
- How can the Navy account for and utilize personalized non-monetary incentives in addition to monetary incentives?
- How can the Navy use retention policies to optimize both the quantity and quality of the retained force?
- How should the Navy optimally set the mid-career bonuses to offset any retention effects of the reduced retirement annuity, including amount and timing by sub-group or individual service members?

The first year of our Retention Analysis Modeling project is designed to determine the best steps forward for answering these questions. In particular, we performed the following analyses:

- Describe the various retention models that have been used to analyze policy levers affecting reenlistment rates. These include the simple reenlistment model, the Average Cost of Leaving (ACOL) model, and the Dynamic Retention Model (DRM).
- Critically assess the advantages and disadvantages of these retention models.
- Indicate what would be needed to obtain more credible estimates from future models, particularly dynamic-programming models.
- Discuss the problems with a one-size-fits-all and one-moment-in-YOS-fits-all mid-career bonuses.
- Make recommendations for tools to address the questions above, in both setting bonuses in real-time and predicting expected impacts in the longer-term.

The menu-of-contracts: This research differs from prior studies on setting retention bonuses in a couple of ways: (1) it is not about building a better predictive model of retention bonus, as many studies have done; (2) it is not addressing the bonus as a monetary incentive per se, rather, it tackles the bonus issue in a much broader way; and (3) it proposes an alternative contract design to set retention bonuses, namely, through a “menu-of-contracts,” to address the two essential problems in military manpower research, adverse selection (i.e., hidden information) and moral hazard (i.e., hidden efforts).

By proposing a menu-of-contracts approach that links bonuses and performance in contract form ex-ante, we address both adverse selection and moral hazard problems, and improve efficiency through both paying the right amount to right people and by inducing officers’ best efforts. Moreover, this approach is non-discriminatory because each officer is presented with the same menu. The beauty of this approach is that officers, knowing their own talent level and taste for effort, maximize their overall utility (including both monetary and non-monetary factors) by self-selecting into the contract structure that fits their talent and taste for effort (i.e., a perfect separating equilibrium), and they will be motivated to exert the right amount of effort after they choose their optimal bonus plan.

The role of naval officers' college education on retention and performance:

Several academic studies find strong correlations between different aspects of college education and other individual features on job performance and retention in the private sector. This report studies whether those associations are also true for a sample of U.S. Navy officers during the initial years of their military career. Separating the sample in URL and RL/STAFF officers, we analyze the attrition decisions of service members at 6 and 10 years of service. In addition, we study officers’ job productivity using two alternative measures of performance: 1) average FITREP scores during the first 6 years of service, and 2) likelihood of promotion to grade O-4.

Findings and Conclusions

The retention analysis model: One of our key findings is that existing models that estimate the effect of policy levers, such as bonuses or retirement-scheme changes, suffer from potentially large biases affecting the estimates. The sources of the biases include:

- Reverse causality in that a lower reenlistment propensity would lead to higher bonuses.
- Measurement error in the correctly coding the bonus considered by the Sailor at the time a decision was made.
- Excess supply in that, sometimes, more sailors want to reenlist than are allowed to reenlist.

Prior reenlistment models had further issues, in addition to the generic problems just mentioned. These include:

- High sensitivity of the results to assumptions on discount rates and other matters.
- Significant omitted-variables bias from pay differences across years capturing the effects of other factors specific to the time-period (e.g., the September 11th attacks and later negative developments with the Iraq War). This means that the pay effects will unwittingly capture the effects of these period-specific effects.

The original reenlistment models were limited by computing power and other matters and were not developed to answer the questions being posed today.

We overview how we plan to push the dynamic programming models forward, to minimize biases and maximize their efficacy:

- We will utilize the increased computing capacity of modern high-performance computing (HPC) cluster servers, and models will be designed from the ground-up to leverage this increased power.
- Non-monetary incentives, other personalized incentives, and measures of service member quality will be incorporated into the model as possible.
- New and more detailed data of individual's socio-economic and professional status will be collected and used in the estimation.

Still, predictive models will be imperfect, and we believe that there are other methods to determine the optimal bonus at a particular point in time. We introduce those other methods in this report. They include:

- Designing market auctions to elicit truthful responses to the lowest bonus needed to reenlist for each Sailor.
- Designing surveys of people who have already made decisions and have no stake in the game for how they would respond if the incentives (e.g. SRBs) were stronger or weaker.
- Aggregate opinions of subject-matter-experts, like what was used to find the USS Scorpion, the skipjack-class nuclear submarine that sunk in 1968.

The menu-of-contracts: The menu-of-contracts retention system is a viable alternative to both the current regression-based retention incentive system and an auction system that has also been explored. The menu-of-contracts can meet the retention needs of the Navy while increasing efficiency. The menu-of-contracts encourages and rewards good performance, while not requiring the military to use past performance to measure expected future performance. This will lead to retention of higher quality service members, which will in turn increase morale leading to better retention in the future as well. It will also induce maximum effort for service members throughout their careers as they strive for the highest possible bonus. The menu-of-contracts does all of this while maintaining the perception of egalitarianism and remaining within the current service member career timeline and promotion structure already in place.

The role of naval officers' college education on retention and performance

Our results provide limited empirical evidence on the effects of college education and other demographics on officers' performance and retention. For instance, we find that none of the individual science, technology, engineering and mathematics (STEM) and non-STEM degrees has a systematic impact on

retention, both for URL and RL/STAFF officers. The only exception is that an engineering major seems to be negatively associated with retention of RL/STAFF officers at both six and 10 years of service.

When we focus on performance, the relation with the individual STEM and non-STEM degrees is also unclear. As an example, for URL officers with an engineering major we find the contradicting result that they seem to obtain lower relative FITREP averages and, at the same time, have higher chances to be successfully promoted to grade O-4.

Finally, we find that some individual characteristics are consistently associated with retention and performance. For instance, both URL and RL/STAFF officers who are females or graduates from USNA or ROTC are more likely to leave the force at 6 and 10 years of service. In addition, RL/STAFF officers who belong to racial minorities seem to be more likely to obtain lower relative FITREP averages and less likely to be promoted to grade O-4.

Recommendations for Further Research

The retention analysis model: Based on what we have learned regarding the current modeling efforts, we will continue this research next year by formalizing the modeling approaches that we find will best support the decisions facing military personnel policymakers, focusing on data-based analysis to support questions regarding military compensation, including the continuation bonus and special pays and retention incentives. We will support the model development each year by focusing on specific questions the model will need to address, for example considering selected communities identified in conjunction with the project sponsor (e.g., aviation continuation bonuses) or decision elements to be included in the model (e.g., service member quality or non-monetary incentives).

We aim to develop a modeling approach that will improve on and complement prior efforts to model retention. With alternative and more accurate predictions, the model will be able to estimate the retention effects of the new retirement system and any changes in military compensation policy and bonuses.

At the same time, we will continue to explore more market-based approaches to retention and assignment policies. These policies will draw on innovative best practices found in civilian sector personnel management.

The menu-of-contracts: The primary disadvantages of this initial menu-of-contracts approach are that it requires the military to estimate the bonus level that will retain the right quantity and quality of service members and it does not incorporate non-monetary incentives. More complex auction designs address both of these concerns. Future research should consider if a more complex menu-of-contracts design, possibly introducing elements of an auction, could also more precisely determine the appropriate bonus levels and incorporate non-monetary incentives.

The role of naval officers' college education on retention and performance: The results of this study must be qualified in two ways. First, the dataset we use does not allow us to address potential selection issues that might bias the coefficients from the regression models. Second, the sample does not contain information about the grade point average obtained by officers, which is a variable that carries relevant information about job performance and retention. We leave these important issues as recommendations for future research in this relevant manpower topic.

N2/N6: INFORMATION WARFARE

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 identified differences between the SGP4 (USAF) and PPT3 (USN) propagation models, and analyzed them to determine the impact of these differences on positional error in orbital determination. Results of the study 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 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 by 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 SG4 has an error of about 1km at epoch which grows about 1-3km per day. Due to this error, the 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]. Their model is based on a 1959 solution of orbital equations by Brouwer [8], as adjusted by Lyddane [9] to avoid numerical problems for orbits with small eccentricities. This model is now known as PPT3 [10]. The study sought to 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 intelligence, surveillance and reconnaissance (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. Details of findings can be found in [11,12,13].

Actions to validate and assess differences between the models compared 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; and 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 MS thesis to carry out the above analysis based on measured data on satellite positions has been completed [13]. SGP4 and PPT3 are running in our lab and we have obtained satellite position data, which was used to assess differences in model accuracy. We found that the PPT3 code supplied to NPS was incomplete, missing the initialization code. Preliminary model assessment was based on hypothetical initialization code synthesized based on analysis of the existing code and published literature. Results confirmed the expected accuracy of the two models. Neither model was significantly more accurate than the other, and errors of both models were largest for near earth orbits, due to different imperfect approximations for atmospheric drag.

Recommendations for Further Research

Future research is recommended to complete the validation using the actual PPT3 initialization codes, run more test data to achieve statistical significance, evaluate impact of advances from space science, including newer 3LE and 4LE models, and determine differences in orbit predictions and the impact of using TLEs, 3LEs or 4LEs as input. Use the results 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.

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

Researcher(s): Dr. Luqi and Scot Miller

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, causing compass directions to 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 are expected to manifest specifically in cases where computations combine positions expressed in different coordinate systems. 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. Submarines have been operating in the Arctic for a long time, and have established systems and procedures for operating there. This has not yet been done for surface ships, since ice has prevented them from reaching the high Arctic, but that is likely to change. The Arctic ice cover has been decreasing in recent years, and projections indicate that the Arctic may become ice free during the summer in the next decade or two.

It has been established that GPS works correctly at the pole and that Electronic Navigation and Voyage Management System (VMS) Electronic Chart Display and Information System-Navy (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 use different coordinate systems, due to either uncoordinated transitions on the platform or networked connections from lower latitudes (such as Link-16).

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 or vice versa, 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 own ship heading and position are the main relevant factors, but precision and higher order effects may matter.

We investigated 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?

We gathered information about PNT issues and POCs' knowledgeable about the current status of ship systems with respect to arctic operations and related issues. These issues 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 designed a simple test case to find out. The researchers used test time at the Space and Naval Warfare Systems Command (SPAWAR) Center Pacific Combined Test Bed (CTB) using a mixture of

simulations and actual systems. This is the highest fidelity source of information at this time, since it is not currently feasible to operate a surface ship to latitude > 85 degrees due to ice coverage.

Ironically, as the testers at the CTB considered the test environment, they realized they had many unanswered questions as well, proving that while the initial research questions are straightforward, understanding the issues and evaluating them is quite difficult. Indeed, the CTB is now merging with the Navigation Sensor System Interface (NAVSSI) test bed to support our test; they realized they had to do this to be successful not only for Arctic PNT, but several other projects.

Differences in test results between running the same scenario at temperate latitudes and in the high Arctic should shed light on potential trouble areas. The intent is to understand for several combat and situational awareness systems what potential trouble areas, if any, are revealed when working at high latitudes. The initial test was completed on Aug 6, 2017 and confirmed our theoretical predictions, 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 relative to normal coordinates 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, including as a first step the coordinate system associated with PNT information. 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.

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NPS-17-N027-A: Synoptic Monthly Gridded and Ocean Modeled Data to Assess Submarine Vulnerability

Researcher(s): Dr. Peter C. Chu

Student Participation: LCDR Coleen McDonald USN, LT Murat Kucukosmanoglu TNF, and LT Albert M. Yudono TNI AL

Project Summary

This project is to answer the question “How can inter- and intra-annual variability in the ocean be leveraged by the submarine Force?” through quantifying spatial and temporal variability in temperature and salinity (T, S) fields and in turn underwater acoustic characteristics such as transmission loss (TL), signal excess, and range of detection. An extension of the Navy’s Generalized Digital Environmental Model (GDEM), called the Synoptic Monthly Gridded World Ocean Database (SMG-WOD) (T, S) data, has been developed for the world oceans from January 1945 to December 2014 with one-month increment using all observational (T, S) data from all available sources including military and civilian, U.S. and ally Navy. The National Oceanic and Atmospheric Administration National Centers for Environmental Information (NOAA/NCEI) conducted quality control and posted to its website for public use. The inter- and intra-annual ocean variability has been determined in the Navy’s hot spots such as the Mediterranean Sea, Philippine Sea, South China Sea, and Yellow Sea through comparison between the synoptic monthly gridded (SMG) and GDEM (T, S) data, and in turn the sound speed profile (SSP). The variability of TL is identified using the Bellhop acoustic model. The TL has strong interannual (3-7 years) variability with less TL in the area between the convergence paths, surface duct, sound channels bottom bounce. Such interannual acoustic variability can be leveraged by submarine force since the ocean environment is directly related to gaining a better understanding of the acoustic wave propagation.

Keywords: *synoptic monthly gridded (SMG) (T, S) data, Navy’s Generalized Digital Environmental Model (GDEM), optimal spectral decomposition (OSD), sound speed profile, acoustic transmission, acoustic ray tracing, acoustic model BELLHOP, geo-acoustic parameter, sediment characteristics, Mediterranean Sea, Philippine Sea, South China Sea, Yellow Sea*

Background

Understanding the ocean environment is imperative and directly coupled to the successful performance of undersea sensors and subsequent employment of undersea warfare weapon systems for submarine operations. The major threats in the littoral are diesel submarines and sea mines. The combination of improvements in noise reducing technology and the development of air-independent propulsion (AIP) technology have made diesel submarines very difficult to detect in both the littoral and blue waters. After a weapon platform has detected its targets, the sensors on torpedoes designed for blue water operations are not designed to acquire a target in a reverberation-crippling environment. Recently, the U.S. Navy has focused much of its research and development efforts in designing high frequency sensors and corresponding acoustic models to overcome the threat in the littoral. In order to optimize the performance of undersea sensors and weapons systems, it is crucial to gain an understanding of the acoustic wave propagation in the ocean. Having an accurate depiction of the ocean environment is therefore directly related to gaining a better understanding of the acoustic wave propagation. How acoustic waves propagate from one to another location undersea is determined by many factors, some of

which are described by the sound speed profile (SSP), and geo-acoustic parameters. The figure of merit (FOM) for ASW is determined by

$$FOM = SL - LE - RD \quad (1)$$

where SL is the source level; LE is the total background noise; and RD is the recognition differential.

Temporal and spatial variability of the global temperature and salinity fields is important in climate change. In the past decade, several new coupled ocean-atmosphere phenomena regarding the temperature, such as the pseudo-El Nino (or sometimes called central Pacific El Nino) and the Indian Ocean Dipole (IOD), were discovered and recognized important in climate variability. The pseudo-El Nino is characterized by warmer sea surface temperature anomalies (SSTA) in the central equatorial Pacific and cooler SSTA in the eastern and western equatorial Pacific^{[1][2]}, which is different from the El Nino with anomalous warming in eastern equatorial Pacific. El Nino and pseudo-El Nino have different teleconnection patterns. Taking the Atlantic Ocean as an example, less tropical storms and hurricanes occur during El Niño events; and more tropical storms and hurricanes appear during pseudo-El Nino events^[2]. Chu^[3] presented heat content tripole in world oceans and found the connection between interannual thermal variability in the tropical Pacific and Indian Ocean. The variability regarding salinity is also important since freshwater gaining from river run-off, surface freshwater flux [precipitation-evaporation (P-E)], and freshwater advection reduces upper layer salinity, stabilizes the water column, and in turn slows down the meridional overturning circulation (MOC).

Using regional data, Phillips and Wijffels^[4] identified an average freshening of 0.2 psu extending from 100°E to Australia, 25°S to Indonesia and down to 180 m depth, for more than 3 years from 1999 to 2002. The observed freshening can be largely explained as a direct response to changes in the air-sea freshwater exchange. Boyer et al^[5] calculated linear trends of zonally averaged salinity anomalies from 1955–1959 through 1994–1998 from the World Ocean Database 2001 (WOD01) and identified freshening and salinization in ocean basins such as freshening in most of the Pacific with the exception of the subtropical South Pacific, deep freshening in the Atlantic subpolar gyre, shallow salinization in the Atlantic tropics and subtropics, and salinization in the Indian Ocean at all latitudes in the upper 150 meter layer, with a subsurface freshening between 40°S and the equator in the 250–1000 meter layer.

Up until 2016, detailed temporal and spatial variability of global temperature and salinity fields has not been investigated from the observational data. This is because ocean observational (T, S) data are irregularly distributed in time and space. To fill the gap, several synoptic monthly gridded (SMG) (T, S) datasets have been produced in this project^[6] with a sufficient resolution in space (1°×1° in global oceans and 0.25°×0.25° in several regional seas) and in time (monthly increment) using the optimal spectral decomposition (OSD) method^{[7]-[12]}. These datasets have undergone thorough quality control by NOAA/NCEI scientists. With SMG (T, S) data, the impact of intra- and inter-annual (T, S) variability on acoustical transmission can be identified.

Findings and Conclusions

Establishment of SMG (T, S) datasets:

Six SMG (T, S, u, v) datasets^[13] have been produced using the optimal spectral decomposition (OSD) method and quality controlled by NOAA/NCEI scientists:

- (1) Synoptic monthly gridded three-dimensional (3D) World Ocean Database temperature and salinity from January 1945 to December 2014, NOAA National Centers for Environmental Information (NOAA/NCEI Accession 0140938) downloaded at <https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0140938>
- (2) Synoptic Monthly gridded WOD Absolute Geostrophic Velocity (SMG-WOD-V) (January 1945 - December 2014) with the P-Vector Method, NOAA National Centers for Environmental Information (NOAA/NCEI Accession 0146195) downloaded at <https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0146195>
- (3) Synoptic monthly gridded Global Temperature and Salinity Profile Programme (GTSP) water temperature and salinity from January 1990 to December 2009, NOAA National Centers for Environmental Information (NOAA/NCEI Accession 0138647) downloaded at <https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0138647>
- (4) Synoptic monthly gridded (0.25°) three dimensional (3D) Mediterranean Sea (T, S, u, v) dataset (January 1960 - December 2013) from the NOAA/NCEI WOD Profile Data, NOAA National Centers for Environmental Information (NOAA/NCEI Accession 0157702), downloaded at <https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0157702>
- (5) Synoptic monthly gridded (0.25°) three-dimensional (3D) Japan/East Sea (T, S, u, v) dataset (January 1960 - December 2013) from the NOAA/NCEI WOD Profile Data, NOAA National Centers for Environmental Information (NCEI Accession 0157703), downloaded at <https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0157703>
- (6) Synoptic monthly gridded (0.25°) Gulf of Mexico (T, S, u, v) dataset (January 1945 - December 2014) from the NOAA/NCEI WOD Profile Data, NOAA National Centers for Environmental Information (NOAA/NCEI Accession 0156423), downloaded at <http://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.nodc:0156423>

These datasets are openly accessed from the NOAA/NCEI website. Among them, first three datasets are for the world oceans with the horizontal resolution of $1^\circ \times 1^\circ$, and the other datasets are for regional seas with the horizontal resolution of $0.25^\circ \times 0.25^\circ$. Table 1 shows the vertical depths of the datasets.

This study identifies the effects of intra- and inter-annual ocean environmental variability on the acoustic propagation in several regional seas such as the Mediterranean Sea, Philippine Sea, and South China, and Yellow Sea using the recently established synoptic monthly gridded (SMG) (T, S) data and an open source acoustic ray tracing model (BELLHOP).

These effects vary with the location and time period. The overall average TL ranges between the two datasets same, but because SMG-WOD data contains intra- and inter-annual variability, several extended ranges were found for acoustic transmission that break out well past the GDEM TL ranges, not by a mere one or two km, but in some cases twice the average TL range such that 20km detection range may jump to 40 km depending in the environment at the time.

For a general study, either database (SMG-WOD or GDEM) would be relevant because the average TL ranges are very close, but for tactical naval application, this research shows that in shallow water, the TL range variations between the two datasets can be significant. Just a few km extension of TL range can

greatly increase the entire ensonification coverage area, which is crucial for sonar operators on submarines or ships, or of unmanned. This research shows that TL ranges may vary up to 10km or further, depending on the combination of source depth to receiver depth, which is important since submarines are not fixed in a vertical position. As the submarine varies its depth, it can greatly affect its detection vulnerability, or based on the season, it may choose to avoid an entire shallow operating area where ranges are poor.

Research Deliverables: Two research papers ^{[12] [13]} and three MS theses in Meteorology and Oceanography. ^{[14][15][16]}

Recommendations for Further Research

This research also reveals the sensitivity of BELLHOP; it is sensitive enough to produce different TL results based on the variations of source and receiver depths when given the same SSP input. BELLHOP is also sensitive to the attenuation values for the bottom sediment, as location E in the Yellow Sea had the hardest, most reflective bottom type and the in both datasets it modeled the longest ranges as opposed to most of the other locations being silty clay or mud and BELHHOP modeled significantly shorter ranges.

Future studies need to use more sophisticated Navy standard underwater acoustic model – CASS-GRAB.

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NPS-17-N183-A: Battle Management Aids – Concepts, Definitions, and Terms of Reference Necessary to Define Navy Requirements

Researcher(s): Bonnie Johnson and John M. Green

Student Participation: No students participated in this research project.

Project Summary

The ability to effectively manage distributed warfare assets for collaborative operation significantly increases our military advantage. Recent studies have pointed to increasing speed of warfare, emerging threat capability and numbers, and data overload from a growing number of sensors and networks. This results in challenges to human decision making when faced with a complex decision space, multitudes of information, and the fast reaction time required. This project investigated battle management aids (BMAs) that have the potential to reduce timelines, increase decision confidence, and optimize warfare

resources. Applying a systems engineering approach to the problem space, this study developed a conceptual framework for tactical battle management aids (BMAs) to support naval and joint warfare missions. A systems approach was developed to (1) view warfare resources as systems, (2) establish a decision scope around the problem space, (3) create a decision space for analyzing the knowledge of the environment coupled with the knowledge of the system resources to develop decision alternatives, and (4) identify characteristics needed in the systems solution to address the complexity. A concept for future battle management aids relies on an adaptive architecture that enables collaboration and emergent behavior, distributed intelligence among the systems, and predictive analytics to evaluate the consequences of warfare courses of action.

Keywords: *battle management aids, decision-making, complex systems, systems of systems, predictive analytics, resource management, human-machine interaction*

Background

This research was related to the NRP project, Big Data and Data Analytics for the Common Tactical Picture, which is an on-going project sponsored by William Treadway of N2/N6 (Zhao, Kendall, Johnson, & Baumgartner, 2015). The Big Data project developed high-level concepts for decision-making analytics to support battle management. This project focused on developing requirements for automated battle management aids. It was based on previous work conducted by the principal investigator and research collaborator in battle automation for the Navy, decision paradigms, data fusion, and systems engineering approaches for decision aids (Johnson, 2001).

Findings and Conclusions

Tactical warfare is complex (Bar-Yam, 2004). It requires agile, adaptive, forward-thinking, fast-thinking, and effective decision-making. Advancing threat technology, the tempo of warfare, and the uniqueness of each battlespace situation, coupled with increases in information that is often incomplete and sometimes egregious are all factors that cause human decision-makers to become overwhelmed (Zhao, Kendall, Johnson, & Baumgartner, 2015). Automated BMAs become a solution to address this complexity—to simplify complexity, to increase understanding/knowledge, and to provide quantitative analyses of decision options.

Automated BMAs are computer-aided decision support systems that are meant to enhance and improve tactical decisions. BMAs may improve decisions by speeding up the decision process; providing greater confidence in the knowledge that decisions are based on; developing more decision options; providing greater understanding of decision consequences; developing options with greater probability of success; and/or improving the optimization of resource usage. The military currently uses BMAs to share and process data to develop operational pictures and situational awareness. However, this research focused on conceptualizing BMAs as envisioned for the future for naval and joint operations.

This project applied a systems approach to integrate analytic and synthetic methods, and to emphasize a holistic perspective in understanding the interactions between warfare system elements and with their external operational environment. The project first characterized tactical decisions and then conceptualized the possible role of future automated decision aids. The outcome was a proposed systems approach and high-level conceptual design of this complex problem space.

Decision Aids for Battle Management: The first phase of research characterized battle management decisions—focusing on how BMAs may be used to support human decision-makers within a military

tactical environment. Four domains of decision complexity were identified: temporal, spatial, proactive/reactive, and rules/policies. These domains were found to affect battle management through time-constraints, multi-spatial threat complexity, consequences of courses of action, and doctrine and rule constraints (Johnson, 2017). We introduced the term, decision space, to refer to all of the input (information, data, knowledge, etc.), decision processes (human and machine), factors/constraints, and objectives/missions—basically everything that influences the decision making. For battle management, the decision space fluctuates from simple to complex as operations range from peace-time to multi-domain threat encounters. Examples of changes to the problem space that affect the complexity of the decision space include: battle tempo (or reaction time), the number of simultaneously-occurring threats (or battle events), the severity of the consequences of battle events, the heterogeneity of threats (due to threat type or spatial domain), and the scope of the event or events (in terms of area or population affected). All of these operational factors translate into multi-dimensional variables that comprise a “decision space.” As the decision space complexity increases, military human decision-makers may become overwhelmed. At this point, having automated BMAs in place can support effective decision-making. Human-machine interaction in the decision process was conceptualized at a high level. We developed the concept of a meta-level decision aid to identify the complexity of the environment and adjust the human-machine-interface to be in the most effective mode.

A Systems Approach to Battle Management: A systems approach was developed based on a four-step process of (1) viewing warfare assets as resource systems, (2) viewing the battle management problem space holistically, (3) viewing the decision space as a system, and (4) developing a complex adaptive systems of systems (CASoS) solution (Johnson, 2017).

The CASoS is envisioned as enabling the distributed warfare resources to interact as systems of systems, exhibiting emergent (force-level) behavior, and adapting to the changing operational environment. This class of systems is a required solution to effectively address complex tactical problem spaces. Engineering future warfare systems to behave as CASoS requires a decision architecture and solution space of automated BMAs that provide the following three capabilities (Johnson, 2018):

- (1) Adaptive relationships—An adaptive intelligent architecture enables agile interrelationships among the constituent systems that comprise an ultimately adaptive system of systems (SoS) that can respond to a changing complex environment.
- (2) A system of intelligent constituent systems—The adaptive emergent behavior of the CASoS is governed by the self-management of the distributed constituent systems to collaborate or act independently as the complex situation dictates.
- (3) Knowledge discovery and predictive analytics— Key to the engineered CASoS is the ability to gain and maintain shared situational knowledge of the environment and the distributed constituent systems. The knowledge is analyzed to prioritize missions; develop tasks and courses of action (adaptive responses to the problem space); and to develop “what-if” and “if-then” predictive scenarios to shape the synthesis of future intelligent decision and adaptive SoS relationships.

The decision space for this complex application can be thought of as a system of BMA systems with holistic force-level management decision aids supporting the orchestration of lower-level BMAs concerned with specific resource or platform systems. The holistic-level BMAs would manage the problem space information and focus on high-level concerns such as evaluating the level of complexity,

establishing decision scopes, and recommending human-machine decision interactions. The CASoS solution will require automated BMAs, an adaptive architecture, warfare resources that are “taskable,” and a command and control culture that supports this systems approach.

Recommendations for Further Research

The battle management problem space is complex and will only continue to grow in complexity with the addition of more sensors, more information, more unmanned threats, more non-state adversaries, and advances in technology. To stay ahead of this problem space, a complex solution space must be conceptualized and eventually realized to facilitate fast-acting and highly responsive warfare utilization. A systems approach provides a method for addressing the multidimensional and adaptive decisions required by offering holism, a systems perspective and the definition of the decision space as a system of systems. It frames the problem as a CASoS and highlights the need for a decision architecture that enables adaptive relationships, intelligence at the system level, shared knowledge, and predictive analytics. The effective use of automated BMAs in support of human decision-making provides the foundation for the CASoS solution space.

Future work is required to develop the CASoS conceptual design and adaptive architecture at the next level of detail. Research in the application of artificial intelligence, machine learning, and data analytics will support the development of a “system of decision aid systems” along with specific decision aids. Finally, further research on complex systems engineering as a sub-discipline of systems engineering will provide the design and development methodology required to engineer a complex systems solution.

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NPS-17-N185-B: Big Data Strategy Plan for Combat ID

Researcher(s): Dr. Neil C. Rowe

Student Participation: Mr. Jim Zhou CIV NPS

Project Summary

This project developed methods for addressing the big-data aspects of combat identification (CID) by pushing some of the processing "to the edge" or nearer to the warfighter. The goal was to reduce data volume of uninteresting data by excluding routine or predictable CID data. This project will be continuing in FY18. In FY17 we developed analysis programs for data from the Automatic Dependent Surveillance-Broadcast (ADS-B) database containing flight records of most of the world's aircraft every second; this unclassified data is easier to work with than our ultimate target of the Navy's classified data. We wrote programs to assess the anomalousness of both individual aircraft records and tracks of aircraft, with the goal of forwarding only the most anomalous data to higher levels of big-data processing. We computed nine measures of anomalousness and took a weighted average of them for each aircraft record. The measures included atypicality of counts and deviations in velocity and speed from expected values in latitude-longitude bins, as well as rarity of the aircraft type, the aircraft operator, the straightness of its track over the earth's surface, and the average rate of altitude change. Experiments with a sample of 107 million aircraft records from 12 days (one per month) over a year identified many interesting anomalies that would be good to report in a Navy context.

Keywords: *combat identification, aircraft, big data, edge, data filtering*

Background

Testing our methods in FY17 used data from the ADS-B satellite-based aircraft-tracking system (FAA, 2018). It uses specific transponders, is not subject to the limitations of radars, and has seen a swift adoption over the world. It was a good start for testing our methods before moving to Navy data.

This work is part of the military's long-term emphasis on smarter forwarding and analysis of sensor data (DoD R&DE, 1998; van Gosliga and Jansen, 2003). Our work this year focused on anomaly detection in the aircraft data. Anomaly analysis is a common big-data task since intelligence gathering wants to hear things it doesn't know already. Eliminating non-anomalies from analysis can provide significant data traffic reduction (SPAWAR, 2016).

Findings and Conclusions

We extracted ADS-B data for one day per month of a year, typically one record per second per aircraft, and used this for training and testing. Coverage was of most of the aircraft in the world in the air. The attributes we selected for testing were International Civil Aviation Organization (ICAO) identification code of the aircraft, type of the aircraft, operator of the aircraft, country of origin, altitude, latitude, longitude, speed, bearing, and timestamp of the position. The ICAO number was used to build tracks; the type and operator were used to distinguish civilian from military aircraft. The ADS-B data is not always reliable, and contains faulty sensor reports as well as many missing records (Tabassum et al, 2017).

Since aircraft have different tendencies in different parts of the world, averaging the data in bins is useful to detect norms by which unusual aircraft behavior can be recognized. We averaged in latitude-longitude bins in our experiments: (1) the estimated rate of aircraft, (2) the average velocity vector, and (3) the

average altitude. We separated statistics on commercial airlines from the other aircraft, since commercial airlines are more consistent. Additional bins we averaged separately were (4) the speed of an aircraft as a function of altitude, (5) the occurrence count as a function of hour of the day, and (6) the count of the owner.

We computed nine measures of anomalousness: (1) count of the latitude-longitude bin; (2) consistency with the commercial/noncommercial split for the bin; (3) heading disparity for the bin; (4) altitude for the speed bin; (5) speed; (6) rarity of the operator; (7) rarity of the time; (8) average deviation of the path from a straight line in latitude and longitude; and (9) average rate of altitude change over the path. Paths were found by sorting first by aircraft ICAO number and then by timestamp. We assigned a weighted linear model to these factors and calculated an overall anomalousness for each record. Records in approximately the top 5% were extracted for further study.

Recommendations for Further Research

Future work will incorporate anomalousness measures from the overall track of the aircraft, as well as results from clustering data on a range of attributes to find anomalous records outside of clusters. Measures can also come from other sensing platforms via a network connection, and anomalousness can be tempered by a measure of the trustworthiness of the data based on its source.

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NPS-17-N194-A: Big Data Architecture and Analytics for Common Tactical Air Picture – Efficient Implementation

Researcher(s): Dr. Ying Zhao

Student Participation: Maj Kyle Ellis USMC

Project Summary

In previous research we demonstrated that big data techniques and analytics can provide potentially useful information assisting the combat ID problem and improving the common tactical air picture (CTAP). Big data techniques allow the distributed acquisition of far more potentially useful information related to the combat ID problem by fusing disparate sources of crucial combat data and information in real time or near real time which means, in theory that the reliability, speed, and trustworthiness of combat ID would be improved. Combat identification (CID) is notoriously a very difficult function, often

more art than science. The process is still very manual and decision makers can experience cognitive overload, so analytics is just one aspect of CID. We investigated related Deep Analytics including machine learning (ML) and artificial intelligence (AI) methods such as anomaly detection method Lexical Link Analysis (LLA). LLA is as an unsupervised deep learning tool which can “red flag” possible patterns and anomalies for further investigation.

Further enhancement and discovering new rules have been made with our use of Google map/earth, Keyhole Markup Language (KML), data-driven documents (D3), and the Defense Information Systems Agency (DISA)’s Big Data Platform (BDP). The various analytics were tested with real world data generated by various sources including Automatic Dependent Surveillance-Broadcast (ADS-B) which will eventually provide world-wide kinematic data for commercial and general aviation.

Keywords: *combat identification, big data, deep learning, data strategy, concept of operations, fusion, correlation, reasoning, deep learning models, pattern recognition, anomaly detection*

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. Big Data, Deep Analytics and Deep Learning (ML/AI) are critical in designing next generation 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 equally important to test and adapt commercially available tools now to satisfy the ongoing needs and requirements of the CID and combat systems. Big Data Analytics and Deep Learning/AI may provide new capabilities on improving the CID processes, and new, big-data analytic techniques can be used to produce a (near) real-time common tactical air picture. New analytic tools and techniques must be optimized and evaluated against alternative concepts of operation in order to determine which tools/techniques and data strategies perform best in alternative scenarios.

Findings and Conclusions

Our research proposal outlined a four-pronged approach to analyzing the CID problem in a CTAP environment: 1) complete the survey of big data tools and techniques, 2) develop a data strategy that recognizes the unique input and output environment of CID services, 3) generate alternative concepts of operation of the integrated CID process for a CTAP environment, and 4) test the integrated CTAP CID services using samples of tactical data from naval and academic partners [1].

We initially investigated the standard big data technology by stack by converting the JSON-formatted ADS-B data via a Hadoop cluster to demonstrate as a proof of concept the viability of parallel data processing to convert large volumes of data. We did see a performance increase by this simple test. ADS-B data is potentially an important data source for CTAP, but for large volumes of data it must be processed in a timely manner. A related item of our study was the investigation of a larger scale big data platform, DISA’s BDP which initially designed to process Big Data Analytics for cyber data, but we’ve concluded that BDP analytics can be used for CID/CTAP. We conducted a small test using ADS-B data and follow on work will do more. Our ADS-B data set consisted of 4Tb (6/2016-7/2017), worldwide every minute, 1440 files each day, 6MB each in a JSON format. With the data set we performed pre-processing including kinematic attributes.

Although they are not big data tools per se, KML (Keyhole Markup Language) and D3 for (data-driven documents) were used to create from ADS-B data rules and virtual airways/tracks that demonstrated the utility of finding big data equivalents.

Our data strategy for the past year was to find data sources where we would gain insight, rules, patterns, baselines, and anomalies for aircraft, and as large as feasible. Most track data are in some plain text format such as XML, JSON or CSV which wasn't a problem for ingestion. For ADS-B we used Hadoop parallel processing to convert to CSV for further processing with various analytics. ADS-B is open source, free, and will eventually be worldwide, so it is an excellent source to augment other (mostly classified sources) such as CEC and sensor data. The lessons learned with ADS-B and other open data sources can be applied to classified data as well.

Per our proposal, we did investigate alternative concepts of operation of the integrated CID process for a CTAP environment. We focused first on rule based and "patterns of life" through our investigation of anomalies, patterns and baselines. Our initial findings strongly indicate, the ability to identify neutral aircraft (with a high probability) based on kinematics using geospatial and time dimension to build specific behavioral/rule models. Our other concept used deep learning method such as Lexical Link Analysis (LLA) to discover patterns, rules, and anomalies that can be combined for classification of neutral or neutral flying objects of ADS-B data.

We tested the integrated CTAP CID services using samples of tactical data from the Navy Civil Engineer Corps (CEC) and the Massachusetts Institute of Technology (MIT) Lincoln Lab. We worked with MIT Lincoln Labs to demonstrate the initial results of the analytics. These various efforts confirm totally our original expectations or predictions that more data and data sources (if selected judiciously) have the potential for improving CID/CTAP, especially when coupled to deep learning and AI technologies. Our results, albeit on a relatively small scale, are very promising and could make a contribution to CID/CTAP if integrated. Our only possibly future limitations in our research procedures would be connectivity to data sources, and if we do not have a secure computing platform and storage. Amazon's AWS Snowball or similar technologies may overcome that problem. This limitation is mitigated if can collaborate more with the MIT Lincoln Lab and access their network infrastructure. The Naval Postgraduate School lacks this infrastructure.

We believe that there are both long-term as well as the short-term implications of our findings. For the long-term the Navy may want to look at its open source data collection policy, and for the short term there may be some immediate use of our analytics as an input to other systems. We may be able to provide such an input next year or the next.

Recommendations for Further Research

One element of our study that is essential is the identification and collection of DoD and open source data that would be used for testing big data Analytics. What is needed today and, in the future, and how will it be stored? As researchers one of our primary problems is to find the data and then get access to it. In some cases, the data may no longer exist since it is thought as perishable. We have just begun to explore BDA and deep Learning/ML, and we are aware of DoD efforts to address these areas, but there can be further research on AI tools beyond. Further research would include taking airborne data such as ADS-B and CEC and taking a deeper look at creating behavioral models that are specific to location and time. There are potentially other data sources that researchers may investigate and contribute to CID/CTAP.

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NPS-17-N194-B: Combat Identification

Researcher(s): Dr. Dan Boger, Dr. Ying Zhao, CAPT Scot Miller USN Ret., Dr. Arkady Godin, Mr. Tony Kendall, and Ms. Bonnie Johnson

Student Participation: Capt Ed Hamer USMC

Research Summary

The emerging Navy big data architecture enables new distributed capabilities for combat identification (CID). These new technical capabilities need to be co-evolved with changes in operational thinking, since often CID processes are stove piped. CID is notoriously a very difficult function, often more art than science. With the advent of technologically advanced peer competitors, it is essential for the Navy to improve in this area. Big data techniques appear to allow the distributed acquisition of far more potentially useful information related to the CID problem. Being able to fuse disparate sources of crucial combat data and information in real time or near real time in theory means that the reliability, speed, and trustworthiness of CID would be improved an order of magnitude. As with all technological breakthroughs, though, aligning the new capabilities to operational processes is a must.

Keywords: *big data, analytics, common tactical picture, ctp, integrated fires, combat identification, CID, abma, bma, battle management aids, data strategy, predictive*

Background

Design and Implementation of big data analytics is critical to gaining the tactical advantage over peer adversaries by contributing to the common tactical picture (CTP), supporting CID, and enabling battle management aids (BMA). Big data analytics can address CTP and CID challenges that include unsupervised learning, self-taught learning, deep learning, pattern recognition, anomaly detection and data fusion. Study of architecture approaches, database design and choice of analytic tools is required to optimize Big Data Architectures and Analytics (BDAA) to support CTP Naval Integrated Fires and CID applications across warfare areas.

Findings and Conclusions

Consider three possibilities for executing combat identification in an integrated air and missile defense (IAMD) scenario:

The first possibility is advancing current combat systems legacy environment (includes Aegis, SSDS, CEC, NIF-CA, SLQ-32, and similar systems), characterized by tracks developed through various sophisticated methods that combine the best of radar, timing, and positioning technologies to create a composite tactical picture. The picture is so accurate that actual firing solutions may be shared between units,

integrating weapons systems as well. The current legacy approach also leverages lines of bearing derived from electronic surveillance measures, as well as identification friend or foe (IFF) technologies. These systems of systems are exquisite engineering marvels developed over many decades, and proven in combat. Identification, though, is a challenging task. The current systems work only in the present with no persistence strategy and access to historical records. Any data generated seconds ago is gone forever. Further, ad-hoc connections to new data sources is a costly endeavor for current legacy environment. Rightly so, the developers and operators of the current systems are very protective of what works. There are plenty of success stories, which is why most countries, if they can afford to, seek Aegis for their air warfare ships.

A second possibility is augmentation of current combat systems environment with advances from emerging big data and cloud capabilities. Over the past decade, the advent of cloud and big data offer new possibilities for combat identification. Big data offers (nearly) unlimited processing and data storage. In theory, the more data one has, the more one can use that data to infer deeper understanding of relationships among objects, connections, and activities, which are the core needs for combat identification. A representative example of big data in support of military operations is the joint Tactical Cloud Reference Implementation (TCRI), born from an Office of Naval Research project called the Naval Tactical Cloud, which in itself was derived from an U.S. Army Intelligence and Security Command (INSCOM) “Red Disk” program, which itself was derived from work done at the National Security Agency (NSA). Bottom line, efforts like TCRI enable large data sets to be captured and analyzed. However, the response time for these systems varies from seconds to minutes, satisfactory for most intelligence and commercial applications. Such imprecise timing is not desired in the fast moving world of IAMD combat identification. Yes, specialized approaches to achieve real time big data have been made, but only in very narrowly defined niche areas, such as the power grid.

We propose a new possibility that resolves the shortcomings of the above two approaches, yet leverages the desirable characteristics of each. Naming this approach is hard. We concluded that “Symbolic Reasoning” is the most representative of our artificial intelligence (AI) approach. Considering AI being critical in advancing knowledge, we chose “Symbolic Reasoning.” First, we want the speed and timing to be precise, just like in the legacy systems. This is problematic considering the other capabilities we want to add, but we believe it can be done. This differentiates our approach from the TCRI of the world. We want to use as much data as possible to help solve the combat identification process. In the near term, we think that the current composite tracks, IFF data, electronic support measures (ESM) derived lines of bearing, and other civilian track and identity sources are sufficient, but in the longer run we believe that all publicly available information (PAI) sources of data available in the world (including data from social media platforms and from space (CubeSat satellite constellations) in whatever form, should be leveraged to minimize uncertainty for combat identification solution. We believe in persisting all combat identification related data for as long as possible, since these data (in accordance with the precepts of the Defense Intelligence Database (DIB) will possess future value. We believe that the characterization of the data can be canonized to improve interoperability in transformational ways, leading to new uses of inference-based reasoning, leading to predictive analytics, and therefore vastly improving combat identification. We believe predictive combat identification analytics will revolutionize prescriptive planning.

In a nutshell, our “Symbolic Reasoning” approach incorporates the value of the current track-derived approach (Aegis, SSDS, CEC, NIF-CA), and leverages good big data practices (large data sets and data

manipulation at speed). By adding our new technologies, we will deliver four new operational capacities, in addition to the capabilities provided by the first two methods.

- 1) Recording (for lookback) and persisting spatio-temporal information for all data modalities including pedigree to authoritative sources required for complete audit and training;
- 2) Enabling adaptive representation of reality in dynamically changing world environment;
- 3) Enabling pattern of life (POL), POL anomalous detection, and other historic analysis capabilities, which solve an urgent emergent Navy IAMD issue;
- 4) Building the foundation for future predictive logics incorporating non-traditional data sources.

We want to reemphasize the focus on speed. We also incorporate a holistic approach to speed. Unlike many other applications involving lots of data, combat identification demands the fastest speeds possible. Every part of our approach recognizes this requirement and takes steps to enable the fastest speed.

In summary, developing combat identification using Symbolic Machine Learning and other new Big Data techniques involves focus on three emergent technologies:

1. Expert understanding of next-gen ingest without reliance on manually-produced adaptors;
2. Expert understanding of heterogeneous data store representations to identify abstract store;
3. Advanced in-memory storage and processing for real-time performance;
4. Knowledge multi data-modal representation with seamless integration of data with ontologies through various typing layers.

This team possesses subject matter experts in each area. Moreover, the Air Force Research Laboratory is already applying these same techniques to a USAF space C2 program that contains nearly the same challenges. This means that fewer resources are required to execute!

Recommendations for Further Research

None provided.

NPS-17-N279-A: Reinforcement Learning for Modeling Large-Scale Cognitive Reasoning

Researcher(s): Dr. Ying Zhao

Student Participation: No students participated in this research project.

Project Summary

In related research we demonstrated that Big Data techniques and analytics can provide potentially useful information in assisting the combat ID problem and improving the CTAP (Common Tactical Air Picture). Combat ID is notoriously a very difficult function, often more art than science, the process is still very manual and decision makers can experience cognitive overload, so analytics is just one aspect of CID. CID would then be a good case study to investigate machine learning and artificial intelligence (AI). The focus of our research has been the question: Are machine learning (ML) and artificial intelligence (AI) systems able to learn and use the existing knowledge models for better and timely decision making for CID? Soar is an open source tool as a cognitive architecture, developed by the University of Michigan,

using expert systems including reinforcement learning (RL). We first used Soar with a thesis student who was a Tactical Action Officer (TAO) that represented the “teacher”, and we empirically showed that learning did take place in Soar. We then began using a Soar version which is integrated into naval simulation software (NSS) as an agent to further aid in the in the CID decision-making process and eventually offered the opportunity to integrate real world data into the process. We also used Lexical Link Analysis (LLA) that provided initial learning rules to Soar. LLA is as an unsupervised deep learning tool that can “red flag” possible patterns and anomalies for further investigation. Our research empirically answered our core question: are machine learning (ML) and artificial intelligence (AI) systems able to learn and use the existing knowledge models for better and timely decision making for CID? We saw error rates go from 3.7% to 0.4% with initial rules provided by LLA.

Keywords: *combat identification, reasoning, reinforcement learning models, rule-based AI*

Background

NSS has capabilities for simulating sensor data fusion and tactical systems to model the formation of situational awareness and the engagement kill chain. In real operational situations, the amount of data and information coupled with the complex decision space can overwhelm operators and commanders’ cognitive abilities in the tactical decision loop. The current naval simulation framework does not address the cognitive layer that is critical to warfare effectiveness assessment from a system of system perspective. These complex cognitive functions include: decision making, sensor fusion, and analytic processes (and workflow), for example, in a kill chain in an integrated fires environment. The current NSS does not have the ability to model, understand, and optimize the complicated decision-making processes and cognitive functions required in a realistic operational scenario, such as a tactical kill chain. A critical modeling gap is the analytic process and reasoning leading to decisions from the situational awareness provided by the common operating picture.

The Soar cognitive architecture (developed at the University of Michigan and used by Soartech) is a well-known modeling tool and has applications in this field. The Soar engine has been integrated into the NSS and has been licensed to NPS as the Warfighting Impact of Simulated Decision Makers (WISDM). This project’s objective is to develop Soar agents in NSS to model the reasoning (using Soar production rules) through knowledge systems, rules, and heuristics. Developing a cognitive model and architecture to represent a realistic warfighting decision process will enhance the Navy’s ability to understand and analyze the kill chain and improve automated decision aids and human-machine-interfaces.

Findings and Conclusions

Our core research question: Are machine learning (ML) and artificial intelligence (AI) systems able to learn and use the existing knowledge models for better and timely decision making for CID? If yes then the corollaries would be, can such a system learn from:

- the historical data with ground truth?
- feedback of a human operator?
- cross-validation of big data?
- the delayed ground truth after actions taken?

To answer our core question we selected the software, Soar, which is an open source tool developed by University of Michigan. Soar is an expert system using a cognitive architecture, including reinforcement learning. We first used the stand-alone version Soar with a thesis student who was a Tactical Action Officer (TAO) that represented the “teacher.” Our first attempt with the stand-alone version of Soar did

empirically show that learning did take place in Soar. We then used a Soar version, WISDM (an integration of two products: NSS and Soar) which is integrated into NSS as a cognitive agent to further aid in the in the CID decision-making process since current naval simulation framework does not address the cognitive layer that is critical to warfare effectiveness assessment from a system of systems perspective. Therefore the addition of Soar would add more of an element of realism. NSS provided the track data (and ground truth) for Soar to process and learn. NSS has capabilities for simulating sensor data fusion and tactical systems to model the formation of situational awareness and the engagement kill chain. We also used LLA that provided initial learning rules to Soar. LLA is as an unsupervised deep learning tool that learn pairwise associations and correlations from data. These rules were programmed and combined into Soar and then used in decision making and acted as an agent when a standard NSS scenario was run using Monte Carlo simulations of naval platforms and missions. The answer to our core question, can the Soar agent learn, was answered by empirical evidence that shows as the number of tracks process from Soar, the overall error rate went from 3.7% (track sequence 1-700) to 0.4%(track sequence 2101-2803). The basic rules were based on standard kinematics and geospatial attributes such as location, altitude, speed, heading, and acceleration. Once the ground truth was known (provided by NSS) a negative or positive reward (numeric value) was given and the rule updated. We demonstrated the four corollaries since we used LLA to establish rules from historical data that assisted Soar, and in early work our TAO provided the human operator feedback. We met the goal to integrate RL into NSS successfully. We demonstrated that Soar was a reinforcement learning system that can learn from simulated data for CID cognitive functions and decision making. An earlier position/methodology paper was published last year in [1].

Recommendations for Further Research

We see the following future research questions:

- Do Soar's activities change how the scenario progresses?
- How to collect rewards from the simulation scenario?
- How to learn from the delayed ground truth after actions taken?

We think data collection of CID decision making collected at such venues as Fleet Synthetic Training (FST) at Tactical Training Group, Pacific (TACTRAGRUPAC) would result in validation of our Soar CID research and improvement and realism of Soar CID decision making.

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NPS-17-N281-A: Improving Navy Long Range Planning: Applications of Emerging METOC Forecasting Capabilities

Researcher(s): Dr. Tom Murphree and Dr. Arlene Guest

Student Participation: LCDR Richard Ilczuk USN, LCDR Gary Vines USN, and LCDR Kelly Byrne USN

Project Summary

Navy long range planning (leads of weeks to years) has been, and will be, substantially enhanced by new and emerging long-range forecast (LRF) systems that the meteorology and oceanography community (METOC) is developing and putting into operational use now and over the next decade. The forecasts from these systems provide increased accuracy, resolution, and coverage (e.g., global, seafloor to space) in describing the physical environment in which the Navy operates. However, these forecasts differ in important ways from the products to which many users are accustomed. For example: (a) LRFs tend to be more probabilistic, categorical, and conditional, and to have large valid periods and regions, compared to short range weather forecasts; (b) LRFs provide much more information about environmental variations and predictability than traditional climatology-based products; and (c) LRF skill can vary substantially by location, season, variable, lead time, and climate regime. These characteristics of LRFs create challenges for: (a) building LRF systems that can effectively support long range planning and decision making; and (b) producing and applying LRFs in operational settings. We worked with LRF developers, producers, and users to identify the main challenges and methods for meeting those challenges. Our focus was on LRFs with subseasonal to seasonal (S2S) forecast lead times (lead times of one week to one year). Our study confirmed that there is a high potential for LRF capabilities to significantly improve Navy long range planning and decision making. However, there is a wide range of challenges that need to be addressed to fully implement that potential (see Findings section below).

Keywords: *long-range planning, decision making, decision support meteorology, oceanography, METOC, atmosphere, ocean, climate, weather, extreme events, long-range forecasts, forecast skill, subseasonal to seasonal (S2S), climate services, climate support, long range support, forecast users*

Background

Prior and ongoing studies of LRF systems, especially S2S forecasting systems, have demonstrated the potential to provide skillful and useful forecasts for national security and other applications (e.g., Turek 2008; Heidt 2009; Stone 2010; Committee 2010; Committee 2016; Gillies 2012; Reitz 2012; Harris 2015; Meyer and Murphree 2015; Ilczuk 2016; Murphree 2017, 2018; Reynolds 2017; Vines 2017; Vitart and Robertson 2018; Mariotti et al. 2018; Byrne 2018). These studies have also identified challenges in: (a) developing LRF systems; (b) operationally producing LRFs; and (c) communicating LRF information to users. The studies have also identified methods for, and progress made in, addressing those challenges.

Findings and Conclusions

For our study, we: (1) synthesized the results from prior and on-going studies; and (2) worked with LRF scientists, system developers, operational producers, and users of LRFs, to characterize the main challenges and identify methods for overcoming them. Our focus was on S2S forecasts for national security applications. Our study team included three NPS graduate students whose research contributed to our study's findings (Ilczuk 2016; Vines 2017, Byrne 2018).

A range of civilian and DoD organizations are engaged in the development of LRF systems, the operational production of LRFs, and/or the dissemination of LRF based products. These include, for example, the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center (CPC), the International Research Institute for Climate and Society (IRI), the European Centre for Medium-range Weather Forecasting (ECMWF), the UK Met Office (UKMO), the Australian Bureau of Meteorology (BOM), the Naval Research Laboratory (NRL), the Naval Postgraduate School (NPS), the Fleet Numerical Meteorology and Oceanography Center (FNMOC), the Naval Oceanographic Office (NAVO), and the U.S. Air Force 14th Weather Squadron (14WS). There is extensive leveraging by these organizations of each other's expertise and products. For example, FNMOC and 14WS use data sets, methods, and LRFs from CPC to generate DoD LRF products. These organizations also share the lessons they have learned about how to best meet user needs.

The products from these organizations are used for both civilian and national security applications. These include applications that support DoD, the intelligence community (IC), and emergency management analysis, planning, and operations. Some of the most common applications deal with long-range forecasting of environmental conditions that could affect a planned operation (for example, LRFs of tropical cyclones, extensive cloud cover, high winds, and waves), or that could lead to the need for an operation that has not yet been planned (for example, flooding that could trigger the need for humanitarian assistance and disaster relief operations). A rapidly growing need is for long term data sets, models, and LRFs that can be used to analyze, model, and anticipate the activities of adversaries or other subjects of interest (for example, LRFs of ocean acoustic conditions and of corresponding submarine operations, or LRFs of cloud cover and of corresponding maritime and land operations).

LRF systems and long range operational support capabilities have grown rapidly in the last 20 years and will continue to do so. This includes advances in: (a) the scientific basis for LRFs; (b) the methods and tools for the operational production of LRFs and long range support; and (c) user awareness of and ability to apply LRF based products. But many challenges remain to implementing the potential of LRFs and long range support systems - in particular:

- A. User requirements for LRF support need to be better identified and prioritized, including new and emerging requirements.
- B. Methods for effectively supporting those requirements through the use of LRFs need to be better identified, tested, and implemented.
- C. Existing and forthcoming LRF capabilities need to be better communicated to the METOC and user communities.
- D. The strengths, limitations, and uncertainties of LRFs need to be better characterized and communicated to METOC support teams and users.
- E. More extensive coordination and collaboration on improving LRF capabilities is needed within DoD, and between civilian and DoD organizations.
- F. Education and training of METOC personnel need to be improved in: climate (including climate variations, climate extremes, and climate change); long-range forecasting of atmospheric, oceanic, and land conditions; the operational impacts of those conditions; and methods for providing long range support.
- G. Improved methods are needed for efficiently storing and accessing, and rapidly applying, very large sets and the outputs from LRF systems for use in producing long range support products.

H. Limitations on organizational resources need to be resolved to allow METOC centers to fully implement long range support capabilities.

Recommendations for Further Research

We recommend that the Naval Meteorology and Oceanography Command create a standing committee to prioritize and facilitate LRF activities within the Navy and with other DoD and civilian organizations (especially USAF and NOAA). This committee would also: (a) identify and prioritize steps for meeting the challenges described above; (b) coordinate with related committees, such as the Committee for Climate Services Coordination (composed of representatives from federal climate service organizations), and the Climate Working Group (composed of representatives from national security organizations that develop, produce, and/or use LRFs and other climate related products). We also recommend continued research and development on improving long range support - especially improving the: (1) scientific basis for providing that support; (2) technological systems for generating and delivering support products; and (3) methods for delivering products and services that meet user needs.

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NPS-17-N342-A: Lexical Link Analysis of Insider Threats Using Digital Forensics

Researcher(s): Dr. Neil C. Rowe

Student Participation: Ms. Sandra Falgout CIV INT, Ma. Edith Gonzalez-Reynoso CIV INT, and Ms. Jennifer Johnson CIV INT

Project Summary

This project applied link analysis to digital forensics data in the form of drive images, copies of secondary storage of computers and digital devices. The goal was to develop ways to find evidence of exfiltration or copying of files between drives that could suggest an insider threat. We analyzed large collection of drives and tested associations of 16 data clues between drives: email addresses, phone numbers, personal names, street addresses, possible bank-card numbers, GPS data, files in zip archives, files in rar archives, hash values on files, words in file names, words in file names of websites mentioned, file extensions, immediate directories of files, file sizes, months of file creation times, and minutes within weeks of file creation. To measure similarity of drives, we computed distributions of document similarity using the cosine similarity TF/IDF formula and Kullback-Leibler divergence formula. We calculated criteria for significance of similarity by experiments with both random and nonrandom data. We also compared similarity and divergence results, investigated the benefits of filtering and sampling the data before measuring similarity, examined the similarities of images from the same drive at different times, and developed a way to visualize similarities and divergences of a set of drives as a step to envisioning a social network. Full details are in a submitted conference paper (Rowe, 2018).

Keywords: *digital forensics, drives, link analysis, similarity, divergence, attributes, significance*

Background

Methods of digital forensics can enable link analysis of social networks by finding connections between drives based on their features and artifacts. Relationships between drives are important in investigating criminal conspiracies and terrorist groups (Al-Zaidy et al, 2012), malware or contraband, and research on communities. However, there are challenges to forensic link analysis (Mohammed, Clarke, and Li, 2016) in the large size of the data and the many possible ways to relate data items found. his work investigated sixteen kinds of clues that could be used to relate drives, clues collected routinely by forensic tools. Comparing drive data of email addresses and bank-card numbers was first explored in (Garfinkel, 2006). Previous work has measured similarities between word distributions in documents for online searches (Forman et al, 2005). For digital forensics, we need to consider similarity beyond words because many distinctive features of digital systems are not words. Speed can be improved by filtering out data not likely not likely to be of forensic interest or by sampling.

Findings and Conclusions

The data studied included 2812 drives (1819 computers and 993 other devices) with 61.9 million files obtained in 32 non-US countries around the world (Garfinkel et al, 2009), plus 182.0 million files from a sample of classroom and laboratory computers at our school and file fragments from 997 mostly unreadable drives. In these, there was some file metadata for 3081 drives, and additional data for these was obtained with the Bulk Extractor tool (Bulk Extractor, 2013) for email, phone, bank-card, URL, GPS, zip, and rar data. Separately studied was the M57 patent corpus (Woods et al, 2011), a collection of 83 image “snapshots” over time for four machines with scripted usage, to test high-similarity situations.

We used several methods to extract artifacts and drive metadata for comparing drives (Rowe 2016; Rowe 2017). For each of the 16 clues we computed cosine similarities and Kullback-Leibler divergences between all pairs of drives in our corpus. Cosine similarity is direction-independent and divergence is direction-dependent. We established significance levels for drive similarity using two methods, a measure of three standard deviations from the mean similarity in a simulation of random drives and in our actual corpus data. We also fit similarity to approximately the inverse of divergence (though we showed the concepts were not true inverses); showed the effects of filtering of uninteresting data on measured similarities (it had only a small effect); computed correlations between similarities on different attributes; compared snapshots of the same drive over time (similarities and divergences changed surprisingly quickly); and developed methods for visualizing similarities and divergences in a two-dimensional space by fitting distances approximated from their values.

We concluded that there are many hidden connections between drives that can only be found by investigation of the similarities on all 16 clues. Of the ones we investigated, email addresses, personal names, names in file names, and file extensions appeared to be most generally useful. When drives contain sufficient numbers of bank-card numbers and GPS information, however, those can be especially helpful. We found our visualization methods for similarities worked quite well at expressing the connections in a set of drives. Students built prototypes of many of our methods (Johnson, 2017).

Recommendations for Further Research

Pooled storage systems such as cloud services should be particularly amenable to these methods since much irrelevant software data is absent within user partitions.

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NPS-17-N342-B: Insider Threat Mitigation Using LLA

Methods

Researcher(s): Dr. Shelley Gallup and Dr. Nelson Irvine

Student Participation: No students participated in this research project.

Project Summary

Current DoD efforts in detecting *insider threats* focus on the use of user activity monitoring (UAM) applications (e.g. SureView). These tools operate on real time data and create alerts for analysts, which then begin processing those alerts according to a priority scheme. Usually only priority 1 and 2 alerts are regarded, leaving lesser priority alerts to be passed off to a database. There is a conundrum here. Those data that are not deemed high priority may actually contain information that is important, and hidden by a clever adversary. This begs the question of how to make use of the data that is not of high priority but might still provide useful information? We followed an alternative means to look at large quantities of UAM data, though were not able to access UAM data directly for this study. As a surrogate for unmined data, we used e-mail as a data source. Lexical Link Analysis (LLA) is a big data tool used in many projects to understand the relationships between themes, words, and actors.

The purpose of this project is to investigate the utility of logged data in detecting and assessing Insider threats, specifically employing the Lexical Link Analysis application in processing these data.

Keywords: *insider threats, user activity monitoring, Lexical Link Analysis*

Background

LLA, developed by Quantum Intelligence, Inc., is a data mining application that can process large amounts of unstructured data. The application extracts word pairs (bigrams) from the data and constructs networks of word pairs that are characterized by themes. The Newman community detection algorithm

employed by LLA computes a measure of the importance of each theme. The themes are divided into three categories depending on the value of this importance measure. They are, in order of importance: Authoritative or Popular themes, Emerging themes and Anomalous themes.

LLA defines word pairs as words that are located adjacent to each other in the original text. Many common parts of speech, such as prepositions, articles, and pronouns are ignored in the LLA analysis (references 1 and 2).

For this investigation, the data examined were 4 ½ years of sent e-mails (including forwarded e-mails) that were contained in nine Word files containing more than 4,000 e-mails and totaling about 128 MB. E-mails were selected for this analysis because of the similarity of these data to the data processed by real time Insider threat user activity monitoring (UAM) applications such as SureView. This analysis is different from the currently used InT applications, which are applied to real time data, in that it reviews historical e-mails up to several years old.

The e-mail data selected were taken from an author's e-mails files to avoid privacy issues and also because familiarity with the contained information would aid in the assessment of the LLA results.

Findings and Conclusions

How the e-mails files analyzed were constructed from an Outlook e-mails sent repository are discussed in Section 4. A means of creating the e-mail log text file in real time was investigated. For a specific user, when an e-mail was transmitted it was also sent to a file where e-mails were accumulated in a text file for LLA analysis. This process had two shortcomings; the text file was cluttered with e-mail header tags and attachments appear as garbled text. Additional work is required to create fully useable text files for LLA processing. For this report the only data analyzed were the text files.

Logged text files to be assessed for insider threat information need not be limited to e-mail files. The U.S. Army maintains an extensive data repository of financial, medical, psychological, job performance, etc. data on Army personnel. This Person-Event Data Environment (PDE) is accessible to properly qualified and vetted researchers. Initial steps were made to assess these data with LLA, but the difficulties encountered in applying LLA to the e-mail data caused this effort to be deferred.

This section describes the procedure for creating text files of e-mails from an Outlook e-mail repository.

The sent e-mail file folder was converted to Word files using the following procedure:

- Right click on the selected e-mails and select the “convert to Adobe PDF” option.
- Right click on the resultant file and select the “combine files in Acrobat” option.
- Save the combined file as a Word document.

This process results in a Word file containing all the open e-mails in a form that can be processed by LLA. This process was executed using Microsoft Office 2010. Later versions of Office may lack the “convert to Adobe PDF” application.

There were several problems with this process:

- The conversion process is very slow and would not work on the full Outlook e-mail file or even large portions of the file. The process was therefore applied to e-mail batches of the order of 500 e-mails.

Even then the conversion could take hours. It is believed the longer processing intervals are related to the number of skipped e-mails (see below).

- Some of the e-mails were “skipped” in the conversion process. These were reported as “item failed”. The numbers skipped was generally under 10 percent but in one case it was 30 percent. Running the same e-mail file a second time could produce a different number of skipped e-mails. There was no obvious way of determining what e-mails were skipped or why.
- The e-mail attachments were not included in the e-mail Word files.

If this process were being applied in a circumstance where data completeness was important the last two items would have to be investigated and resolved. But in this instance, the primary objective was to create a large realistic e-mail data base for LLA to operate on, and that has been achieved. A total of more than 4,000 e-mails sent over a 4 ½ year interval are contained in nine Word files.

In this analysis LLA has distilled 3 ½ years of sent e-mails to a table containing typically about 100 word themes. Thus, LLA would limit the InT analyst’s job to scanning these themes for something that raises a potential concern. If the analyst finds something of concern he can search the original e-mail data base for the word pair and investigate the context.

In its present configuration, LLA’s utility to an InT analyst reviewing an historical e-mail log is not evident. Analysis of historical e-mail files could prove helpful in addressing the insider threat, but it is anticipated it would be more useful to analyze such a database with an algorithm that resembles that employed by UAM systems.

Recommendations for Further Research

Further research is needed, employing the Personnel Data Environment (PDE) which is the repository for much of the data being included in insider threat operations. A current project is being refined to bring the PDE into the NPS Joint Worldwide Intelligence Communications System (JWICS) environment, where more appropriate testing can occur. The use of LLA in that environment could show more promise, as LLA is being used in anomaly detection work in other domains very successfully.

N3/N5: PLANS & STRATEGY

NPS-N16-N422-A: China's "New Asian Security Concept" and US 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 Measure 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 shows 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 enhances 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.”¹ 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 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 that includes a new

¹ 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

“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.²

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.³ 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 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 should be universal (*pubianxing*), equal (*pingdengxing*), and inclusive (*baorongxing*).

Findings and Conclusions

This section presents the main findings for this project. The research included a thorough analysis of Chinese-language writings and English-language discussions of the NASC. I also conducted 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 on a research trip to Shanghai and Beijing.

First, China’s decision to propose and promote the NASC and attempt to reshape the regional security architecture is driven by a 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

² 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.

³ 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.

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.

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NPS-17-N111-A: NATO Resilience and Nuclear Deterrence

Researcher(s): Dr. Mikhail Tsyarkin and Dr. David Yost

Student Participation: No students participated in this research project.

Project Summary

This project examined resilience challenges in NATO-Russia deterrence relations. It identified key issues concerning resilience and cohesion in crisis contingencies involving nuclear threats.

There are several reasons to expect the Alliance to retain its cohesion in a grave crisis, including the disastrous consequences of collapse for Allied security. Some observers have nonetheless expressed fear that Alliance cohesion could break down in a nuclear confrontation for various reasons, including Russian efforts to break NATO unity. Some observers hold that Alliance cohesion in a nuclear crisis would ultimately depend on U.S. leadership, though some speculate that the so-called P3 (Britain, France, and the United States) might lead NATO.

Some Allied observers find scenarios of Russian limited nuclear attacks calculated to break NATO cohesion implausible, while others consider such scenarios possible and consistent with various hypotheses as to why Russia might be more likely to use nuclear weapons than was the Soviet Union.

Russia has been seeking new means — nuclear and non-nuclear — to intimidate and coerce the NATO Allies, with special attention to long-range (around 4,000 km) cruise missiles. Such missiles could function effectively as elements of “strategic non-nuclear deterrence,” owing to the deficiencies in air defenses of the NATO Allies, including the United States.

Keywords: *Russia, nuclear weapons, NATO, resilience, deterrence*

Background

This research was inspired by the work performed for the sponsor in previous fiscal years. The previous research efforts were entitled *Responding to Russian Noncompliance with Nuclear Arms Control Agreements* (Fiscal Year 2016) and *Evolving Russian Views on Nuclear Weapons and Their Significance for the United States and NATO* (Fiscal Year 2017).

Findings and Conclusions

Russian nuclear messaging and signaling for purposes of intimidation and blackmail are more likely than operations involving the actual detonation of nuclear weapons. The Russians have, in contrast with NATO, cultivated a certain “mental preparedness” for nuclear contingencies by organizing military exercises with nuclear use simulations and conducting civil defense drills. Limited nuclear use would be consistent with the “de-escalation” options discussed by the Russians since the late 1990s.

The Russians would like NATO to believe that they are truly confident that they could use their theater nuclear weapons to de-escalate a conventional conflict. After all, convincing one’s opponent that his actions would bring about a nuclear attack is the essence of nuclear deterrence. Their recent pursuit of “strategic non-nuclear deterrence” suggests, however, that the Russians are not as confident in their concept of “escalation to de-escalate” as they would like NATO to believe.

The force that the Russians foresee for their strategic non-nuclear deterrence consists primarily of long range cruise missiles – the conventional versions of the nuclear cruise missiles capable of carrying weapons to targets up to 4,000 km away. Moscow could use such missiles to send a powerful signal to NATO by threatening to create environmental disasters by attacking industrial facilities, as well as key transportation nodes, government facilities, and energy distribution networks. Strategic non-nuclear deterrence, as the Russians see it, would serve as a pre-nuclear step on the escalation ladder, thus giving the country’s leadership more flexibility and time in case of war.

Russian strategic non-nuclear deterrence would present NATO, which has no defenses against a large-scale attack by cruise missiles, with a serious challenge. Responding with nuclear weapons might seem disproportionate, and, more importantly, would likely result in a nuclear war in Europe, and perhaps in a global nuclear war.

The Russians are likely to encounter at least two problems with strategic non-nuclear deterrence. First, the deterrent effect of conventional weapons is incomparably less than that of nuclear forces, with the public and politicians in Western democracies raised in fear of a nuclear holocaust. Second, guaranteed destruction of targets with conventionally armed cruise missiles, however accurate, would likely require substantially more delivery systems and platforms for them than nuclear warheads; this would put additional strain on the sluggish Russian economy.

Strategic non-nuclear deterrence remains an untested concept. Conventional explosives are less powerful than nuclear ones, and therefore a shift to strategic non-nuclear deterrence would require substantially more cruise missiles than the nuclear deterrence posture. This would involve additional costs at a time when the Russian economy is sluggish and the defense budget is under pressure.

Moreover, by making its reliance on non-nuclear deterrence obvious, Russia might suggest that in reality it would prefer to avoid the use of nuclear weapons in order to turn the tide of a conventional war. This would contradict what Russia has wanted the world to believe since the late 1990s.

Recommendations for Further Research

Future researchers should examine the full panoply of Russian instruments of influence, intimidation, and coercion, and consider the diverse views within the Alliance about modernizing its deterrence and defense posture and obtaining the capabilities that would enhance resilience and cohesion. The Russian concepts of “de-escalation” and “strategic non-nuclear deterrence” in particular deserve extensive analysis.

NPS-17-N112-A: New Directions in Arms Control and Strategic Stability

Researcher(s): Dr. Mikhail Tsypkin and Dr. David Yost

Student Participation: No students participated in this research project.

Project Summary

From the perspective of experts in NATO capitals, the prospects for enhancing strategic stability through arms control are poor. Allied observers have drawn attention to:

1. Russia’s declared conditions for new arms control negotiations;
2. Russia’s violations of the Intermediate-Range Nuclear Forces (INF) Treaty, the Open Skies Treaty, the Vienna Document, and other agreements;
3. Russia’s threats to withdraw from the New Strategic Arms Reduction Treaty (START);
4. Russia’s use of “strategic stability” concepts to express threats and justify its suspension of compliance with agreements; and
5. Russia’s nuclear force modernization and messaging.

At the same time the UN General Assembly negotiations for a treaty to ban nuclear weapons have created an unfavorable political context for the sustainment of nuclear deterrence in NATO nations.

While the United States will no doubt remain committed in principle to the pursuit of mutually beneficial arms control, including multilateral regimes as well as bilateral accords with Russia, it will probably find it prudent to increase investments in sources of strategic stability other than arms control — above all, deterrence.

Keywords: *Russia, arms control, nuclear weapons, New START Treaty, INF Treaty, ban treaty*

Background

This research was inspired by the work performed for the sponsor in previous fiscal years. The previous research efforts were entitled *Responding to Russian Noncompliance with Nuclear Arms Control Agreements* (Fiscal Year 2016) and *Evolving Russian Views on Nuclear Weapons and Their Significance for the United States and NATO* (Fiscal Year 2017).

Findings and Conclusions

Russia’s lack of interest in pursuing practical arms control measures in recent years has been evident in its proposals for limitation regimes that are so extensive and comprehensive (including missile defenses, anti-satellite systems, and conventional forces in addition to nuclear forces) as to be infeasible.

Some of the treaties that have become most controversial in the past decade, including the 1987 INF Treaty, the 1990 Conventional Armed Forces in Europe (CFE) Treaty, and the 1992 Open Skies Treaty, were negotiated under Mikhail Gorbachev, the last president of the Soviet Union. These agreements are unpopular and controversial in Russian elite circles partly for this reason.

The Russians have in recent years portrayed the United States as a violator of the INF Treaty in order to promote the impression that there are INF compliance issues on both sides. The Russians have pursued this propaganda theme in the context of their noncompliance with certain other arms control agreements affecting strategic stability — e.g., the Vienna Document and the Open Skies Treaty. Despite decades of dialogue and Strategic Arms Limitation Talks (SALT) and START agreements, the extent to which Moscow has endorsed and embraced American concepts of how to compose arms control agreements in pursuit of strategic stability objectives remains subject to debate.

In addition to publicizing exercises involving the coordinated launch of intercontinental ballistic missiles (ICBMs), submarine-launched ballistic missiles (SLBMs), and cruise missiles, the Russians have been messaging about new capabilities that may soon be produced and deployed, such as the Sarmat ICBM, which Russian sources describe as the world's largest ICBM.

The proposed treaty to ban nuclear weapons could have significant implications for strategic stability, even without the participation of nuclear-weapon states. The ban treaty's explicit delegitimization objective would be politically damaging to the maintenance of the nuclear postures of Britain, France, the United States, and NATO, including burden-sharing and non-nuclear support to nuclear capabilities. The erosion of the P3 and NATO deterrence postures would undermine strategic stability.

Moreover, the ban treaty would contradict and undercut the 1968 Treaty on the Non-Proliferation of Nuclear Weapons (NPT), a key foundation for International Atomic Energy Agency (IAEA) safeguards, inspections and verification.

The agreed NATO position is that the conditions for nuclear disarmament have to be satisfied before the abolition of nuclear weapons can be undertaken.

If the prospects for enhancing strategic stability via arms control are poor, however, owing to the policies of specific countries (such as Russia) or the shortcomings of prospective new multilateral arms control regimes (such as the nuclear ban treaty), the question arises: What policy instruments other than arms control can contribute to strategic stability?

The traditional response has been to develop, maintain, and improve military forces capable of denying operational success to adversaries (deterrence by denial) and holding their highly valued assets at risk (deterrence by punishment). Military capabilities have historically provided a hedge against the failure of arms control and other adverse geopolitical changes, and they may lower the probability of major-power war and thereby enhance prospects for strategic stability. In sum, resilient military capabilities for the deterrence of adversaries and the assurance of allies may serve strategic stability.

Recommendations for Further Research

Future researchers should carefully examine Russian behavior in relation to established arms control agreements. The NATO Allies, including the United States, will continue to seek opportunities to bring Russia into compliance with arms control agreements, including the INF Treaty, as a means of promoting strategic stability. Moscow's behavior has nonetheless created grounds for investigating other sources of strategic stability, such as deterrence. The research agenda should therefore encompass means of pursuing strategic stability in addition to arms control.

NPS-17-N306-A: The Navy's Role in Potential Regional Conflicts

Researcher(s): Dr. James Russell, Dr. James. J. Wirtz, Dr. Donald Abenheim, and Dr. Christopher Twomey

Student Participation: LTJG Barry Scott USN

Project Summary

The Navy is the midst of a sweeping re-organization to better enable it to connect its plans, programs and policies to broader national and maritime strategy. The DCNO for Information, Plans & Strategy (N3/N5) is taking the lead in developing a new organizational structure to assist in this broad effort. The Department of National Security Affairs has been actively supporting this effort in the N3/N5 through the NRP for the last two years. In year one, a research team examined the Navy's existing processes of conceiving and executing naval strategy. In year two, a team of NPS researchers provided research and analysis to help various offices in the N50 with their tasks of helping design current and future strategy and the role that diverse global phenomena could have on future fleet design. NPS professors delivered a series of short papers to address different qualitative scenarios to assist N5's Strategy Division (N50) team in developing requirements for future fleet design. In addition, the NPS team developed a paper that examined the implications of developing maritime strategy in different geographic theaters of the world and the emerging challenges in the areas facing the United States Navy. Last, the NPS team delivered a reference paper that examined the historical roots of naval power and maritime strategy in the United States.

Keywords: *strategy, programming, planning, budgeting, PBBS*

Background

The methodology for this study focused on upon qualitative research by the social scientists in the Department of National Security Affairs as well as those done by researchers at allied and coalition partner civilian and military institutions. This qualitative research focused upon the issue areas as requested by the N50 and, more generally, with the challenges facing the Navy in designing its future fleet involving contingencies in a variety of different areas of operations.

To facilitate a broader discussion about the Navy's strategy and potential role in such conflicts, this project provided timely yet in-depth studies of key sub regions in Europe and the Middle East, including the Arabian Gulf, the eastern Mediterranean Sea, the Black Sea, and the Baltic Sea. Each section of the report will address the following questions: (1) What features of the maritime geography define the context of potential conflicts in the specified region? (2) What are the potential adversary's national policy

aims, military strategy, naval strategy, and key capabilities? (3) What is the principal military challenge that the United States and its allies/partners are likely to confront? (4) What role do other countries or actors play in that region, and what role would they play in a potential conflict?

Findings and Conclusions

The research report found that evolving geopolitical environment speaks to the enduring imperatives of U.S. maritime power. The U.S. Navy has so long been a core feature of U.S. global influence and leadership, and as much as new technology may alter the face of war to come, geography and its maritime aspect remain unchanging. Ageless therefore is the necessity for this nation to project significant power in maritime forces throughout the world's oceans. Three truths of sea power are manifest here. First, the U.S. Navy must preserve its ability to apply American power in the littoral waters of the leading continents of geopolitical conflict in order to deter in crisis, and, if necessary defeat adversaries in a war.

Second, the U.S. Navy must organize itself around sensible strategic concepts that provides for the security of the nation, its interests and allies, and accord with the needs and ends of policy as a whole in its domestic and external aspects. Embracing sound strategic principles can ensure that the evolution of the U.S. Navy proceeds in a way that supports national strategy. The Navy must do all it can in American government and before its citizens to make this vital case, one which is ignored or simply taken for granted by too many until it is often too late. Third, the Navy must organize itself in its fighting line and in all the subsidiary structures to support this strategic concept. These three truths of sea power form the basis for sound strategy at sea and must be kept constantly in the forefront of the present debate about the size, shape, and composition of the Navy's force structure.

Recommendations for Further Research

Study is phase one of project to produce two edited volumes on topic of maritime strategy and naval innovation. Phase two will be implemented in FY19, pending approval by sponsor.

N4: MATERIAL READINESS & LOGISTICS

NPS-17-N101-A: The Role of Raw Powder Characteristics in Additive Manufacturing (AM) of Metals and Alloys for Naval Applications

Researcher(s): Dr. Claudia C. Luhrs

Student Participation: LT Sam Murphy USN

Unclassified - Project Summary

Powder bed fusion additive manufacturing (PBFAM) is one of the common techniques used to 3D print metals and alloys. The process involves the use of a laser to join individual particulates (raw powders) and create a complex part layer by layer. During the 3D fabrication steps certain regions of the powder interact directly with the laser beam and finish being part of the solid produced, however, adjacent particles that do not become a section of the build, are still exposed to higher temperatures and to the printing environment. In order to deliver the cost savings expected from this fabrication method, the powder that remains in the printing bed should be reused.

This study aimed to determine if the characteristics of the powder that remains in the PBFAM system change after some reuse cycles. We employed techniques such as electron microscopy, energy dispersive X-ray spectroscopy (EDS) and X-ray diffraction (XRD) to study the powder elemental components, their distribution and crystalline structures. We also analyzed and compared solids made from virgin and reused powders. For the later, hardness and electron backscatter diffraction (EBSD) data were also collected at diverse locations.

Keywords: *metal additive manufacturing, 3D printing metals, AM metal powder reuse*

NPS-17-N126-A: Car-Sharing on Navy Installations

Researcher(s): Dr. Douglas MacKinnon

Student Participation: LCDR Robert Cullinan USN, LT Christopher Allen USN, and LCDR Gregory McCleery USN

Project Summary

The Navy leases more than 3,300 vehicles annually to commands and bases throughout the United States; however, the management model is antiquated, and there are now new fleet management options available. The purpose of this study is to examine the costs and benefits of utilizing a commercial car-sharing model or implementing a fleet-sharing solution to replace the current ownership model administered by Naval Facilities Engineering Command (NAVFAC). We will use a cost-benefit analysis (CBA) framework to analyze a data set provided by NAVFAC for the Naval Air Station (NAS)

Jacksonville (JAX) locality and compare the net benefit of three available alternatives. The first alternative is continued operation with the current model (Status Quo). The second alternative is replacement of the current model with a contractor operated commercial car-sharing model. The third alternative involves integrating a fleet management hardware/software solution (fleet-sharing). The goal of this CBA is to compare alternatives in order to identify the one with the highest net benefit. The data set conclusively supports alternative three, which provides a reduced initial cost versus the status quo and a cumulative net present value. Therefore, we recommend implementing a fleet-sharing solution to the existing fleet at NAS JAX.

Keywords: *car-sharing, linear regression, return on investment, vehicle pool, net present value*

Background

The U.S. Navy currently maintains a fleet of approximately 3,300 motor vehicle assets to support its operations and mission requirements across the globe. Many of these vehicles are leased by individual Navy commands on a long-term basis and are then utilized for a few hours each day, or sometimes less, spending the remaining time idle in the parking lot. In an era of shrinking budgets and increased financial accountability, requirements such a large and potentially underutilized fleet represents a significant cost driver for the Navy. Naval Facilities Engineering Command (NAVFAC), the government entity charged with the responsibility for managing the Navy's motor vehicle fleet, believes there is a potential for significant cost avoidance and efficiency gains through a reduction in motor vehicle fleet size and its associated costs. Two alternatives identified to achieve this reduction identified by NAVFAC are the adoption of a commercial car-sharing model, exemplified by Zip-Car and Enterprise Car Share, or the adoption of a fleet-share model, which integrates commercial fleet-sharing technology into the preexisting motor vehicle fleet. Collectively, these two options are referred to as vehicle sharing for the duration of this cost-benefit analysis. NAVFAC estimates the potential introduction of a vehicle-sharing alternative to the existing model on a naval installation to be feasible and the return relatively high.

Findings and Conclusions

The goal of a cost-benefit analysis (CBA) is to provide a rational recommendation for decision making based on a net benefit analysis of all selected stakeholders. Ideally, a global view is preferred for a CBA to understand the impact to everyone, however that depth of detail is outside the preferred scope of this project so a national perspective was selected. The goal of this CBA is to answer the following questions with a comprehensive support structure.

1. Could implementation or integration of a commercial car-sharing model or software be financially beneficial to the Navy? If so, how?

Based on the five-year calculations, both models prove to be beneficial from a financial standpoint. However, the car-sharing model is only beneficial using the five-year model due to the initial benefit received from the sale of the excess government vehicles. Over time, however, the costs of car-sharing to the government exceed the benefits and the model becomes more expensive than the Status Quo. This indicates a significant risk associated with adopting a car-sharing model. The sensitivity analysis also revealed significant risk associated with adopting a car share model. When the parameters were flexed and a worst-case scenario was adopted the net present value (NPV) of the car share model was significantly negative which represents a loss of value to the Navy. Given the large degree of uncertainty associated with many of the variables analyzed there is a high degree of risk associated with the adoption of car-

sharing at NAS Jacksonville. The NPV of the fleet-sharing model on the other hand is positive, and to a greater degree, in both the long run (end of the analyzed five-year period) as well as the short run (one year into the study). The sensitivity analysis revealed there is also less risk associated with adopting a fleet-sharing model than a car-sharing model. When parameters were flexed and the worst-case scenario adopted the NPV for fleet-sharing was still positive. Expanding the fleet-sharing model to other larger naval installations will increase the costs savings and provide a significant net benefit to all shareholders.

2. Can vehicle utilization be increased, while reducing fleet size using available alternatives? If so, by how much?

The prior pilot studies proved the concept of increasing vehicle utilization by decreasing quantities of available vehicles while maintaining acceptable levels of customer satisfaction, though the long-term costs and benefits of doing so were not explicitly studied or calculated. Reducing the fleet size without changing the demand elicits an increase in vehicle utilization from 22% to 45%. The challenge of the CBA is to identify which method is more beneficial to use while providing the same or better opportunity for end user access to mission specific vehicles.

3. What are additional pros and cons of the available alternatives, and what are the specific challenges from the Navy perspective?

The unknowns and the uncertainty of several key variables are the biggest concerns. Implementing hardware that stores and transmits user data into a government owned vehicle carries force protection and safety concerns as does the data retention service and the feasibility of allowing a non-government entity manage the data. The DoD Instruction 8510.01 “Risk Management (RMF) Framework for DoD Information Technology (IT)” (DoD, 2014) requires that all “DoD IT that receive, process, store, display, or transmit DoD information” must have an Authorizing Official (AO) and are required to undergo a cyber-security review to identify and address vulnerabilities prior to implementation (DoD, 2014). The cost associated with the cyber security review and approval process was impossible to ascertain and thus not included within the scope of this CBA. The review in question is for the hardware and technology, which is not solely applicable to NAS Jacksonville. It is estimated that the man hours associated with conducting the cyber security review of the fleet-sharing hardware and software systems may cost in excess of a million dollars, which would be a one-time cost absorbed by NAVFAC if they choose to implement fleet-sharing technology.

Recommendations for Further Research

1. CBA Increased Scope to Include Costs and Benefits at the DoD or National Level

Standing was used at the Federal Government level restricted to the JAX NAS local, however a wider scope would impact results if the CBA were implemented on a *big navy* perspective.

2. Evaluate the Impact of the Manning Requirements due to Changes in the Vehicle Management.

The short-term (5-Year) assessment in this CBA cannot adequately project the impact to the manning over a long-term change. Contracting a commercial car-sharing provider across all Navy installations would have a significant impact on the long-term employment of NAVFAC mechanics, administrative personnel, and even military support staff.

3. Perform a Monte Carlo Analysis

Due to limitations in both available time and resources, the sensitivity analysis was conducted using a worst-case approach. A full Monte Carlo Analysis in which all of the variables are changed incrementally and the simulation is then run thousands of times could give analysts a more precise understanding of the risk associated with adopting each vehicle-sharing model.

4. Cost of Adding Common Access Cards (CAC) Radio-frequency Identification (RFID) Capability
Currently the General Services Administration (GSA) is studying the feasibility of adopting RFID technology to the CAC cards already carried by all government personnel. This would eliminate the requirement for personnel to carry an additional dedicated RFID card to access government vehicles equipped with fleet-sharing technology. This convenience factor has the potential to increase the benefits associated with the fleet-sharing alternative. The costs associated with RFID CAC cards are unknown at this time.

5. Daily and Hourly Rates for Car-Sharing

All calculations for costs associated with the car-sharing model were made assuming only hourly rates were available. In the commercial car-share market many vendors offer daily rates in addition to hourly rates for customers that require the use of a vehicle for longer periods of time. Enterprise Car Share, for example, offers an hourly rate of \$8.50 for a sub-compact car and a daily rate of \$70.00 for the same vehicle. If the vehicle is needed for more than 8.24 hours, it becomes more economical to utilize the daily rate. A daily rate may be convenient for some commands whose personnel utilize the vehicle for overnight or multi-day trips and the adoption of a daily rate into the car-sharing contract in addition to the hourly rate may impact the NPV associated with the car-sharing alternative.

6. Disaggregate Base Support, Vehicle and Equipment (BSVE) Costs

As previously described, the majority of cost savings associated with adopting a vehicle-sharing alternative come from the reduction in annual BSVE payments made by tenant commands to NAVFAC for the long-term use of government vehicles. The BSVE is designed as a break-even rate for reimbursable costs associated with maintaining the NAVFAC vehicle program, including direct labor costs, direct costs other than labor and indirect, or overhead costs. Although this was the best metric available for estimating the costs savings associated with vehicle sharing, it is unclear just how accurately this metric reflects the true costs savings associated with reducing total number of government owned vehicles in Jacksonville. If the BSVE could be disaggregated and a true cost could be assigned to vehicle procurement, maintenance, depreciation, program administration, personnel and facilities at NAS Jacksonville, it might change the NPV associated with both alternatives.

7. Utilization as Metrics are Tracked

If a vehicle-sharing program is adopted at NAS Jacksonville, analysis of utilization data provided by either the government owned or commercial car-sharing telematics units could be conducted. Currently utilization data at NAS Jacksonville for the motor vehicle fleet is not tracked, so for the purposes of this CBA it had to be estimated based on actual mileage and a host of assumptions. The utilization data provided by a multi-year pilot at NAS Jacksonville will help future vehicle-sharing pilots and CBAs conducted by the Navy.

8. Increased Use due to Increased Ease of Vehicle Availability

In the fleet-sharing pilot conducted by NAVFAC at Naval Submarine Base (NSB) Bangor, Cook et al. (2013) noted that the implementation of vehicle sharing at this location actually increased the required number of vehicles. Prior to implementation employees were using their personally operated vehicles (POV) for government business because the system in place was overly burdensome. The employees found the vehicle-sharing pilot to be more convenient and utilization increased significantly. If a vehicle-sharing alternative is adopted it will once again be informative to review the data to see the impact of vehicle sharing on utilization.

9. Right Sized Fleet to More Sedans Instead of Trucks

Of the 121 vehicles deemed eligible for vehicle sharing only 10 are sedans. Commands who lease a small number of B-Pool assets have a large ratio of vans and trucks because an individual can use a truck or van to go across base to a meeting but a command cannot use a sedan to get 15 passengers to a gun shoot or pick up bulk supplies at Servmart. If vehicle sharing were adopted, users will have the ability to choose the appropriate vehicle for each task and activity with the vehicle sharing rates for sedans significantly less than the vehicle sharing rates for large trucks and vans. This could affect the NPV calculations associated with vehicle sharing as utilization data becomes available after implementation.

NPS-17-N129-A: Reducing Transit Fuel Consumption and Enabling Additional Time on Station with an Improved Transit Fuel Planner (TFP)

Researcher(s): Mr. Alan Howard and Mr. Brandon Naylor

Student Participation: No students participated in this research project.

Project Summary

This program aimed to create an improved version of a program called the Transit Fuel Planner (TFP) that allows surface ships to reduce transit fuel consumption by taking advantage of mixed-mode engine efficiencies (Gerald Gerard Brown, 2011). Our research has resulted in a program called OTTER (Optimized Transit Tool and Easy Reference) that applies the fuel-saving mechanics of the TFP across any ship type and gives users more control over transit parameters and suggested transit solutions. Unlike TFP, OTTER allows users to plan for drill sets or disruptions in their transit, account for operational constraints such as engine mode limitations, and predict replenishment needs. By adding a few engine configuration changes into their transit plan, ships using OTTER can complete their transits in the same amount of time but finish with more fuel available to conduct operations without needing to resupply. Under ideal conditions, OTTER and OTTER mini are expected to enable surface ships to reduce their transit fuel consumption by 10 to 15% in typical transit scenarios, but actual savings could be higher or lower depending on factors such as mission requirements or operating preferences.

Two separate versions of OTTER were created to balance future capabilities against current limitations. The “full” version of OTTER is a macro-based program that allows users to plan and optimize transits for entire battlegroups. We hope that in the future this version will be able to communicate with shipboard systems in order to use real-time fuel consumption data to improve its transit solutions. The second

version, OTTER mini, is a macro-free program that was developed for use on ships where local computer configurations will not allow macros to run and is currently undergoing sea trials on the USS Wasp. OTTER mini is ready for further testing in an operational environment, but the macro-based version of OTTER will require further development to reach its full potential. Both programs are usable and stable in their current forms, but further work is required to polish the programs and develop training and support documentation before they are ready for full integration.

Keywords: *OTTER, OTTER mini, TFP, fuel, logistics, Excel, energy, operations, transit, surface fleet*

Background

In recent years, the Navy has put an increased focus on issues concerning operational energy. Naval combatants require vast amounts of fuel to carry out their mission, but acquiring and distributing this fuel creates significant financial burden and operational vulnerabilities. If fuel demand could be reduced in a way that did not compromise operational effectiveness, combatants would benefit in the form of additional operational flexibility, more time on station between replenishments, increased resilience to disruptions in supply, and more.

The original TFP was a great innovation in reducing surface ship transit fuel consumption, but it never saw widespread use. The benefits of the tool had been successfully demonstrated on the USS Chosin (CG-65), but various environmental factors limited its appeal at the time and created obstacles to widespread adoption.

OTTER first came into existence as a collaboration between NPS thesis student LCDR Warren (Korban) Blackburn and Mr. Brandon Naylor (Blackburn, 2016). LCDR Blackburn wanted to adapt the TFP to work with every class of ship and generate easy reference tables for ship operators, while Mr. Naylor introduced new features such as the ability to accommodate drill sets and training occurring during a transit. When LCDR Blackburn graduated in April 2016, OTTER had shown great potential as an improved Transit Fuel Planner, but would still require significant research and development before it would be ready for widespread use.

Findings and Conclusions

Once deployed, OTTER will help N45 achieve their energy goals by reducing the fuel required for surface ships to complete transits without sacrificing operations. Ships using OTTER will arrive at their transit destinations with more fuel in their tanks so that they are able to participate in operations without needing to refuel first. Alternatively, ship operators could use OTTER's drill set planning functions to schedule more training time during transits without increasing the amount of fuel required to complete the transit.

Originally, the research team had anticipated producing a more robust version of the macro-based OTTER program. After continued unsuccessful efforts to place developmental versions of OTTER on ships for testing, it was realized that the reliance on macros posed a significant obstacle to testing the program at sea. Shipboard computer systems would not allow macros to run unless the testers went through a lengthy process to get special permissions, so even the commands who had volunteered to work with us were unable to use the program. To work around this issue, we created the macro-free OTTER mini program. It would be more limited in its potential capabilities than the macro-based program, but the new format presented fewer barriers to conducting real world testing. OTTER mini is currently

undergoing testing on the USS WASP (LHD-1). A successful demonstration on the WASP will hopefully create opportunities for further development, testing, and adoption. At the time of writing this, the WASP has returned transit data showing that OTTER's base case fuel consumption estimates are consistent with actual fuel use, but the ship has not yet sent any data from transits where OTTER's optimized transit solutions were employed.

Laboratory testing of OTTER has suggested that surface ship fuel savings of 10-15% under ideal conditions, but actual savings will be highly dependent on mission or operational constraints and base case used to compare fuel use before and after using OTTER. Knowing the ship's nominal fuel consumption for a given movement speed and engine configuration is also required in order for OTTER to produce effective transit plans. Sea state also impacts the fuel consumption during a given transit, but OTTER gives the user the ability to create alternative fuel profiles that account for things like rough seas or hull fouling.

In its current state, OTTER mini is ready for additional testing or use in an operational environment, but potential users should coordinate directly with the Energy Academic Group to receive training and improved versions of the program as they become available. The macro-based full version of OTTER is not recommended for user testing at this time but has the potential to become a much more powerful tool in the future. Eventually, the principal investigator (PI) envisions OTTER and OTTER mini taking the place of Battlegroup Optimum Speed Calculator (BOSC) and Ship Energy Conservation Assistance Training (SECAT).

Recommendations for Further Research

More work is needed to prepare OTTER for widespread use across the fleet. OTTER mini is ready for further testing and deployment, but the macro-based version of OTTER requires further development if the fleet ever wishes to make use of its expanded capabilities. Work also remains in developing an official program for distributing OTTER and training ship operators in its use.

References

- Blackburn, W. (2016, March). Otter: an optimized transit tool and easy reference. Monterey, California, United States of America: Naval Postgraduate School.
- Gerald Gerard Brown, J. E. (2011). *Patent No. 8050849*. United States of America.

NPS-17-N130-A: Measure the Potential Impact of Fuel Planner Systems on Surface Fleet Time on Station

Researcher(s): Mr. Alan Howard and Mr. Brandon Naylor

Student Participation: LCDR Jeremy Duke USN, LCDR David Lewis USN, and LCDR Javier Araujo USN

Project Summary

This project aims to measure the potential impact that the Optimized Transit Tool and Easy Reference (OTTER) tool would have on fleet operations and logistics. By using OTTER to plan their transit speeds, surface ships could reduce their fuel consumed during transit, allowing for additional time on station

between replenishments. The expected fuel savings vary between ships and between transits, which means that operational impact would also be highly situational.

This study aimed to evaluate transit data from past transits on multiple ship types and attempted to model those same transits within the OTTER program to determine the program's potential to save fuel and increase time on station. This effort was hindered by difficulties in acquiring data for surface fleet transits and fuel consumption. A student thesis team was able to gather a small collection of Shipboard Incentivized Energy Conservation (iENCON) reports describing fuel consumption during transits, but factors such as inconsistent reporting practices and suspected human error limited the value of these reports. A separate thesis team will later conduct a secondary analysis that will attempt to adjust for these factors.

A separate set of notional transits were modeled in a macro-free version of OTTER, but these transits were based on the development team's understanding of a "typical" transit and were not taken from actual ship logs. Typical potential fuel saving for these notional transits were found to be in the range of 10-15%, adding as much as entire days of extra time on station before refueling. These savings would be limited in cases where ships applied additional constraints such as avoiding single engine modes for redundancy, but OTTER at least is able to show the potential benefits of using these modes so ship operators can make informed decisions when weighing risks and benefits.

A variation of OTTER known as OTTER mini is currently being tested on the USS WASP (LHD-1) to validate the program in an operational setting. At the time of writing this, the Principal Investigator (PI) has received data from the WASP that shows OTTER's base case fuel consumption estimates closely reflect actual fuel consumption. We have yet to receive any fuel consumption data where the ship is attempting to implement OTTER's optimized transit solutions.

Keywords: *OTTER, OTTER mini, TFP, fuel, logistics, Excel, energy, operations, transit, surface fleet*

Background

In recent years, the Navy has put an increased focus on issues concerning operational energy. Naval combatants require vast amounts of fuel to carry out their mission, but acquiring and distributing this fuel creates significant financial burden and operational vulnerabilities. If fuel demand could be reduced in a way that did not compromise operational effectiveness, combatants would benefit in the form of additional operational flexibility, more time on station between replenishments, increased resilience to disruptions in supply, and more.

A tool called the Transit Fuel Planner (TFP) was created to help save fuel on surface ships using a method known as Mixed-Mode Fuel Minimization (Gerald Gerard Brown, 2011). The original TFP was a great innovation in reducing surface ship transit fuel consumption, but it never saw widespread use. The benefits of the tool had been successfully demonstrated on the USS Chosin (CG-65), but various factors limited its appeal and created obstacles to widespread adoption.

OTTER first came into existence as a collaboration between NPS thesis student LCDR Warren (Korban) Blackburn and Mr. Brandon Naylor (Blackburn, 2016). LCDR Blackburn wanted to adapt the TFP to work with every class of ship and generate easy reference tables for ship operators, while Mr. Naylor introduced new features such as the ability to accommodate drill sets and training occurring during a

transit. When LCDR Blackburn graduated in April 2016, OTTER had shown great potential as an improved Transit Fuel Planner, but would still require significant research and development before it would be ready for widespread use.

Findings and Conclusions

This study benefits the sponsor, operations, and logistics communities by providing data that supports the adoption of the OTTER program. Demonstrating the potential value of OTTER will hopefully address concerns that would make commands hesitant to use the program. Once ship operators begin using OTTER, they should see immediate improvement in fuel consumption during transits, which will result in increased operational and logistics flexibility.

For most typical transits modeled within the program, expected transit fuel savings from OTTER ranged from 10-15%. Unfortunately, it was difficult to come up with “typical” savings for transits with atypical limitations, but even in these cases OTTER showed some improvement over historical fuel consumption values. In practice, the effectiveness of the OTTER tool will be highly dependent upon mission requirements and the operator’s willingness to follow OTTER’s optimized transit solutions.

Three NPS students (Araujo, Duke, Lewis, 2017) have assisted in this research efforts as part of their theses. Their efforts included working to acquire ship transit records, creating model transits based on those records, and running those transits through OTTER to determine how much fuel could have been saved on those same transits. They are also evaluating the BOSC (Battlegroup Optimum Speed Calculator) and SECAT (Ship Energy Conservation Assistance Training) programs to compare their functionality and fuel saving potential against OTTER. Their findings were inconclusive due to inconsistencies in the operational reports from which their data was taken; the original reports contained multiple data points that were in direct contradiction to each other, so recreating those transits in OTTER introduced a large degree of uncertainty depending on how one wished to interpret the original records. A second thesis team is beginning work on a more thorough analysis that will attempt to adjust for these inconsistencies.

We had originally planned to model fleet operations and logistics using the Fuel Usage Study Extended Demonstration (FUSED) modeling tool to determine how decreased transit fuel command would impact supply logistics. A team of summer interns had been working to improve the FUSED model for use in this study, but the model is still in need of work. Future work is being planned to finish updating the FUSED model so that it will provide a better picture of how OTTER would influence operational and logistics capabilities beyond the immediate conservation of fuel during transits.

Recommendations for Further Research

More work is needed to prepare OTTER for widespread use across the fleet. OTTER mini is ready for further testing and deployment, but the macro-based version of OTTER requires further development if the fleet ever wishes to make use of its expanded capabilities. Work also remains in developing an official program for distributing OTTER and training ship operators in its use.

References

- Blackburn, W. (2016, March). Otter: an optimized transit tool and easy reference. Monterey, California, United States of America: Naval Postgraduate School.
- Gerald Gerard Brown, J. E. (2011). *Patent No. 8050849*. United States of America.

NPS-17-N131-A: Develop FUSED as an Operational Fuel Planner

Researcher(s): Mr. Alan Howard and Mr. Brandon Naylor

Student Participation: No students participated in this research project.

Project Summary

The objective of this project was to develop an Excel-based tool to assist Navy surface ship operators in predicting fuel consumption during transits and operations. Having such a tool would aid operators in determining when to schedule replenishments and could help improve time on station by allowing operators to compare the expected fuel consumption of different maneuvers. Originally, this new tool was going to be developed from a variation of the FUSED (Fuel Usage Study Extended Demonstration) model, but we determined that macro restrictions on shipboard systems would make the resulting tool unusable. Instead, we developed predictive replenishment needs calculations into a macro-free variant of OTTER known as OTTER mini. Adding these features into OTTER mini has produced a more useful tool that is capable of optimizing transit efficiency, determining replenishment requirements during long transits, and calculating how long a ship can remain on station before reaching a user-specified fuel safety level. The new tool is more user friendly than either FUSED or OTTER and does not require any special permissions to run because it does not use any macros. At the time of writing this, OTTER mini is undergoing testing at sea on the USS WASP (LHD1) that aims to validate the optimization and predictive capabilities of the program.

Keywords: *fuel, logistics, optimization, modeling, operations, operational energy, FUSED, OTTER, Excel, transit, RAS*

Background

This project was inspired by the Energy Academic Group's (EAG) work on a fuel consumption model called FUSED (Alan Howard, 2015). FUSED allowed users to predict how certain policy, practice, or technology changes would impact surface fleet fuel consumption and logistics. Originally, we believed that by making minor adjustments to FUSED, we could develop it into a tool to help surface ship operators plan their operations more effectively to reduce fuel consumption and improve allowable time between replenishments.

Findings and Conclusions

This research effort supports the sponsor's mission by potentially improving the Navy's ability to plan more efficient operations and replenishment efforts. The results of this project have potential impact in both the operations and logistics communities by providing surface ship operators with a tool to predict and optimize surface fleet fuel consumption. OTTER mini demonstrates the predictive capabilities of fuel consumption modeling and how modeling tools can be implemented to use fuel more effectively.

We had originally expected to use the FUSED model as the base for our program development, but later chose OTTER mini instead because of concerns regarding Excel macros. On surface ships, Excel macros cannot run unless given special permissions, so we were forced to develop a tool without macros if we wanted anyone to ever use the program in an operational environment.

When we began testing OTTER mini, we found very few ships willing to take on the program. Even those that were interested in using the program implemented operational constraints that would limit the effectiveness of the program's fuel optimization solutions. In the end, we were only able to convince the USS WASP to test the program at sea, and we are still awaiting full results from this test. We have received results from early testing that confirmed that OTTER mini's base case fuel estimates were in line with actual fuel consumption.

While the OTTER mini program does not provide the same level of comparative analysis that was expected of a FUSED-based program, it still accomplishes the original main objective of predicting fuel consumption and replenishment needs. The program draws from knowledge gained through interviews with SWO students at NPS and the background knowledge that went into the original FUSED program. OTTER mini has gone through various stages of user testing to receive feedback from SWOs and other stakeholders. The program is currently undergoing trials at sea which we hope will further validate the program and provide useful feedback for future development.

Recommendations for Further Research

The FUSED and OTTER mini tools present many opportunities for future research and development efforts. Because we were only able to test OTTER mini on a single ship, a lot of work remains to accurately measure its effectiveness under different conditions and on different ship types. There is also room for improvement in both the user interface and predictive capabilities. Further research is also needed to determine the best way to distribute and use OTTER mini across the fleet.

References

Alan Howard, B. N. (2015). Removal of the Plan of Intended Movement (PIM) Moving Window. Monterey, California, United States of America: Naval Postgraduate School.

NPS-17-N171-A: Using Stanford's DeepDive Deep Learning for Logistics in Support of Distributed Lethality

Researcher(s): Dr. Doron Drusinsky,

Student Participation: No students participated in this research project.

Project Summary

I developed a general purpose predictive logistics software package based on three primary components:

- a. A spreadsheet of orders such as the one provided by LCDR Charles Reed and Mr. Paul Vanhoosen.
- b. A Probabilistic Temporal Finite-State Machine (PTFSM) automatically learned from that data.
- c. (Optional) Expert rules written in English.

The delivered tool-set predicts orders per *Ship-ItemType* pairs. It has two main prediction modes:

- Predict a probability of an order (for one or more *Ship-ItemType* pairs) to be required in n weeks.
- Predict the number of weeks required for the probability of an order (for one or more *Ship-ItemType* pairs) to exceed some given value p .

Keywords: *predictive logistics, probabilistic temporal finite-state machines*

Background

Distributed lethality seeks to capitalize on the mobility and dispersed presence of naval forces through increased lethality over time looking out to 2030. Operating over an extended geographic area, particularly in the littorals, creates a range of operational problems for an adversary by diluting its force to locate distributed, but lethal, surface action groups (SAG), further complicating the adversary's ability to focus on the high value unit. Distributed lethality (DL) also presents a complicated logistics problem in supporting that distributed force. A key component of DL is predictive push-logistics, where suppliers use a push model rather than waiting for consumers to pull. This research focuses on predictive push-logistics.

Findings and Conclusions

The prime deliverable is a command-line tool named *Alpha*. Given a spreadsheet of orders made in the past, Alpha uses machine learning to generate a file named *orders.txt* that contains logistic predictions expressed as probabilities of orders. See the examples below to understand this file. The command-line options for Alpha are:

1. One argument: *n*. Alpha predicts order(s) *n* weeks into the future. This is done per PTFSM (i.e., *hmm.json*) file in the *Data/meaningfulShipItemtypeFile* directory.
2. Two arguments: (i) *n*, (ii) ship name (wrapped in quotes). Alpha predicts order(s) *n* weeks into the future for the given ship. Alpha works of all PTFSM generated files (i.e., *hmm.json* files) for the given ship that exist in the *Data/meaningfulShipItemtypeFile* directory.
3. Three arguments: (i) *n*, (ii) ship name (wrapped in quotes), (iii) item type name (wrapped in quotes). Alpha predicts an order *n* week into the future for the given Ship-ItemType pair. Alpha works of the PTFSM generated file (i.e., *hmm.json* file) for the given Ship-ItemType pair that exist in the *Data/meaningfulShipItemtypeFile* directory.

Some command-line examples for Alpha are:

1. `java -jar alpha.jar 10` - Predicts orders 10 weeks into the future.
2. `java -jar alpha.jar P0.55` - Predicts the number of weeks until the probability of an order is greater than 0.55.
3. `java -jar alpha.jar +10` - Predicts orders 10 weeks into the future, like example #1, but uses an algorithm where time advances by the mean delay in all X\$Y states, until *n*-weeks are consumed, rather than advancing time by a single *n*-week value.
4. `java -jar alpha.jar 10 "USS SPRUANCE DDG 111"` - Alpha predicts order(s) 10 weeks into the future, for the ship "USS SPRUANCE DDG 111".
5. `java -jar alpha.jar 10 "USS SPRUANCE DDG 111" "DIAPHRAGM"` - Alpha predicts the order for, "DIAPHRAGM" 10 weeks into the future, for the ship "USS SPRUANCE DDG 111"

Recommendations for Further Research

Future research should apply other kinds of machine learning techniques to this problem and compare their accuracy.

References

- [Ra] L. W. Rabiner, *A Tutorial on Hidden Markov models and Selected Applications in Speech Recognition*, Proc. of the IEEE, Vol 77, No. 2, 1989

NPS-17-N236-A: Additive Manufacturing: Technical Issues and Test of Large Scale Adoption in Naval Domain

Researcher(s): Dr. Amela Sadagic

Student Participation: LCDR Michael Grimshaw USN

Project Summary

Project studied and designed a set of comprehensive approaches and strategies in support of diffusion and wider adoption of additive manufacturing (AM) in the naval domain. The work was accomplished by establishing a long-term collaboration with multiple institutions and organizations that provide AM resources in Naval domain (examples: Fabrication Laboratories, Innovation Labs and Simulation Centers), and collecting data and insights about their operations. Project work also included data collection from potential adopters – our interest focused on their attitudes, skills, ownership of digital technologies in general, current and projected needs for AM, as well as exposure to and use of media. We identified both technical and non-technical barriers to adoption process, and generated recommendations on how to resolve them. The considerations included infrastructure needed to support AM domain; distribution of resources across naval domain; training approaches; endorsement and support of leadership; accountability and motivation; peer endorsement and promotion. The effort also selected and tested a series of 3D tools in support of AM domain, and advised on technical elements found to be missing from a desired comprehensive support environment. The effort proposed strategies and elements of adoption model specially designed to support accelerated adoption of AM, and provided advices about phased approach suitable for wider, self-sustainable adoption of AM in the naval domain. The work on this research effort has been used to further refine our model of Diffusion of Innovation in Military Domain.

Keywords: *additive manufacturing, 3D printing, technology adoption, diffusion of innovation, FAB LAB, energy savings*

Background

The potential that additive manufacturing (AM) brings to the naval domain, and military domain in general is well recognized, yet the evidence of systemic adoption and effective deployment of AM systems and products in everyday lives and operations conducted by active duty units, is still lacking. The particular domains that are projected to greatly benefit from small and medium scale AM are maintenance and logistics (productions of spare parts on demand), medical domain (manufacturing of instruments, sprains and prosthetics), operational domain (manufacturing of devices and systems on demand, like UAVs), training (mock-up terrains and instruments), and in the case of large scale AM like contour crafting with concrete, it is expeditionary warfare (building protection structures, blast walls, shelters), and humanitarian aid and disaster relief missions (shelters).

Our recent study aimed at collecting data on adoption of AM in the U.S. Navy and US Marine Corps [Friedell-2016] returned interesting results – the majority of surveyed active duty military members think that AM has great potential both at home (74% agreeing) and within their work spaces (70% agreeing). Nevertheless, the survey data also suggests that current ownership and use of 3D printers is extremely low

- only 2.5% of surveyed individuals confirmed their home use of 3D printed items, and 3.33% of surveyed individuals confirmed that their units have and use some 3D printed items. It is also interesting that 40.83% of surveyed individuals believe that a house could be 3D printed in the next 10 years,' and 55% of surveyed individuals believe that they could make parts with AM technology in their place of work (if that capability was available at their workplace.)

It is highly likely that reasons for this situation have roots in multiple elements of the diffusion process [Sadagic-2015]. Of note is that, for example, 12.50% of surveyed individuals did not know if their immediate units had 3D printing capabilities (additional 13.33% did not answer this question), and 50% of subjects responded that they had no knowledge about Navy and USMC efforts in pursuing 3D printing technology [Friedell-2016]. Good solutions do not happen by chance in any domain – they are the result of long-term, continuous and focused efforts by all parties that have a vested interest in that domain. One of the understandings that we identified while working on this type of research questions suggests that people and institutions believe that end users will recognize the value of novel technology on their own, and that the large scale, immediate adoption will follow. This expectation and belief regularly remains to be only the expectation; quite contrary, considerable efforts on promotion, demonstration of values in peer community, strong communication channels, and supporting infrastructure are needed if full success is to be reached ([Davis-1986], [Davis-1989], [Rogers-1995], [Yates-2013], [Sadagic-2015], [Grimshaw-2017].)

Findings and Conclusions

The work on this research project included following activities:

1. Field visits with data collection related to institutions and spaces that provide AM services in the U.S. Navy and US Marine Corps fabrication laboratories (FABLABS), innovation labs; Science, Technology, Engineering and Mathematics (STEM) labs, as well as institutions that can influence and assist the diffusion process (simulation centers).
2. Data collection efforts (research that included human subjects study).
3. Tests of 3D printing and 3D scanning technologies, and production of resources that could be used by service members.
4. Support of and participation in events.

Field Visits: The research team worked in close collaboration with N415 office, our Topic Sponsor CAPT Bridges and his team, and established close collaboration with fabrication laboratories and innovation labs in both the USN and the USMC. As part of that work we completed field visits with data collection to following organizations:

- 1) FABLAB, Marine Corps Air Ground Combat Center (MCAGCC), USMC, Twentynine Palms, CA,
- 2) STEM Lab, MCAGCC, USMC, Twentynine Palms, CA,
- 3) Battle Simulation Center (BSC), Marine Corps Air Ground Task Force Training Command (MAGTFTC), MCAGCC, USMC, Twentynine Palms, CA,
- 4) Marine Corps Logistics Operations Group (MCLOG), MCAGCC, USMC, Twentynine Palms, CA,
- 5) Camp Wilson Simulation Lab, MAGTFTC, MCAGCC, USMC, Twentynine Palms, CA,
- 6) Training Support Center (TSC), MCAGCC, USMC, Twentynine Palms, CA,
- 7) Marine Corps Systems Command (MC SYSCOM), Additive Manufacturing Cell, Quantico, VA,
- 8) FABLAB in SW Regional Maintenance Center, USN, San Diego, CA,
- 9) Mid-Atlantic Regional Maintenance Center, Innovation Lab, Naval Sea Systems Command (NAVSEA), Mid-Atlantic Regional Maintenance Center (MARMC), USN, Norfolk, VA,

- 10) Fleet Readiness Center East, Naval Air Systems Command (NAVAIR), Cherry Point, NC,
- 11) 2nd Marine Logistics Group, Camp Lejeune, USMC, NC.

This type of work was augmented by our participation in regular telecons with FABLABs organized by Topic Sponsor's team.

Data collection efforts: We conducted two major data collection efforts:

1. *Data collection in FABLABs*: All field visits were used as opportunity to collect data related to institutions and spaces that have been providing AM services to service members. Data sets included detailed understanding about lab objectives and goals, space available for daily activities, acquired AM infrastructure (hardware and software), training programs developed by the lab, type and number of personnel actively engaged in the work of the lab, cybersecurity measures, incentives, leadership endorsements, advertising campaigns, lab funding, as well as plans for future work and growth.
2. *Data collection from human subjects*: This effort was organized as a part of student thesis research done by LCDR Michael Grimshaw, who produced a master thesis with Dr. A. Sadagic as the main thesis advisor [Grimshaw-2017]. This data collection effort was approved by the Naval Postgraduate School (NPS) Institutional Review Board (IRB) Committee, and it included data gathering from NPS students (USN, USA, USAF) via the LimeSurvey tool hosted by NPS. The type of data collected included demographics data, use of technology, exposure to media, technology influences, use of applications, individual and unit trends in adoption of digital technologies, service leaderships' impact on technology adoption, their knowledge of 3D printing, use of 3D printing (AM) technologies, opinions on usefulness of AM in their services, awareness of service pursuit of 3D printing, and use of 3D printed artifacts. The thesis presented comprehensive results of this data collection, and it discussed the most salient points.

The overall conclusion regarding the adoption of AM in the naval domain is that the interest and readiness of service members does exist, including their familiarity with examples of related digital technology. The spaces where more work is still to be done is in increasing leadership support on all levels, distributing infrastructure across the naval domain, and ensuring that necessary support mechanisms are present (examples: training, incentives, recognition).

Tests of 3D printing and 3D scanning technologies: The project team tested several 3D scanners and 3D printers and reported that work in the following documents:

1. 3D Scanning Using 3DSense for Windows
2. 3D Scanning Using iSense for iPad Air 2
3. 3D Scanning with Phi 3D Dot Product
4. 3D Scanning with Project Tango
5. Comparison of Photogrammetry and 3D Sense Scanner for Use in 3D Printing
6. 3D Printing with MakerBot
7. Hololens Repair with 3D Printing

Resulting manuals were written having in mind the needs and skills of a large majority of Sailors and Marines – individuals who have limited technical knowledge and no prior experience with 3D printers and 3D scanners. The same manuals were made available to FABLABs across the naval domain, and copies were stored in NPS-developed Navy Model Exchange portal that is designed and developed by Dr. Brutzman and his team.

Events supported: project team supported and actively participated in following events:

1. Modeling, Virtual Environments and Simulation (MOVES) Research Working Group (MAWG) event organized by MOVES Institute in May 2017. Dr. Sadagic and Dr. Brutzman presented a talk titled “Additive Manufacturing (AM): Research and Initiatives at NPS.” They also hosted a lab tour and introduced AM research efforts conducted by MOVES faculty.
2. Naval Additive Manufacturing Technology Interchange (NAMTI) event organized by the USN and USMC in August 2017 in Quantico, VA. Dr. Sadagic and LCDR Grimshaw actively participated in sessions organized during this event. The event addressed a number of topics: DoN's Additive Manufacturing (AM) Vision and Implementation Plan, concept of employment for AM, qualification and certification of AM components, digital Infrastructure and network impacts, Maker Space/Fabrication Lab Development, modified or new acquisition models to fully exploit AM, and development of naval expeditionary printing capabilities.
3. Discover NPS Day: Dr. Sadagic designed a number of demo stations that were made available to NPS visitors in MOVES laboratories. They included one 3D printer (this was made operational on the day so that visitors could see the way 3D printing works), AM-related posters developed for the needs of our project, and a number of 3D printed objects. Final demos were supported by Dr. Sadagic and three other project team members – Erik Johnson, Ryan Lee and Eric Heine, as well as a number of MOVES students.

Classes, lecture materials and thesis supported: Resources and materials acquired and produced during this project were used to enrich and support following classes and student thesis:

1. MOVES and CS courses: MV3922, MV4001, CS3004,
2. Two round table discussions on Innovation in DoD (with emphasis on innovation using AM): This was organized as a part of MOVES Brown Bag lectures (MV4924). Both discussions were moderated by Dr. Sadagic.
3. Student thesis: Faisal Rashid, a MOVES master degree students who graduated in Sep 2017, with thesis titled “Use of VR technology and Passive Haptics for MANPADS Training System”. Squadron Leader Rashid was able to use AM resources in MOVES lab to design and build (3D print) a segment of his prototype training system that acted as passive haptics.

Recommendations for Further Research

Adoption of any technology is a process – at times a very long process – rather than one-time event, and the success of such endeavor depends on a number of factors. Likewise, the research on this topic needs to take a form of longitudinal study and constant effort in terms of data collection, contacts with adopters and service leadership, data analysis with opportunity to reshape adoption model and provide updated understanding about next phase approaches. A unique position that NPS finds itself in is that by the nature of our engagement with DoD, we represent the place where researchers can obtain detailed insights of the needs of adopters (service members that include NPS students), and NPS has numerous opportunities for close dialog with service leadership and decision makers. The main recommendation for future work is to extend and expand this line of work and involve more students who will act not only as researchers but also as a next generation of instigators of AM adoption DoD-wide.

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NPS-17-N244-A: X3D Model Data Strategy for Navy Additive Manufacturing Digital Thread

Researcher(s): Dr. Don Brutzman

Student Participation: LT Michael Grimshaw USN

Project Summary

X3D Graphics can enable a Model Data Strategy to meet multiple Navy needs for reusable 3D printing and scanning, export of computer-aided design (CAD) engineering assets, logistics, trusted information transfer, maintenance, simulation, training, and qualification. 3D printing and additive manufacturing already provide dramatic positive impacts in fleet experimentation. 3D scanning and digital thread (DT) add even more virtual assets, but lack of a Navy 3D strategy stifles reuse, interoperability, and adaptability. Comprehensive approaches are needed for sharable 3D model libraries to provide new opportunities. Establishing an exemplar Extensible 3D (X3D) Naval Model Exchange enables practitioners to effectively explore new technical capabilities. Expected impacts are huge and immediate, since 3D printing turns “bits into atoms” and 3D scanning turns “atoms into bits,” all of which must align with original 3D CAD product designs.

Keywords: *X3D Graphics, additive manufacturing, digital thread, CAD, 3D Printing/Scanning, Logistics Measures Metrics, Model Exchange*

Background

Years of work have demonstrated that Extensible 3D (X3D) International Standard and open Web formats together provide comprehensive sharable solutions for afloat and ashore 3D challenges. Just as digital print libraries reduced space requirements by solving intellectual property requirements, 3D digital asset libraries can benefit the fleet if data and legal issues are resolved. This project demonstrates exemplars for full chain of 3D uses, focused on making return on investment (ROI) measurable. Years of NPS teaching and research activities in Web-based 3D visualization provides compelling communication techniques that can be applied to many domains. Originally named Virtual Reality Modeling Language (VRML), the Extensible 3D (X3D) Graphics International Standard has long supported student education, thesis work, dissertation research, and a broad variety of research projects. NPS online course MV3500 is an X3D modeling course that has been taken successfully by students in each school, with online assets offering possibility of further student activity via distance learning. Prior efforts sponsored by Naval Research Program (NRP) Topic Sponsor N415 (Additive Manufacturing Office) helped determine that while originally designed for Web usage, X3D models can directly support CAD, 3D Printing and 3D Scanning model interchange with the added rigor of contained structured metadata. Perhaps two dozen faculty staff and students from across campus have declared interest in 3D printing activities, with more expected to follow.

Process, Findings and Conclusions

Continuing NRP work has explored how additive manufacturing (AM) – sometimes called 3D printing – can benefit the Navy and USMC in a variety of ways. NPS is standing up a Navy X3D Model Exchange by adapting open-source software from National Institutes of Health (NIH) 3D Print Exchange. This initiative has received declared interest from Office of the Secretary of Defense (OSD), US Army, Special

Operations Command (SOCOM) and USMC activities in 3D printing. The technical benefits of broad 3D interoperability remain fully dependent on Web3D/X3D standards progress. This work is opening the door for any printable NPS 3D product to be reproducible by Navy and USMC personnel, either ashore or deployed.

In order to best support usage and adoption of additive manufacturing and 3D printing across the Naval enterprise, the NPS team has stood up the X3D Model Exchange. Extensive assets and documentation can be found online, now ready for further usage and growth by the Navy/Marine Maker communities. Significant personnel gaps occurred due to medical problems and availability of qualified backup staff late in FY2017, coupled with unexpected software implementation problems. Continuation work in FY2018 has now finished prior tasks, nearly finishing Developers Beta development with several dozen off-site partners tracking our progress.

Innovative adaptation of legacy Drupal portal software with gitlab.nps.edu version control is showing that sharing of 3D models with necessary metadata, searchable catalogs, visualization and 3D printing can be performed in a Web-friendly, product-agnostic manner for long-term effectiveness of (AM).

Recommendations for Further Research

The NPS open-source implementation of the X3D Model Exchange has successfully adapted a port of the NIH Model Exchange. Work continues. The next stage of this NRP project is complemented by USMC support to conduct Soft Launch operations with our first 100 users. This project is well suited for follow-on work. Naval Facilities Engineering Command (NAVFAC) is pursuing complementary shared visualization of ships/piers/ports using the SPIDERS3D system. Expeditionary Warfare Command (EXWC) and Space and Naval Warfare Systems Command (SPAWAR) are exploring how to port these assets to next-generation Navy Marine Corps Intranet (NMCI). The USMC is examining whether we can exceed capabilities shown in earlier Marine Maker prototypes.

Areas of ongoing activity include: Cybersecurity of 3D models, user-facing training, interchange compatibility for specialty industry solutions, customizable adaptation for Navy/Marine Makers, and applying metrics to perform ongoing assessments of diffusion of innovation for additive manufacturing.

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N8: INTEGRATION OF CAPABILITIES AND RESOURCES

NPS-N16-N168-A: USV ASW Employment

Researcher(s): Dr. Luqi

Student Participation: LT Steven Fahey USN, LTJG Umut Aslan TNF, Capt Khoubeib Bouthour TAF, LT Michael Grimshaw USN, LT Andrew Mauldin USN, LT Keith Nelson USN, LT Alexis Peppas HN, 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, Maj Oleksandr Tytarenko ZSU and Capt Matthew Zach USMC

Project Summary

This project investigated details of unmanned surface vehicles (USV) anti-submarine warfare (ASW) employment, with focus on strike group protection in the context of Concept of Operations (CONOPS) “Maritime Shield” and “Protected Passage”. Communication and coordination needs among swarms of unmanned surface vehicles (USVs) and other platforms were analyzed in the context of ASW. Risk analysis indicates that solutions involving large numbers of small inexpensive USVS are likely to be most effective with minimized cost. Work is leveraging previously developed requirements, system, and context models for ASW USVs. The objective of the study is to answer the following questions:

- (a) What USV employment approaches best support ASW CONOPS “Maritime Shield” and “Protected Passage”?
- (b) 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?
- (c) 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. A Master of Science (MS) thesis on how to measure/evaluate the contributions of autonomous capabilities was completed.

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 four 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 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 investigated alternatives for this option to inform future decisions.

Findings and Conclusions

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, # of USVs employed, and # of buoys employed was carried out. Case studies to determine which aspects of the USV should be autonomous, which should be done by people, how the people should interact with the automated parts, and to analyze the implications of limited communications bandwidth at sea explored many plausible options for ASW USVs. An MS thesis aimed at determining the value of autonomy and which aspects of ASW benefit most from automation [9], and a related one on planning the interactions between operators and unmanned systems [10] have been completed. Two conference papers [11,12], one conference presentation [13], and three technical reports [14-17] describe results of this study.

The 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, the damage does not leak across the partitioning barrier. This requires creating 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. Perfect realization of 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 in 2016 [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 of 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 received 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 may not be visible to sensors and can lead to unprecedented situations that are not covered by prior data. 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 recovery fails, that bring the USVs into a safe state if possible and self-destruct otherwise.

Recommendations for Further Research

We recommend further investigation of potential benefits of renewable sonobuoys for mitigating difficulty of small USVs in keeping up with a transiting strike group in high sea states. Such a study would seek the most effective way to retrieve the buoys at the trailing edge of the group for redeployment further ahead. Would this be done best by a manned platform, autonomously by a large USV, a large USV carrying a small temporary crew or by some other method?

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NPS-17-N212-A: Enhancing Campaign Analysis with STORMMiner

Researcher(s): Dr. Thomas Lucas and Dr. Susan Sanchez

Student Participation: LT Devon Cobbs USN

Project Summary

A modeling environment that provides information for many important Navy and joint studies is the campaign-level simulation Synthetic Theater Operations Research Model (STORM). A suite of automated post-processing tools known as STORMMiner was developed in a previous Naval Research Program (NRP) project to facilitate drawing insights from a set of simulated campaigns in STORM. This phase two effort enhances STORMMiner's functionality and applies it to a classified scenario to assess the robustness of the scenario's concept of operations (CONOPS). STORMMiner has also undergone extensive testing and documentation (SEED, 2018), and hands-on training and direct study support have been provided to Navy users.

STORM is an extremely complex environment and requires massive amounts of input data to construct a scenario (Morgan et al., 2018). It takes a multidisciplinary team of several analysts many months to specify the attributes, capabilities, and decision rules for the thousands of simulated entities in a full-scale scenario. One of the most challenging tasks for STORM users is to create, test, and certify the CONOPS of the simulated combatants. The CONOPS within a complicated scenario involve hundreds of temporally and spatially dependent rules and algorithms that contain thousands of variables. This research analyzes a classified future warfighting scenario to explore the impact selected command and control factors have on campaign outcomes. It is a proof of concept study that demonstrates a methodology that can facilitate future STORM analysts in reducing the time required to generate and assess large scenario CONOPS (Cobbs, 2018). The resulting CONOPS should prove to be more robust to scenario variations—which are inevitable in the real world and thus important to study in stochastic simulation models.

STORM contains many thousands of input variables that interact in potentially unpredictable ways. Moreover, there is uncertainty about the true values of many of these inputs. Therefore, STORM users need experimental methods that enable them to efficiently explore numerous factors simultaneously and fit complex response surfaces to a breadth of diverse responses. This research has advanced our ability in both of these areas by improving the quality and speed with which we can glean insights through experimentation with STORM (Erickson, Ankenman, and Sanchez, 2018).

Keywords: *campaign analysis, simulation, operations research, big data, STORM, data farming.*

Background

Resourcing decisions made today impact future U.S. Navy capabilities and concepts of operation (CONOPS). Use of models across the spectrum of fidelity, from engineering-level models to campaign-level models, is one analytic means available to guide critical resourcing choices. At the campaign level, the most widely used model by Service Headquarter staffs is the Synthetic Theater Operations Research Model (STORM). The Navy and other Services use STORM to evaluate warfighting risk and assess the utility of emergent CONOPS, advanced capabilities, and impacts of actions by postulated adversaries. STORM is a large stochastic campaign-level model that requires highly detailed data from mission-level models and assessments from the intelligence community and generates a vast amount of output data.

Previously, NPS's Simulation, Experiments and Efficient Design Center for Data Farming (SEED) Center (<https://harvest.nps.edu>) teamed with N81 analysts in developing and testing STORM-specific post-processing and analysis methods. The goal of the previous research was to develop new post-processing and analysis capabilities for STORM that facilitate an analyst's ability to quickly obtain insights from a well-designed set of simulation experiments—with an emphasis on being able to identify what it takes to win (WITTW) measures in potential future campaigns.

To enable STORM users to quickly obtain insights from STORM, a software tool called STORMMiner was developed, refined, tested, and delivered to OPNAV N81 in 2016. STORMMiner is a collection of unclassified, non-proprietary, government-owned R and Scala scripts. STORMMiner presents to the user a number of analysis artifacts (tables, graphics, etc.) that more quickly and effectively reveal meaningful insights to the analyst. These insights may help illuminate portions of the scenario no analyst has yet seen or recognized, and thus help with quality control, debugging, and highlighting areas for additional scrutiny. STORMMiner is continuing to be developed, tested, and used in Navy campaign analysis. These tools, in combination with new management constructs OPNAV has internally developed, have enabled OPNAV N81 analysts to complete some of their studies “approximately 33% faster and 16% less expensive” (Morgan et al., 2018).

Findings and Conclusions

This research project focused on four major areas. The first was enhancing STORMMiner by adding new features and extensively testing the software. The second was in supporting Navy analysts in learning and using STORMMiner. The third was in applying the new capabilities to a large, existing, classified scenario to assess the robustness of the scenario's CONOPS. The fourth was to advance our ability to design and analyze STORM experiments.

Improvements to STORMMiner were made after consulting OPNAV N81 and their representatives regarding additional features they would like to have. The new features include better visualization of various system losses, an expanded ability to interactively plot units' command and control plans, and additional ways to examine metrics within and after a campaign. There is also expanded functionality for interacting with graphs and tables based on conditional subsets of data, for example, getting results only for those runs in which a certain objective was met or a phase occurred. An update to the STORMMiner user's manual covers the additional capabilities (SEED Center for Data Farming, 2018).

New versions of STORM and STORMMiner were installed at OPNAV 81, one of their contractors (Science Applications International Corporation, SAIC), and at NPS. At all three locations, STORMMiner was used to help analyze a classified scenario recently developed at OPNAV N81. NPS representatives participated in the analysis in each location. In particular, new insights were obtained as to how several command and control variables affect the ability of the joint force to meet campaign objectives.

This research also advanced our ability to explore and fit metamodels to complex simulations such as STORM. A new design algorithm—sliced full factorial-based Latin hypercubes—provides for efficient sequential sampling while preserving desirable projectivity and near orthogonality properties (Duan et al., 2017). We have also explored the use of Gaussian Processes, which are an increasingly popular technique for fitting and optimizing response surface models. Extensive experimentation found that the accuracy of these methods is extremely dependent on the software used (Erickson, Ankenman, and Sanchez, 2018).

Recommendations for Further Research

STORM is used annually to inform senior leaders on tens of billions of dollars worth of decisions that impact our national security. STORM will continue to grow in complexity in order to meet future campaign-level analysis requirements. The capabilities outlined above, while substantial, are only scratching the surface of what could be useful for future STORM analyses. Thus, the Navy should continue to improve upon its ability to design, execute, and analyze STORM experiments.

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NPS-17-N304-A: Sonar Detection Mission Planning Tool

Researcher(s): Dr. Isaac Kaminer and Dr. Claire Walton

Student Participation: Dr. Sean Kragelund CIV

Project Summary

Autonomous vehicle teams have great potential in a wide range of maritime sensing applications, including mine countermeasures (MCM). Motion planning algorithms are required for designing trajectories for autonomous vehicles to follow, a key enabler for successfully employing these vehicles in

naval missions. Motion planning algorithms must consider the capabilities and limitations of each team member by incorporating their dynamic and operational constraints to ensure that trajectories are feasible. An especially important goal for MCM mine hunting missions is maximizing vehicle sensor performance in the presence of uncertainty. Optimal control provides a useful framework for solving motion planning problems with dynamic constraints and different performance objectives, and recent advances in numerical methods have made it possible to solve non-standard optimal control problems with parameter uncertainty. This capability has produced a general mathematical and computational framework—generalized optimal control (GenOC)—for numerically solving optimal search problems with multiple searcher, sensor, and target models.

This project employs the GenOC framework to solve motion planning problems for different MCM search missions conducted by operationally relevant autonomous vehicles and sonar systems. The resulting optimal search trajectories improve mine detection performance when compared with conventional lawnmower survey patterns conducted under time or resource constraints. Simulation results also highlight the flexibility of this approach for optimal motion planning, pre-mission analysis, and solving inverse problems relating MCM search performance to sonar design, vehicle team composition, or MCM Concept of Operations (CONOPS) development.

Keywords: *optimal control, optimal search, mine countermeasures, motion planning, autonomous vehicles, unmanned vehicles, unmanned surface vessel, autonomous underwater vehicle, sonar, detection models, mission planning*

Background

Mine countermeasures (MCM) is an extremely challenging and complex Navy mission, driven largely by the wide variety of potential threats and operational environments MCM forces may encounter. Mine hunting requires a number of different capabilities and techniques to address these challenges (U.S. Navy, 2004; PEO-LMW, 2009). Today, unmanned vehicles and advanced sensor systems play an integral role in many missions. Therefore, it is imperative that MCM commanders and vehicle operators have the ability to maximize the efficiency and utility of these valuable resources.

Mine hunting missions are often conducted in three distinct phases: 1) wide area detection, classification, and localization (DCL) of mine-like objects (MLOs) with long-range, low-resolution sensors; 2) reacquisition and identification (RID) with short-range, high-resolution sensors; and 3) neutralization (Abreu & Matos, 2014). The first two phases are increasingly conducted with autonomous vehicles and are therefore the focus of this research project. Historically, phase one has been addressed as a coverage problem (Abreu & Matos, 2014; Bays, 2012; Hyland & Smith, 2015; Nguyen, Hopkin, & Yip, 2008), especially when there is no prior information about mine locations. Likewise, phase two can be considered as a targeted coverage problem, guided by prior information about the expected target locations. Algorithms have been developed to visit each target location and conduct a standard coverage pattern comprised of parallel track lines at multiple headings in an attempt to image the target from different aspect angles (Bays, 2012; Bays, Shende, Stilwell, & Redfield, 2012).

Nearly all of these methods utilize lawnmower-type waypoint patterns to exhaustively cover a search area with an idealized sensor model having an assumed sweep width (Paull, Saeedi, Seto, & Li, 2013). Many of these idealized sensor models do not reflect an actual sonar's dependence on array design, vehicle trajectory, and three-dimensional search geometry. These techniques often grew out of past needs for

computational simplicity in vehicle and sensor modeling, and they can be easily implemented by vehicle autopilots, but they tend to produce overly conservative solutions. An alternative, engineering-based approach to modeling sensors like radar and sonar calculates "signal excess" from physical models of the sensor and its operating environment to determine when detection is possible (Wagner, Mylander, & Sanders, 1999; Washburn, 2002). Moreover, the Poisson Scan model described in (Kim, Lee, & Eagle, 2010; Washburn, 2002) can be used to derive a sensor's detection rate. Sensor models of this form are used to solve optimal search problems in (Foraker, 2011; Foraker, Royset, & Kaminer, 2015; Walton, Gong, Kaminer, & Royset, 2014), and (Walton, 2015) describes how models based on rate functions can be calibrated to "shape" their performance and solve a wide variety of problems.

This research project developed sonar detection models based on signal excess for several mine hunting sonars (Kragelund, Walton, & Kaminer, 2016). These models were incorporated into a generalized optimal control (GenOC) motion planning framework. Based on recent theoretical results described in (Foraker, 2011; Phelps, Gong, Royset, & Kaminer, 2012; Phelps, Gong, Royset, Walton, & Kaminer, 2014; Walton et al., 2014), GenOC can solve optimal search problems with different search vehicle, sensor, and uncertain target models. This research project formulated different MCM mine hunting operations as optimal search problems whose solutions yield motion plans for a team of autonomous vehicles. These motion plans not only specify trajectories that each vehicle can execute to optimize the performance of a given sensor payload, but also establish performance benchmarks for a given problem (Kragelund, 2017).

Findings and Conclusions

This research applied new theoretical results to problems of practical interest to naval mine countermeasures (MCM) forces. Specifically, physics-based sonar detection models were developed for several mine hunting payloads typically deployed from autonomous vehicles. Smooth "shaping functions" were applied to accurately reflect these sonar systems' three-dimensional fields of view. These sensor models were combined with dynamic motion models of fleet-representative unmanned vehicles (e.g., the SeaFox unmanned surface vehicle and REMUS 100 autonomous underwater vehicle) to explicitly relate sonar detection performance to vehicle trajectories, an aspect of motion planning that has been typically overlooked.

Another contribution of this effort applied generalized optimal control (GenOC) to optimize sensor performance in two relevant MCM sensing missions: 1) wide area detection, classification, and localization with long-range, low-resolution sensors; and 2) reacquisition and identification (RID) with short-range, high-resolution sensors. This demonstrated the flexibility of the GenOC modular framework by ingesting different target models (i.e. unknown mine locations with varying degrees of prior information), search vehicle dynamics (e.g., surface and underwater), and multiple sensor models (e.g., forward looking and side-looking sonar). The utility of this approach was demonstrated by generating optimal MCM search trajectories and establishing performance benchmarks for a given scenario.

This effort found that optimal trajectories do indeed improve mine detection performance over conventional exhaustive search (e.g., lawnmower) patterns, but only when mission planners are under time or resource constraints. A key conclusion was that mission planners can typically find a lane spacing parameter that allows a lawnmower pattern to achieve detection performance equivalent to the optimal performance benchmark computed by GenOC. This result naturally extends to a mission planning tool that can generate the best vehicle trajectory to follow for a given vehicle, sensor, and mission.

The GenOC framework can also be used to solve so-called “inverse problems.” Since the sonar detection models developed during this project include numerous sonar design parameters, this tool can be used to rapidly perform Monte Carlo analysis and gain insights on optimal sonar design. Similarly, numerous simulations can be employed to determine optimal vehicle team configurations for a given mission. As such, this method may have additional utility for developing new MCM concepts of operations (CONOPS).

Recommendations for Further Research

The sonar detection models developed during this project made several simplifying assumptions about the environment, neglecting complex reverberation and multipath sound propagation effects. Future work can extend these results by leveraging environmental databases maintained by the Naval Oceanographic Office to incorporate environmental effects on sonar effectiveness. Furthermore, this effort relied on signal excess for target detection. Many modern sonars generate high-resolution imagery and target detection occurs through laborious post-mission analysis. Further research should analyze mine detection performance based on the imagery created along a vehicle’s trajectory through the environment, to include aspect dependence and background clutter. Optimal trajectories that reduce the amount of unusable sonar imagery collected could dramatically improve mine clearance rates, as post-mission analysis of sonar data by human operators remains one of the bottlenecks in the MCM operational timeline.

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N9: WARFARE SYSTEMS

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

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Student Participation: CPT Jason Gay RSA

Project Summary

The U.S. Navy has an existing procurement and retirement plan for fighter 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 translating these changing tactical and operational environments, including new capabilities of adversaries, into informed decisions regarding the characteristics of future combat aircraft, is the responsibility of the Office of the Chief of Naval Operations (OPNAV). This requirement for a quick response for emerging air-combat scenarios motivates this project.

This project focuses on fighter aircraft in air-to-air combat and offers a general analytic framework for studying the impact of physical and operational features of such aircraft in various scenarios. Understanding which capabilities and characteristics of the aircraft are most important will help OPNAV make initial cost-effective procurement decisions in the future. We develop lower resolution (in relation to detailed simulations) analytically tractable models that can provide “first order” results regarding in-context operational effectiveness of certain mixes of physical characteristics and capabilities. More specifically, the models can help find a good balance among design attributes such as maneuverability, stealth, velocity, survivability, detection, and onboard weapon effectiveness.

Our study uses Stochastic Duels and Markov Chain machinery to evaluate Measures of Effectiveness (MOEs) of fighter aircraft. We focus on one-on-one interactions between aircraft that incorporate established kinematics and flight theories. This approach allows us to directly relate the physical characteristics of the aircraft to their mission-level performance. Furthermore, our model remains analytically tractable and is easy to implement on a computer, while maintaining the fidelity of the model to actual air combats. Our model provides air combat analysts and decision-makers a quick avenue to obtain first-order evaluations of fighter aircraft performance to reinforce their focal areas for larger-scale, higher-order evaluations using traditional, more elaborate (and costly) simulations.

The main beneficiary of this study is the Office of Chief Naval Operations (OPNAV). Specifically, the Air Warfare Division (N98) will be able to leverage our results to conduct low cost, time efficient, first order analysis of alternatives in their decisions regarding future naval fighter aircraft.

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

Main Contributions of the Study

1. Developing a transparent, analytic and easily implementable model for quickly evaluating aircraft characteristics in one-on-one air combat.
2. Reflecting real-world tactical considerations of air combat in a relatively simple mathematical model.
3. Translating detailed physical and engineering parameters of aircraft into probability measures that produce, through the stochastic model, relevant MOEs.

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 designed, 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 that 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, meaning that the simulation model is difficult to verify and validate. Most of all, simulations are costly in terms of time and money. Notwithstanding these limitations, simulations are indispensable at advanced R&D stages when the fine-tuning of characteristics is 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 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 Stochastic Duels and Markov Chains.

Findings and Conclusions

Our model is a one-on-one duel between fighter aircraft that comprises two phases. The description of the phases and the tactical details thereof are based on discussions with a retired F18 pilot, CAPT Jeffrey Hyink. The model and analysis are given in a thesis written, under our supervision, by Captain Jason Gay of the Singapore Army.

In the first phase – the Approach - the two aircraft enter the duel at a range beyond visual contact. During that phase, both aircraft race to detect and fire at each other with the main goal of shooting the opponent down. At this phase, there is no maneuvering. If the two aircraft survive the first phase, they will enter the second phase where they engage in a dogfight. At the dogfight phase, the two aircraft contest to out-maneuver each other and to shoot each other down. The dogfight features a Pursuer—the aircraft

pursuing its opponent from the rear and attempting to shoot the opponent down – and an Evader – the aircraft in front of the Pursuer attempting to break off and become a Pursuer.

For the first phase, we use a probability model to represent the missile exchange between two approaching aircraft and incorporate the kinematics of both aircraft and missiles. The resulting model captures the dynamics of a missile exchange at beyond-visual range to determine the likely outcomes given the specifications of both the aircraft and missiles.

For the second phase, we use a Discrete-Time Markov Chain to model the dogfight. We augment the underlying formulation of the Markovian model with flight theories that are relevant to the aircraft's measure of performance. Specifically, we combine the relationships of the aircraft's specifications, such as the turn performance, to the key tactical maneuvers in the state transition of the Markov Chain. This allows us to capture greater resolution of the dogfight's dynamics without significantly reducing the analytical tractability of the model.

We illustrate the result of our model using a numerical example featuring two actual, dissimilar aircraft and their specifications. Specifically, we used the EF-2000 Eurofighter as the Blue aircraft and the Multi-role Su-30 FLANKER-F as the Red aircraft. Our model reveals that both aircraft have comparable capabilities during the first phase, albeit the EF-2000 has some advantage over the Su-30. However, once the two aircraft enters the dogfight, the EF-2000 dominates the Su-30 because of its superiority in aircraft maneuverability.

We complete the numerical example with a sensitivity analysis of the model using smart experimental design methods. Our analysis reveals that in Phase 1 the time to detect and fire at the enemy, the single shot kill probability of the aircraft's missile, and the aircraft's velocity have significant effects on the probability of win. For the overall duel, we discover that the single shot kill probability, aircraft velocity in Phase 1, flight velocity in Phase 2, and the maximum load factor of the aircraft to be most influential in increasing the win probability.

Recommendations for Further Research

Tactical assessments and evaluations are not limited to only one-on-one duels. Therefore, we propose two major areas of future research using similar approaches for force-level evaluations of air combats. These are 1) many-on-many air combat evaluations using stochastic duels and 2) air-to-ground mission evaluation using advances in firing theory.

- **Many-on-Many Air Combat Evaluation using Stochastic Duels**

We propose an extension of our modeling approach to develop a many-on-many air combat stochastic duel. The fact that typical air combat comprises a relatively small number of aircraft on each side (2-4) enables the use of engineering-level specifications to compute mission-level performance, as demonstrated in the one-on-one case.

Similarly to the one-on-one case, we will adopt a two-phase approach. Phase 1 will feature a two-sided missile exchange where cases of coordinated and uncoordinated fire will be explicitly addressed. This scenario may be developed using a binomial-type, combinatorial formulations to determine the number of kills on each side depending on their type of firing. Phase 2's tactical maneuvers involving two or more aircraft could potentially be approximated using a slightly more complex version of the kinematic

formulations presented in the one-on-one case. A good starting point will consider the key maneuvers in a two-on-one duel, followed by a two-on-two duel. Many-on-many air duels are composed of multiple individual duels of this type.

- **Air-To-Ground Mission Evaluation Using Stochastic Duels**

Here the objective is to model the effectiveness of bombers against ground targets or opponents. A similar construct as the Phase 1 model is a potential approach, except that one side of the duel comprises static targets on the ground. Both Air-to-Surface and Surface-to-Air missiles may be used to model the missile exchange between the two sides. A model in this scenario will be useful to the Naval aviation community as the ground unit in the model can easily be adapted and extended to surface warships.

Researchers in this area should consider the potential use of kinematic approximation in the stochastic duel to determine the probability of an aircraft evading a Surface-to-Air missile by maneuvering itself defensively, thus enhancing the fidelity of the air-to-ground model.

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NPS-17-N028-A: Transfer and Correlation Functions between Underwater Hydrographical and Optical Parameters

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Project Summary

Optical communication/detection systems have potential to get around some limitations of current acoustic communications and detection systems especially increased fleet and port security in noisy littoral waters. Identification of environmental effects on underwater optical transmission is the key to the success of using optics for underwater communication and detection. This paper is to answer the question "What are the transfer and correlation functions that relate measurements of hydrographic to optical parameters?" Hydrographic and optical data have been collected from the Naval Oceanographic Office

survey ships with the High Intake Defined Excitation (HIDEX) photometer and sea gliders with optical back scattering sensor in various Navy interested areas such as the Arabian Gulf, Gulf of Oman, east Asian marginal seas, and Adriatic Sea. The data include temperature, salinity, bioluminescence, chlorophyll-*a* fluorescence, transmissivity at two different wavelengths (T_{Red} at 670 nm, T_{Blue} at 490 nm), and back scattering coefficient (b_{Red} at 700 nm, b_{Blue} at 470 nm). Transfer and correlation functions between the hydrographic and optical parameters are obtained. Bioluminescence and fluorescence maxima, transmissivity minimum with their corresponding depths, red and blue laser beam peak attenuation coefficients are identified from the optical profiles. Evident correlations are found between the ocean mixed layer depth and the blue and red laser beam peak attenuation coefficients, bioluminescence and fluorescence maxima in the Adriatic Sea, Arabian Gulf, Gulf of Oman, and Philippine Sea. Based on the observational data, an effective algorithm is recommended for solving the radiative transfer equation (RTE) for predicting underwater laser radiance.

Keywords: *radiative transfer equation (RTE), beam attenuation coefficient, absorption coefficient, volume scattering coefficient, scattering phase function, bioluminescence, chlorophyll-a fluorescence, HIDEX, SEAGLIDER, EODES*

Background

For almost a century, the United States Navy has relied on acoustic sensors to map, detect threats or obstacles, and transmit information. However, with limited resources available and the desire to limit exposure to equipment and crew, alternative methods to conduct operations in anti-submarine warfare (ASW), mine warfare (MIW) and naval special warfare (NSW) are being developed. One such development is the use of electro-optic sensors in conjunction with acoustic sensors to detect, classify, localize and identify sea mines. For example, the AN/AQS-20A Mine Hunting System is a towed body sensor that is operated from naval helicopters. Another sensor deployed in MIW operations is the Airborne Laser Mine Detection System (ALMDS). Increased deployment of autonomous underwater vehicles (AUVs) in a wide range of theaters in support of operations in MIW, fleet survey team (FST), ASW, and NSW has highlighted the limitations in current communications of autonomous systems. AUVs must surface to receive telemetry information and send back data due to the attenuation of radio frequencies in sea water. Two approaches are available for the underwater communication: acoustics using sonar system and optics using light modems to transmit data through water. The advantage of light modem is an unprecedented bandwidth of 1 to 10 megabits per second at up to 200 meters. When combined with acoustic based communications equipment the range can be extended out to much longer ranges[1]. To aid in the deployment and operation of optical sensors in support of Navy operations, the Electro-Optical Detection and Simulation model (EODES) was developed. However, the data input required by the EODES model is not readily available to the sailors in the operational area or as part of a reach-back team. This paper attempts to bridge the gap between readily available data and a high-fidelity performance prediction tool.

The environmental effects on underwater optical transmission has been determined using the HIDEX data collected by the Naval Oceanographic Office (NAVOCEANO) survey ships in regional seas with the Navy's interests: the Arabian Gulf and Gulf of Oman, East China Sea, South China Sea, Yellow Sea, Philippine Sea, and Adriatic Sea are selected for this study. The Yellow Sea features a number of large, polluted river outlets including the Yangtze and Yellow Rivers, which serve to add sediment and large particles to the ocean, possibly leading to optical impacts in the measurements obtained [2] [3]. The East

China Sea is also a relatively shallow sea that is bounded by mainland China to the west, Japan and the Ryukyu Island Chain to the east, Taiwan to the south, and by the Yellow Sea on its northern border. The most striking bathymetric feature in the East China Sea is the Okinawa Trench, an area of deep water directly to the west of the Ryukyu Island Chain^[4]. The area of data collection is mainly located in the western portion of the South China Sea off the coast of Vietnam in the vicinity of Hainan Island and on the shelf in the northern portion of the South China Sea^{[5][6]}. The Philippine Sea is composed of a deep abyssal plain bounded by the Ryukyu Island Chain to the west and a north-south ridge extending from central Japan down to the Marianas Island Chain to the Marianas Trench^[7].

The HYDEX-BP generation II is a fully integrated system that features an improved light collection chamber, new remote telemetry and data acquisitions systems, and most importantly, addition of new sensors to meet expanded measurement requirements. It measures vertical distribution of in situ hydrographic parameters (temperature and salinity), inherent optical parameters such as beam attenuation coefficient at near 670 nm (red light) and 490 nm (blue light), bioluminescence, and chlorophyll-a fluorescence ($\mu\text{g/L}$)^{[8][9]}. The hydrographic and optical data collected by NAVOCEAN HIDEX-II were analyzed by Chu 's students for the Adriatic Sea^[10], east Asian marginal seas^[11], Arabin Gulf, and Gulf of Oman^{[12][13]}.

SEAGLIDER is remote operator programmed to perform a series of downward and upward glides while collecting various oceanographic data parameters using variable installed sensor packages^[14]. The NAVOCEANO's SEAGLIDER is fitted with the Seabird Electronics SBE 41 CP CTD sensor (hydrographic measurement) and WET Lab s' Environmental Characterization Optics puck, which is comprised of three sensors: a flourometer measuring the bio-optical parameter chlorophyll-a at 470/700 nm wavelengths and two separate and distinct optical sensors measuring the optical backscattering coefficients at the 470 nm and 700 nm wavelengths^[15]. The optical backscattering coefficient is measured so that oceanographers can discover various useful factors about the seawater that has been sampled^{[16][17]}.

Findings and Conclusions

The ocean environmental effects on underwater optical transmission have been identified in several regional seas such as the Arabian Gulf, Gulf of Oman, East China Sea, South China Sea, Yellow Sea, Philippine Sea, and Adriatic Sea using the data collected by NAVOCEANO from survey ships with HIDEX and SEAGLIDERS. Statistical analysis on the HIDEX and SEAGLIDER data shows strong negative correlation between (chlorophyll-*a* fluorescence, temperature, salinity) and transmissivity (or strong positive correlation to beam attenuation coefficient). Statistical model has been established to link profile of beam attenuation coefficient (*c*), or transmissivity for the red light (670 nm) (T_{red}) and blue light (490 nm) (T_{blue}) from profiles of temperature (*T*), salinity (*S*), bioluminescence (*B*), and chlorophyll-*a* fluorescence (*F*). Strong correlation can also be identified from the vertical cross-sections along the observational track of the parameters. The isothermal layer is highly correlated with the isohaline layer. The maximum bioluminescence, fluorescent chlorophyll-*a*, beam attenuation coefficients (m^{-1}) for red and blue lights were all presented at the base of the mixed layer. Such observational results provide opportunity to link the hydrographic features to underwater optical characteristics. Evident correlations were also found in other regional seas such as Adriatic Sea, East China Sea, South China Sea, Yellow Sea, and Philippine Sea. Regression equations were established for each sea,

$$\hat{T}_{red,blue} = \alpha_0 + \alpha_1 T + \alpha_2 S + \alpha_3 B + \alpha_4 F \quad (1)$$

The regressed transmissivities ($\hat{T}_{red}, \hat{T}_{blue}$) are verified by the observations. Discrepancy is evaluated by the

normalized root mean square errors between \hat{T}_{red} and T_{red} , and \hat{T}_{blue} and T_{blue} , which are the root mean square errors divided by the root mean square of T_{red} or T_{blue} .

Recommendations for Further Research

Underwater environment provides a promising area for the application of optical detection and wireless communication. Scattering by seawater and particles including chlorophyll-a causes light attenuation. Besides, bioluminescence is commonly observed as a result of a ship or other surface craft moving through a body of water containing a population of luminous organisms, which is important for submarines operating at depths of zero to 50 meters in coastal waters where bioluminescence is most abundant. Therefore, one of the main targets is to evaluate the overall path loss which is essential for calculating link budgets and signal-to-noise ratio.

Bioluminescence represents an operational threat to night-time operations or additional capabilities in detecting and tracking surface and subsurface movement during the night. As submarines are getting quieter, this alternative mean of detection is prevalent in littoral zone where conventional acoustic surveillance is challenging. However, the source term (i.e., bioluminescence) is neglected in the existing Navy's Electro-Optical Detection Simulator (EODES)^[15]. Future research includes bioluminescence as the source term in the EODES. Furthermore, we recommend a high efficient numerical algorithm with capability to assimilate underwater optical parameters to predict the optical path loss in the Navy's hot spots such as Persian Gulf, South China Sea, East China Sea, and Japan Sea. This algorithm is crucial for undersea warfare since the optical path loss is a major factor in optical detection and communication.

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NPS-17-N043-A: Modeling and Analysis of Total Ownership Cost for Surface Ship Electro-Optical/Infrared Systems

Researcher(s): Dr. Shelley Gallup and Dr. Johnathan Mun

Student Participation: No students participated in this research project.

Project Summary

The current project is to model the lifecycle and total ownership cost (TOC) of Surface Electro-Optic Infrared (EO/IR) sensors for Naval Sea Systems Command (NAVSEA). The deliverable of the research includes Excel models with simulation and predictive modeling capabilities as well as a Word document meant to get the reader started using the models. The analysis starts with the basics of TOC modeling over the life cycle of the EO/IR, including the inception phase of Acquisition Costs, followed by annual operations and maintenance (O&M) costs, and a final set of Disposition Costs at the end of life of the sensor. The models and methodologies are extensible to include multiple sensors as a way to compare them under an analysis of alternatives paradigm.

Keywords: *total ownership cost, lifecycle cost management, electro-optical infrared sensor, simulation, forecasting, predictive modeling, analysis of alternatives*

Background

Based on NAVSEA’s Design Practices Manual (2017), EO/IR is a broad spectrum of sensors and equipment, including but not limited to: Image Intensification (I2) devices, low-light level (LLL) imagers,

active (light or laser aided) imagers, and infrared imagers; lasers such as laser rangefinders (LRF), laser pointers (LP), laser illuminators (LI), laser designators (LD), and laser target markers (LTM); EO/IR directors; EO/IR devices such as visual augmentation systems (VAS), optical sights, optical augmentation (laser retro-reflection), and certain free-space optics (FSO) equipment; electronic counter-countermeasures (ECCM) for sensor protection; still and motion image processing such as video target detection and tracking, still image photo (SIP) and motion imagery (MI) compression, image metadata (MD), imagery and MD dissemination interfaces on-board ship, and signal transport; and other EO/IR associated equipment.

Design requirements, detailed manuals, and technical specifications have been exhaustively published by NAVSEA and other departments within the Department of Defense (DoD). However, there is one issue facing the DoD in terms of EO/IR implementation: the correct, valid, defensible, and objective quantitative computation of its lifecycle and total ownership cost. Such future costs are sometimes unknown or subject to significant amounts of uncertainty. These uncertainties tend to compound over time and the final cost results will be inaccurate at best. The current research applies modern techniques and modeling capabilities to calculate these costs over the life of the equipment.

Findings and Conclusions

In standard lifecycle-based TOC analysis, a basic set of assumptions includes the fact that there are typically significant acquisition costs prior to the system being operational, usually denoted as Year 0, followed by subsequent operational years, where operations and maintenance (O&M) costs apply. In the last year of operations, additional disposition or salvage costs may be incurred to either dispose of the system or render it inoperable. Furthermore, the total costs can be computed as a simple summation of all expenses incurred and to be incurred throughout the life cycle of the system.

Conversely, applying economic theory, these costs can be discounted annually at some prespecified discount rate to account for the time value of money (i.e., a dollar tomorrow is not equivalent in purchasing power to a dollar today, due to various factors such as economic growth rates, purchasing power parity, inflation, and interest rates, as well as opportunity cost of holding money). Finally, the O&M costs may be themselves subject to changes over time (e.g., due to inflationary pressures, budgetary cutbacks, periodic technology insertions, cost inflation, and the like), and the proposed methodology allows for such manual adjustments.

One of the areas of improvement in the lifecycle cost model is the inclusion of Monte Carlo risk simulation, a very potent predictive modeling methodology. Simulation is used when there is uncertainty as to the outcome(s) in the future, and in the present research, the uncertain cost levels. For the practitioner, simulation opens the door for solving difficult and complex but practical problems with great ease. Monte Carlo simulation creates artificial futures by generating thousands and even millions of sample paths of outcomes and looks at their prevalent characteristics. And in all cases, when modeled correctly, Monte Carlo simulation provides similar answers to the more mathematically elegant methods.

Recommendations for Further Research

Obtaining the correct cost projections over the lifecycle of an EO/IR program is critical to making the correct strategic decisions in terms of portfolio program selection subject to a set allocation of cost. Finally, the recommended next step is to collect real-life data to implement the proposed methodology, and to create a modeling standard for analysis of alternatives of multiple EO/IR sensors and beyond.

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NPS-17-N089-A: Applying Model Based Systems Engineering (MBSE) and Simulation to Explore the Operational Effectiveness of the ASW Autonomous Unmanned Vessel (ACTUV)

Researcher(s): Dr. Eugene P. Paulo and Dr. Paul Beery

Student Participation: LT Kristjan Casola USN

Project Summary

The Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessel (ACTUV) is a 130 foot totally autonomous and unmanned surface vessel designed to track and trail submarines. While the support of ASW was the original intent for the ACTUV, Defense Advanced Research Projects Agency (DARPA) and the Office of Naval Research (ONR) are interested in the possibility of other operational applications for the ACTUV. We analyze the vessel's potential contribution to distributed lethality as a surface warfare (SUW) platform. We establish traceability, requirements and capabilities, while determining the architecture framework in accordance with the Department of Defense Architecture Framework (DoDAF). Then, using an experimental approach to operational analysis we demonstrate, through the use of model-based systems engineering (MBSE) and simulation tools, the effectiveness of an SUW version of the ACTUV in supporting

Keywords: *model-based systems engineering, unmanned surface vessel, distributed lethality, surface warfare*

Background

The U.S. Navy is in the process of implementing a new operational strategy for surface warfare (SUW). This model, called distributed lethality (DL) is centered around the premise of employing combatant units in an offensive manner that forces the adversary to disperse his forces (Fanta et. al 2015). For the surface navy, this means having enough warships to form multiple offensive "hunter killer" surface action groups to take the fight to the enemy in his own backyard. It also means these warships must possess a lethality that warrants attention from the adversary and presents a threat.

One possible solution to consider is the use of unmanned surface ships. The ACTUV, also known as *Sea Hunter*, an autonomous surface ship displacing 145 long tons, was designed and built to hunt submarines. While its original role is for anti-submarine missions, the vessel has significant potential to perform a myriad of other missions, such as surface warfare. With its two separate mission support areas on the

main deck, the author envisions the vessel as a mobile anti-ship cruise missile (ASCM)-launching platform (Figure 1).

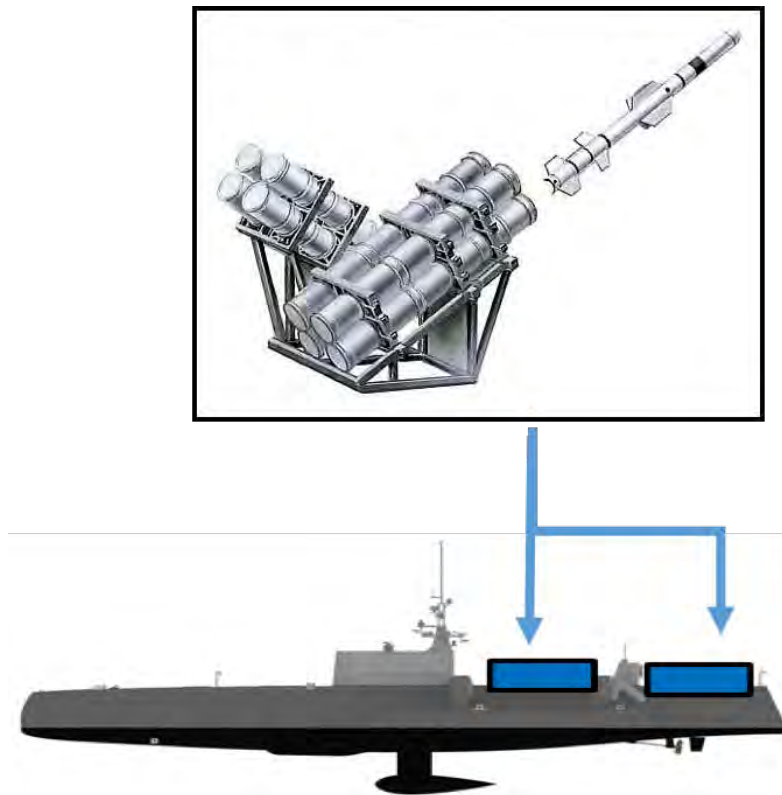


Figure 1: Proposed Location of ASCM Launchers on *Sea Hunter*. Source: Littlefield (2016).

The DL high level needs for conducting SUW with *Sea Hunter* as part of an adaptive force package (AFP) are determined to be ease of integration, logistics, system size and scalability, command and control, and lethality. These needs are further decomposed into requirements to be met by specific functions. A physical architecture traces the functions to allocated physical components. Diagrams depicting functional and physical hierarchy (Figure 2), as well as functional flow diagrams, provide visual aids to understand the established architecture. Scenarios for the computer-based simulations are loosely based on previous wargames featuring several *Sea Hunters*. In those scenarios the ACTUVs were used as picket boats to conduct reconnaissance and gather intelligence on the adversary surface force, as well as an offensive platform by simulating their launching of anti-ship cruise missiles.

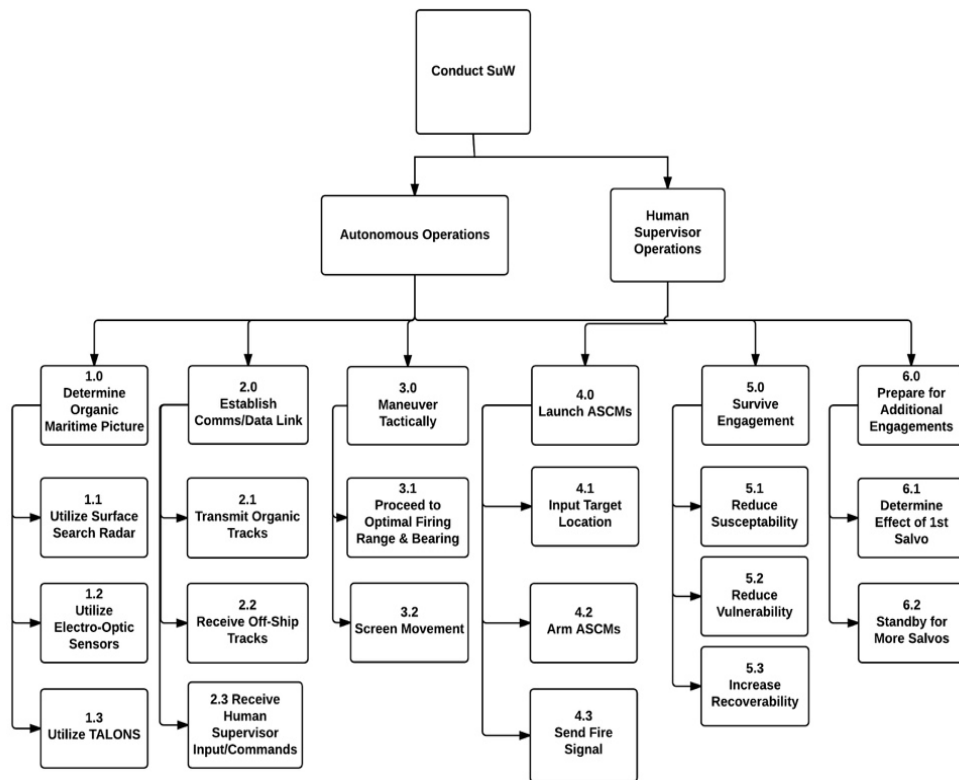


Figure 2: Functional Hierarchy of Surface Warfare for *Sea Hunter*.

Findings and Conclusions

Comparative analysis of salvo exchange results is performed through the use of equations originating from Hughes’ Salvo Model. Spreadsheet calculations provide analysis of force-on-force engagements. Inputs include number of vessels, number of missiles launched per vessel, number of incoming missiles each vessel can engage, and number of missile hits required to take a vessel out of action. Results of two opposing forces of equal capabilities demonstrate the need for a significant force size advantage if casualties are to be minimized.

The results of the Salvo Model simulations indicate the need for a more robust missile defense. The first two scenarios simulate the effects of utilizing a defense ship version of the *Sea Hunter*. This defensive ship provides a short-range integrated air and missile defense (IAMD) by employing the SeaRAM system. Each SeaRAM system provides an integrated search and tracking radar and fire control system along with eleven RIM-116 missiles. Simulation results indicate significant decreases in the number of *Sea Hunters* lost in an engagement.

A final scenario proposes the use of a *Sea Hunter* defense ship as a “missile sponge” by increasing its probability of being targeted by an incoming ASCM. In reality, an increase in radar cross section could accomplish the same result. To counteract the increase in hostile targeting, the defensive ships were

simulated to employ countermeasures, such as chaff. Unsurprisingly, this configuration resulted in the fewest friendly *Sea Hunter* casualties, whether defense ships or ASCM-launching ships.

Recommendations for Further Research

We recommend further investigation on utilizing the *Sea Hunter* platform for SUW. One change may be to examine slight variations of platform design, such as increasing hull size or hull depth, which could increase mission capability. Another recommendation would be to study the possibility of an AFP configured of one manned ship with multiple *Sea Hunters*. For example, an Aegis destroyer could provide the local watch team supervision of the ACTUV while the unmanned vessels are augmenting the IAMD capabilities of the destroyer. The rest of the AFP could be comprised of SUW variant *Sea Hunters*, and ACTUVs for anti-submarine warfare and mine warfare. This has the potential to reduce the tasking of conventional manned ships while reducing operational costs.

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NPS-17-N089-B: ASW Continuous Trail Unmanned Vessel (ACTUV) Operational Vignettes Study

Researcher(s): Dr. Shelley Gallup, Nelson Irvine, Doug MacKinnon, and Brian Wood

Student Participation: Lt Cdr Akhtar Zaman Khan PN, LCDR Kevin K. Solem USN, LT Kristjan J. Casola USN, and LT John Tanalega USN

Project Summary

The *ASW Continuous Trail Unmanned Vessel (ACTUV)* prototype was built under a Defense Advanced Research Projects Agency (DARPA) program and is currently undergoing testing of its autonomous capability at Pt Loma, California, now under the Office of Naval Research (ONR). ACTUV, now "*Sea*

Hunter” represents a large step in the evolution of autonomous capabilities. It is significantly larger than other unmanned systems (130 feet), and is intended to be fully autonomous. With its wave-piercing bow and hull form (trimaran) it can sustain speeds enabling it to match operational needs, whether sprint or loitering and be at sea for up to 90 days. As a prototype, ACTUV was envisioned to bring capability to major warfare areas in addition to anti-submarine warfare (ASW) surface warfare (SUW), electronic warfare (EW), mine warfare (MIW), and support many individual mission tasks. As the “envelope of possibilities” expanded, many potential autonomous tasks have emerged. These are still very much at the concept level. One difficulty is in taking such an important emerging capability and without having the actual capability to test, begin to discern what is most possible and what effects it would have. This project is intended as a first step in developing operational vignettes in which ACTUV may be tasked to perform these mission areas. The emphasis is on the operations research provided by thesis students and was intended to be a concurrent effort with other ACTUV projects at NPS.

Keywords: *ASW Continuous Trail Unmanned Vessel (ACTUV), Sea Hunter, autonomy, mission areas*

Background

This project started with a request by DARPA for faculty and student involvement in development of an autonomous vessel that would have operational impacts for the fleet. A faculty team was created, sponsored by DARPA, and workshops, brown bag seminars, thesis topics and cross-discipline discussion ensued. There are now many individual projects at NPS spawned by this effort. A workshop co-sponsored by DARPA and NPS was conducted to determine what mission areas are appropriate to an autonomous vessel (now being called MDUSV for Medium Displacement Unmanned Surface Vessel) in the near, middle and far term. Eighteen were selected as having the most potential, and of those, five were the subject of thesis topics. The areas of individual research included mine warfare, convoy protection, autonomy in distributed lethality, ASW with a paired P-8 and ACTUV, and a classified thesis exploring autonomy in surface tactics.

Findings and Conclusions

The thesis work by students was primarily operations research centered, so that the questions being addressed had to do with employment of the Sea Hunter with assumed capabilities that would allow the vessel to participate in ways similar to a manned asset. So, the efforts had more to do with answering “if I have more of these assets and place them in a certain way, with operational capabilities that can be modeled, is there an advantage?” What was not addressed in the theses were the means to integrate the capabilities into the vessel, or the level of autonomy that would be needed.

As a summary of thesis abstracts give some understanding of the work:

(Akhtar; Convoy Protection Under Multi-Threat Scenario) “Convoy screening has long been studied and practiced to minimize losses of ships supplying forward battle areas. Today, the threat of surface and subsurface platforms equipped with torpedoes and anti-ship cruise missiles (ASCMs) requires reevaluation of the best protection measures taken by warships, aircraft, and unmanned systems to screen convoys. This research used agent-based simulation to develop and analyze the effectiveness of 18 models based on two basic screening methods: zone defense and close escort. Variants were developed based on stationing and type of combatant platforms—manned and unmanned. They were tested for robustness against two Red submarine approach tactics based on weapon priority and various acoustic conditions. The study determined the optimum weapon/sensor capabilities of combatant platforms for effective

protection. We showed that layered defense in the outer screen is the most robust and effective defensive model against any Red weapon priority tactic and in any acoustic condition. A model with ASW helicopters in the intermediate screen was found to be the most effective against submarines with torpedo as priority weapon. Models with ASW helicopters or MDUSVs and two Guided Missile Destroyers (DDGs) in the outer screen, however, were found to provide better defense against submarines with ASCM as priority weapon.”

(Casola; System architecture and operational analysis of medium displacement unmanned surface vehicle; Sea Hunter as a Surface Warfare Component of Distributed Lethality)“ This thesis analyzes the vessel’s potential contribution to distributed lethality as a surface warfare (SUW) platform. The author first attempts to establish traceability, requirements and capabilities while determining the architecture framework in accordance with the Department of Defense Architectural Framework (DoDAF). Then, using an experimental approach with a basic operational analysis, this thesis demonstrates, through the use of model-based systems engineering (MBSE) and simulation tools, the effectiveness of an anti-surface warfare (ASUW) version of the Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessel (ACTUV) in supporting distributed lethality. Analysis is built on ACTUV simulation data already available as well as results from the author’s simulations.”

(Solem; Quantifying the Potential Benefits of Anti-Submarine Warfare (ASW) Continuous Trail Unmanned Vessels (ACTUV) in a Tactical ASW Scenario) “The U.S. Navy faces a critical challenge in maintaining dominance in the undersea domain. The upward trends of submarine operations and capabilities of potential adversaries, coincident with shrinking U.S. inventories, will test U.S. anti-submarine warfare (ASW) capabilities. One line of effort toward maintaining dominance is to find advantageous ways to integrate unmanned systems into existing ASW operations. One interesting concept is augmentation of P-8A Poseidon (P-8) aircraft with ASW Continuous Trail Unmanned Vessel (ACTUV) operating as an extended sensor and weapons platform. This research uses agent-based simulation to model ACTUV/P-8 integration in a tactical ASW scenario in order to quantify potential mission benefits. In the baseline scenario for testing, a target submarine transits an area 110 nm wide by 50 nm long at a speed of 6–10 knots and must be detected, localized, and engaged. The model simulates prosecution of the submarine by the ACTUV alone, P-8 alone, and ACTUV/P-8 working together. Analysis of 198,000 simulated ASW missions shows that ACTUV augmentation of P-8 (1) increases the mean probability of detecting, classifying, and localizing a submarine within a weapons release envelope from 0.58 to 0.88 and (2) reduces the mean time required to do so from 3.26 to 2.76 hours.”

Finally, an analysis of the mine countermeasures capability that could be placed on Sea Hunter/MDUSV was conducted. The results showed the possible technical integration possibilities for the vessel.

Recommendations for Further Research

Specifying future scenarios before the actual adoption of the systems is made difficult as specification is not possible. Instead, there are many assumptions that must be made, any of which in reality could be very hard to engineer, integrate and put into operational practice. But, the works engaged by students and faculty in this project show that ideas are forming and questions are being asked that will slowly begin to evolve into more specific recommendations for employment in operational contexts. Future research needs to employ more simulation of the decision making software by these vessels, possibly including AI and machine learning.

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NPS-17-N094-A: AquaQuad - Hybrid Mobil Vehicle for Persistent Surface and Underwater Reconnaissance

Researcher(s): Dr. Vlad Dobrokhodov, Dr. Kevin Jones, Dr. Paul Leary, Dr. Kevin Smith, in collaboration with Dr. Mark Paulus, and Mr. Wade Kempf of Undersea Test Ranges & Fleet Readiness, Keyport

Student Participation: LT Joseph B. Testa USN

Project Summary

The project aims to build an experimental model as a proof of concept of a novel anti-submarine warfare platform, AquaQuad. The envisioned vehicle is a hybrid, including features and capabilities of a drifting sonobuoy and a multirotor vertical take-off and landing unmanned aerial vehicle (UAV), both powered by an environmental energy harvesting system. As such, AquaQuad integrates a multicopter UAV with a tethered acoustic sensor, environmentally hardened electronics, communication links, and a solar recharge system. The AquaQuads are designed as hybrid-mobile, collaborative platforms that ride on ocean currents and fly over significant distances when required by the mission. Flight is triggered to enable rapid repositioning for submarine tracking, collision avoidance, and communication with neighboring vehicles. As envisioned, the distributed swarm of energy independent and autonomous AquaQuads represents an information harvesting and communication system that, depending on the specific objectives, can be focused on various naval and civil applications.

To date the project has identified the mathematical models of key subsystems of the AquaQuad in the major modes of operation. They include two distributed (over depth) components - the surface and submerged units, connected via a tether, which operate autonomously in passive search while in energy harvesting drift and in energy bursting flight modes; a number of submodes is envisioned/included to address specific nature of silent operation under strict communication and energy constraints. An experimental setup of the surface unit and the submerged data acquisition (DAQ) system has been built. Operational capabilities of separate components are verified in controlled laboratory experiments. System identification experiment has been performed to identify the maximum achievable capabilities of the ARM CORTEX M4-based data acquisition system and the potential bottlenecks of the envisioned information processing architecture.

Keywords: *underwater acoustics, energy harvesting, acoustic sampling, digital signal processing (DSP), embedded system, beam forming, target motion tracking, path planning, UAV, flight control*

Background

The Persistent Littoral Surveillance Network (PLUSNet) (Steward & Pavlos, 2006; Benjamin, Schmidt, Newman, & Leonard, 2010) is a concept for cooperative anti-submarine warfare (ASW) that is considered in the proposed work as the most navy relevant design-defining framework. The key objective of PLUSNet is to enable cooperative persistent detection, classification, localization, and tracking (cooperative DCLT) capabilities with significant onboard autonomous decision-making. The PLUSNet concept addresses a broad range of technologies (Scott, 2007) that include the platform design, power, persistent autonomy, communication, mobility, navigation, signal processing, acoustic wave propagation, network level tracking and response, environmentally adaptive sensing, and networked control. Despite the significant advances made in the development of ASW technologies (Scott, 2007; Martin, 2005), the most significant gaps still exist in the areas of responsive mobility and timely communication of acquired contacts; in short, it takes too long to communicate the positively identified signatures to either the cooperative vehicles and/or remote data processing centers to guarantee correct classification of potential threats. Low bandwidth and operational range of communication links and low mobility of the undersurface autonomous platforms within the existing onboard energy budgets are the key constraining factors of the current state of the art of ASW technology.

Motivation for a new approach: On the ocean surface, buoys and disposable floaters are frequently used, but are subject to ocean currents, providing mobility, but not (Steward & Pavlos, 2006) mobility in the desired direction. They typically provide limited sensing at or near the surface, and are usually limited to low-bandwidth satellite communications or data storage until they are retrieved. Underwater there are few solutions. For example, sea gliders (Martin, 2005) provide long endurance and at least some mobility beyond ocean currents. However they are limited to undersea and surface sensing, and are typically out of communications most of the time, again limited to low-bandwidth communications when they are on the surface. Wide area, long endurance coverage in the air over the ocean is also challenging. One ongoing study, Tactical Long Endurance Unmanned Aerial System (TaLEUAS) (Camacho, Dobrokhodov, & Jones, August 24-29, 2014) proposes to utilize a flock of networked airborne gliders that use a combination of natural, convective lift in the environment and photovoltaic cells coupled to high specific energy rechargeable batteries to provide 24/7 aerial coverage. While this concept is promising for aerial missions, intelligence, surveillance, and reconnaissance (ISR), communications-relay, etc., it is not of much use for sensing at the ocean surface, underwater, or ground sensing where severe proximity limitations exist, such as looking for mines buried in the beach. None of these schemes are able to cover all environments, air/sea/ground, and each includes constraints for communications, mobility, and/or survivability in harsh weather.

The Aqua-Quad (see conceptual picture in Figure 1), is a true hybrid platform (Jones & Dobrokhodov, 2014), capable of use in all these environments, with both air and surface mobility, 24/7 sensing, and high bandwidth communications. The multicopter-based AquaQuad uses a mix of floating and flight segments, and through the use of modern high efficiency solar cells and high specific-energy rechargeable Lithium batteries, the mission endurance for the vehicle can be extended indefinitely, flying when necessary, but floating and riding ocean currents most of the time while performing sensing tasks with minimal power consumption.

Findings and Conclusions

Envisioned concept of operation: There are many possible mission scenarios and sensory capabilities that would be of interest for both DoD and non-DoD applications. However, the present work focuses on the use of passive acoustic vector sensors, deployed to a depth below the thermal layer, used by a flock of AquaQuads to collaboratively detect and estimate the position and motion of underwater targets. In the envisioned concept of operation (see Figure 1), a “flock” of Aqua-Quads is outfitted with deployable, passive acoustic/magnetic sensors, and distributed in a grid over the sea surface to search for undersea objects of interest. The first vehicle that picks up a signal and collects a sufficiently rich sample might pop-up high enough to form a network with nearby Aqua-Quads to announce its detection and to enable cooperative target motion estimation (distance/bearing only, time difference of arrival (TDOA) etc.), or to relay the information to nearby manned or unmanned surface or airborne assets including the communication of data over a satellite link.

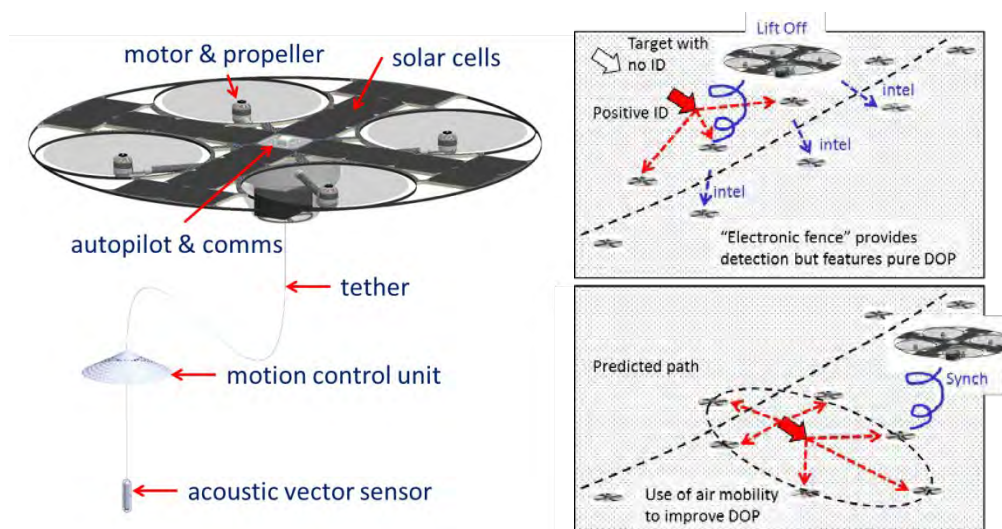


Figure 1. AquaQuad Vehicle (Left) and the Concept of Distributed Operation (Right)

Summary of the technical approach:

Due to the interdisciplinary nature of the project, the work includes a number of tasks from several adjacent engineering disciplines. For simplicity they are divided into hardware and software tasks focused on the surface and the underwater components of the AquaQuad; therefore giving us 4 distinct R&D directions to pursue. During the FY17 research the focus areas included optimization of the avionics, propulsion system, and airframe, development of design tools required to optimize the enclosure to provide up-right floating stability along with a self-righting capability, and the development of a data-acquisition system and embedded software for the proposed acoustic payload and the surface processing unit. The tasks of the tether design (that connects the surface and the submerged acoustic units with power and data) and the long distance command and control (C2) communication are the research directions of the following FY18 effort.

On the hardware design side, the team has explored various design options for onboard autopilots that rapidly evolve thus featuring more compact and higher performing hardware, software, and communication components. In particular, the project is looking at migrating from the Pixhawk autopilot to the new, much smaller Pixracer, which costs less, weighs less, and has increased compute

power, a higher precision and robustness inertial measurement unit (IMU), and a GPS unit capable of picking up four satellite constellations for improved precision and reliability. In the first prototype, one of the central frame plates was a printed circuit board (PCB) that included sensors for tracking power flow from solar to batteries and electronics. This plate has now been replaced with a much smaller PCB that includes a data-acquisition (DAQ) system along with power regulation for avionics and payloads, and the frame plate was replaced with a stronger, lighter Carbon fiber plate. The DAQ is an off-the shelf, very low size, weight, and power (SWAP) device that is based on ARM microcontroller that retails for about \$30. Components from the rapidly evolving drone-race market are being investigated as replacements for some of the propulsion system in particular, the electronic speed controls (ESCs). Newer options are smaller, lighter, and considerably more efficient.

Software of the surface processing unit includes a number of tasks such as signal identification, energy management, global and local path planning, local and long distance communication, and high-level decision making tasks to name a few. All of those tasks are parts of the soft-real time information flow process that is to be implemented within the client-server architecture conveniently provided by the robot operating system (ROS). While ROS is considered as a well-established framework for the implementation of distributed processes, it is also recognized as merely a prototype software environment which, if necessary, can be easily changed to a more specific solution; MOOSE, SPREAD (and many others) are similar candidates for implementation with their own pros and cons. However, ROS is well-supported by the robotics community and provides rich support of standard commercial off-the-shelf (COTS) components like wireless communication links, sensors, actuators, and communication protocols. The design of the onboard distributed client server architecture leverages our current research work entitled “MULTI-DAY ENDURANCE OF GROUP 2 UAS UTILIZING PACIFIC ENERGY RESOURCES” and funded by the Office of Assistant Secretary of Defense.

Path planning is one of the most computationally intensive tasks of the surface unit. The task is to find the energy-optimal trajectory for the AquaQuad in transition from one point to another within the given constraints of energy available onboard. The computational load required was evaluated in our previous work (Dillard, 2014) that relied on fundamental ideas of space sampling by the rapidly exploring random tree (RRT*) algorithm. Some operational deficiencies of the original RRT* were addressed by modifying its logic and designing the energy-relevant cost metric that allowed significant increase in speed of calculations. However, the central processing unit (CPU) load was verified to be the heaviest among the other envisioned tasks to be performed by the surface processing unit. To address the complexity of verifying the ‘closeness’ of a feasible path to the optimal solution given by RRT* modification in (Dillard, 2014), we address the problem of energy efficient path planning by utilizing a different class of methods – boundary value problem. The energy optimal path planning is now formulated as a two-point boundary value problem with the cost function reflecting the energy required for transition. The vehicle is modelled as a point mass dynamic system that has solar energy capture capability. The vehicle moves in a vector field that represents known ocean currents of the operational domain; if the currents are not known, a separate task evaluates them in a parallel process. The limit of the available energy is natively bounded by the energy capacity of the onboard batteries. The objective of the optimizer is to find the minimum energy path within the time-varying field of currents and possibly stationary obstacles. The task is first solved semi-analytically in MATLAB and then transitioned to the embedded Python process running in the ROS as an action-client/server task. The computational load of the solution was specifically addressed. While the first version of the task took nearly eight hours on a typical Core-i7 based desktop, the latest release running on the target CPU Odroid takes about one minute for the same

computation. This energy optimal path planning effort leverages our current research work entitled “MULTI-DAY ENDURANCE OF GROUP 2 UAS UTILIZING PACIFIC ENERGY RESOURCES” and funded by the Office of Assistant Secretary of Defense.

On the submerged acoustic sensing side, work has been performed in collaboration with researchers in the NPS Physics department and at Naval Undersea Warfare Center (NUWC), Division Keyport. The initial proposed payload is an acoustic vector sensor (VS-301 by Wilcoxon (Wilcoxon Sensing Technologies, n.d.)) which would notionally hang on a thin tether from the bottom of AquaQuad to sense at a suitable depth. The sensor produces a mix of high bandwidth analog (acoustic signal) and digital (attitude) outputs that need to go through a data acquisition phase, and then run through post-processing filters to attenuate noise, identify the signals of interest, perform coordinate transformation and beam forming, and reduce the data to a manageable quantity for transmission via tether to the surface level. The DAQ currently being investigated (Teensy 3.6 by PJRC, n.d.) is based on 32-bit 180 MHz ARM Cortex-M4 processor with floating point unit. It has sufficient compute power to enable concurrent analog to digital conversion (ADC) of multiple analog channels as well as data processing - all running in multithreading mode. DAQ weighs less than 5g and requires less than a 1 Wt under heavy CPU load.

Software development included the design of information flow architecture of the surface and the submerged acoustic units. The objective of the acoustic unit is to process data of the VS sensor in hard real-time; the unit is built around the VS-301 sensor and ARM-based microcontroller that reads its data. While the wide band acoustic data is sampled and processed in hard real-time, the resulting output will ultimately contain only low bandwidth ‘derivative’ information (beam direction in inertial coordinate frame) suitable for communication over long tether to the surface C2 platform. That is, all processing, currently including fast Fourier transform (FFT) processing discrete Fourier transform (DFFT) version), and beam-forming operations in the future, is done onboard the DAQ, in order to send only the data necessary for target motion tracking and operational decision making to the surface vehicle.

Software development for the DAQ component and the experimental evaluation have shown that the ARM microcontroller and the embedded software can reliably and accurately identify known signals comprised of multiple frequencies in the frequency range starting as low as 20Hz. Significant effort is in place to extend the range to the order of 1Hz frequencies. Concurrent sampling of analog data that is supported by the ARM Cortex board does not introduce any significant computational load. Spectral processing of acoustic data is implemented by highly optimized libraries at the CPU level; computational load due to the discrete FFT (DFFT) is the smallest among several other loads considered at the verification step. Detailed description in the following sections explicitly illustrates the sufficient performance of DFFT processing on ARM Cortex-M4 embedded platform in comparison with the DFFT algorithm running in MATLAB (The MathWorks, Inc., 2017) in computationally unrestricted Core-i7 Intel CPU.

In addition, a detailed control architecture is currently implemented which allows the surface vehicle to control the DAQ sampling protocol, altering sampling rates and other processing parameters depending on current operational tasks and signals of interest. The architecture implements a ‘language’ of communication between the surface control unit and the underwater DAQ capable to follow the high level commands. For example, the control structure currently allows for broadband acoustic monitoring, but if a target or other feature is identified in a specific frequency range, the DAQ may be commanded to

alter sampling rates and resolutions to allow high resolution data in a narrow band of interest. The software is written in low-level embedded C language running at CPU clock (180 MHz) with no operating system (OS) overhead. In turn, the surface C2 unit is based on a much higher level computational platform – Odroid C2 that supports most of the services of conventional desktop; and yet it is tiny and ultra-low-power. The software architecture here is based on the ROS operating system running in Ubuntu Linux; the software development relies on general purpose language Python and a plethora of relevant scientific packages for digital signal processing and communication. In particular, Python implements interfacing to the onboard autopilot, C2 communication (WaveRelay (Persistent Systems, n.d.) for local and Iridium for global reach), power, and the mission management subsystems.

Communication between the Odroid CPU at the surface and the submerged ARM-based unit relies on high-bandwidth serial communication, yet to be implemented as a tether solution. In addition the tether will be required to carry power to the submerged ARM-based unit. An exploration of various power and communication options was performed. The most promising solution is power over RS-485 bus. This protocol allows communications speeds up to 2 Mb/s with a 90m long tether, while minimizing weight through shared lines (power & signal). Fiber optic communications with power over fiber (PoF) is also a viable technology. The fiber optic technology will allow greater data transmission and less weight while consuming the same power as RS-485. This will be considered for future work.

Key accomplishments

Major Accomplishments to date include the following:

- Identified mathematical models of key subsystems of the AquaQuad in the major modes of operation:
 - flight dynamics of a multicopter with slung payload
 - flotation dynamics of AQ on the surface with stability margins of self-righting capability
 - energy harvesting and storage
 - major data processing models including the acoustic data sampling and spectral processing
- Built an experimental setup of the surface unit and the submerged DAQ system. Operational capabilities of separate components are verified in controlled experiments:
 - AquaQuad prototype has been tested in open waters of Monterey bay.
 - ARM-based DAQ and signal detection embedded software has been tested in the lab.
- System identification experiment has been performed to identify maximum capabilities of the ARM-based DAQ system and the potential bottlenecks of the envisioned architecture. Identified issues have been analyzed with the proposed solutions in the areas of custom tether design and the software modifications.
- Performed integration of major components for two separate proof of concept experiments:
 - read multiple harmonics signals and identify the single known signature of interest, and communicate reduced data response to the surface unit for further analysis and communication
 - outdoor flotation test of the AquaQuad surface unit with SWAP characteristics analogous to the envisioned design
- identified technology for the communication and power tether.

Recommendations for further research

The research results obtained to date serve two major purposes – they confirm the feasibility of implementation of chosen architecture, and they frame the scope of additional tasks within the architecture. The following is a highlight of specific ideas to be evaluated in the following research steps.

In particular, the results confirm the feasibility of implementation of a hybrid energy harvesting platform in the tasks typical for ASW missions. Both, the energy harvested onboard and utilized by the vehicle in drifting mode are sufficient to power the onboard distributed instrumentation and to enable short term flying mode that provides the “mobility on demand” feature of the AquaQuad. On the other hand, the processing performance of the ARM Cortex M-4 CPU and the ADC sampling resolution are more than sufficient to implement the acoustic sampling and the spectral processing of the multiple concurrent signals in hard real-time.

Additionally, the separation of all the computational loads between the surface and the underwater parts of the AquaQuad needs to be accurately balanced. An adequate implementation mechanism needs to be found to execute the multiple tasks (analog sampling, digital input and output (IO), coordinate transformation, communication of data, etc.) within the OS-less CPU. On one hand, OS-less architecture provides no OS overhead that tremendously improves computational performance. However, managing multiple tasks becomes a delicate task to handle.

While we already identified and prototyped in software a number of solutions to the above task of “balancing” computing load, we still need to complete a few tasks in the underwater segment; the acquisition of the attitude data from the digital IO channels, calculation of the beam forming solution, and the communication of processed data to the “surface.” Each of those tasks will introduce an additional load to the currently estimated CPU load. While there is no problem in accommodating more load in the current architecture, the problem is in designing the computational flow so that if necessary it can be easily transitioned to a more powerful CPU without significant modification; this in fact guarantees the scalability of the data processing. What we want to preserve is the ability of distributed DAQ to be interactive over long distances; short commands to readjust the acoustic sampling to the specific frequency range should not result in hanging the computational flow of the AquaQuad.

As per the software architecture of the surface segment, it is based on key advances of the ROS operating system. Flexibility of the ROS architecture allows adding software tasks (clients, servers, services) at any time. While some of the future tasks are not identified, we aim to integrating the core minimum of tasks sufficient with the key functionalities of the AquaQuad. To accomplish that, we need to integrate the power management and distribution (PMAD) service, the weather (currents and wind) estimation service, and the local and long-haul communication clients.

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NPS-17-N262-A: Development of Nontraditional Detection Algorithms for Undersea Warfare Cont..

Researcher(s): Dr. Timour Radko and Mr. John Joseph

Student Participation: LT Thomas Danner USN, LT Damon Sitgraves USN, and LCDR David Lorfeld USN

Project Summary

This report summarizes the results generated during the period of performance of the project NPS-FY17-N262-A, supported by the Office of the Chief of Naval Operations (OPNAV), DCNO for Warfare Systems, Director for Undersea Warfare (N97). The research activities are focused on the analysis of stratified wakes generated by propagating submersibles. The key objective of this project is how the identification of detection vulnerabilities will affect the tactics of undersea warfare by narrowing search areas for USW.

Keywords: *nontraditional detection; undersea warfare; battlespace environment; submarine search; detection and avoidance.*

Background

This study uses a combination of numerical simulations, analysis of field data, and laboratory experiments to identify measurable hydrodynamic signatures induced by a moving submersible in the ocean. We anticipate that the comprehensive analysis of the hydrodynamic wake signatures for various ambient conditions, as well as the speed, size, and motion pattern of a submersible itself, would offer valuable guidance for development of nontraditional detection systems, thereby enhancing operational Undersea Warfare (USW) capabilities. The project has involved six NPS Navy students. LT Danner has successfully completed his MS thesis entitled “*Thermal detection of wakes generated by submerged propagating objects in a stratified environment*” (Sep. 2017). LT Sitgraves has successfully completed his MS thesis entitled “*Laser based detection of thermally stratified wakes generated by towed submerged bodies*” (Sep. 2017). LT

Lorfeld has successfully completed his MS thesis entitled “*The effects of Earth’s rotation on the late submarine wake*” (Dec. 2017). LT Davis, LT Guerrero, and LT Danieleto are continuing our research into non-acoustic detection as their thesis projects. LT Davis is investigating the potential of thermal-based detection in high-latitude regions of the World Ocean. LT Guerrero is numerically modeling turbulent wakes generated by objects moving at non-uniform speed and exploring the detection vulnerabilities associated with the rapid acceleration of submersibles. LT Danieleto is performing laboratory experiments aimed to quantify effects associated with the radiation of internal waves generated by propagating objects in the stratified ocean.

Findings and Conclusions

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

LT Danner: A thermally based method for detecting submerged, propagating objects is critical for the U.S. Navy to continue to lead in the undersea environment. The viability of using a vertical array of temperature sensors was tested. Open-ocean experiments were conducted using a scaled towed body to mimic a self-propelled submerged body. Considerations were made for the impacts and potential bias from the tow ship on the thermal signature. Previous laboratory work and direct numerical simulations were used in this study to compare against field-work. Theoretical research and field-work yielded consistent and similar estimates of the thermal signal. This thesis concludes that detection of a submarine wake using thermal sensors is feasible and requires further investigation. Autonomous vehicles could be one of many platforms on which to conduct detections of adversary submarines around the world. Additional research activities are required to test different sensing equipment and deployment platforms and employ a full-scale experiment. Additional research should be conducted to improve our knowledge of the characteristics of the submarine wake (e.g., its duration, size, and the influence of ocean currents).

LT Sitgraves: As modern technologies progress to counter acoustic means of detection, non-acoustic alternatives must be developed to disrupt adversaries’ rise to parity. To this end, it is necessary to observe other signatures emitted into the water by propagating submerged bodies. It has been found that with the appropriate temperature stratification, the mixing action from a wake allows for non-acoustic detection. Considerable work has been done in this arena to exploit those thermal transients by way of conductivity temperature detector (CTD) and other temperature detectors. This thesis is the first of its kind to study those thermal perturbations by way of a laser-emitting diode. It has been observed that the shift in the index of refraction, due to temperature differences in a stratified water medium, produces a means by which a laser-emitting diode can be effective in wake detection. By calculating the deflection of the laser ray immediately following a wake-producing event, we have set out to establish a baseline from which to determine if a submerged body of interest is in the area. The calculation of the laser deflection produces a method by which classification of a particular propelled submerged body may be possible in terms of Froude and Reynolds numbers.

LT Lorfeld: Detection and tracking of submarines by acoustic means alone has become increasingly difficult due to quieter submarines, which underscores the need for non-acoustic detection methods. One hydrodynamic method available is through wake detection and the tracking of the resulting vortices created by the turbulence. Until now, it has been assumed that these vortices have large enough Rossby numbers such that the rotation of the earth can be ignored. This study examines the vortices that persist in the late submarine wake and explores the effects of rotation on the detectable characteristics of these wakes. We used numerical simulations to model the vortices in the late submarine wake with and without

rotation. Comparisons between these results have shown that the direction of rotation of vortices in the late submarine wake are affected by the rotation of the earth and that Coriolis force must be taken into account.

Publications: The key non-sensitive results obtained during current period of performance were combined, restructured into a cohesive, self-contained entities and reported in following publications:

Title: On the Structure and Dynamics of Stratified Wakes Generated by Submerged Propagating Objects.

Journal: *Journal of Operational Oceanography*, 2017, vol. 10, pp 191-204.

Authors: Zachary E. Moody, Christopher J. Merriam, Timour Radko, and John Joseph

Abstract: The structure and intensity of the intermediate wake generated by a submerged propagating body in a stratified fluid was studied using a combination of (i) numerical simulations, (ii) field measurements, and (iii) laboratory experiments. The numerical component offered guidance for the field work performed in Monterey Bay (CA, USA) in the summer of 2015. The field work focused on subsurface thermal signatures of a submerged propagating object. Vertical temperature profiles suggested that long-term changes in thermal stratification can occur after the passage of a towed body. Horizontal temperature variability, measured by an autonomous underwater vehicle facilitated the identification of the wake using perturbation temperature variance as the key diagnostic variable. Analogous thermal signatures of stratified wakes were found in ocean observations and in modelling results. The influence of the tow ship on the wake was shown to be minimal. Laboratory experiments focused on the surface expression of stratified wakes were used to complement numerical simulations and field measurements. All three components of this project indicate that detection of the wake of a submerged object based on its thermal signatures is a viable and effective approach.

Title: The fate of pancake vortices.

Journal: *Physics of Fluids*, 2017, vol. 29, 031701.

Authors: Georgi Sutyrin and Timour Radko.

Abstract: Nonlinear evolution of pancake-like vortices in a uniformly rotating and stratified fluid is studied using a 3D Boussinesq numerical model at large Rossby numbers. After the initial stage of viscous decay, the simulations reveal exponential growth of toroidal circulation cells (aka Taylor vortices) at the peripheral annulus with a negative Rayleigh discriminant. At the nonlinear stage, these thin cells redistribute the angular momentum and density differently at the levels of radial outflow and inflow. Resulting layering, with a vertical stacking of sharp variations in velocity and density, enhances small-scale mixing and energy decay. Characteristic detectable stretching patterns are produced in the density field. The circulation patterns, induced by centrifugal instability, tend to homogenize the angular momentum in the vicinity of the unstable region. We demonstrate that the peak intensity of the cells and the vortex energy decay are dramatically reduced by the earth's rotation due to conservation of total absolute angular momentum. The results have important implications for better understanding the fate of pancake vortices and physical mechanisms of energy transfer in stratified fluids.

Recommendations for Further Research

This project should be further developed using a combination of field measurements, a suite of high-resolution simulations, laboratory experiments and theory, which explore surface and subsurface wake signatures and their sensitivity to current environmental conditions. Field measurements could be performed using unmanned systems, including unmanned underwater vehicles (UUV) (REMUS) and unmanned aerial vehicle (UAV) (DJI drone), which are immediately available to our team. The

experiments in Monterey Bay offers several key logistical and physical advantages. The stratification is characterized by a shallow thermocline and the expected signatures are readily detectable using basic temperature sensors.

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NPS-17-N301-A: Applying Model-Based Systems Engineering (MBSE) and Architecting to Address Future Mine Countermeasures (MCM) Force Capabilities

Researcher(s): Dr. Eugene P. Paulo and Dr. Paul Beery

Student Participation: Deana Archambault CIV USN, Tina Baxter CIV USN, Jason Boxerman CIV USN, Christopher Harrington CIV USN, Lauren Hawkins CIV USN, Susan Johnson CIV USA, Benjamin Mitchell CIV USN, and Lisa Winsett CIV USN

Project Summary

As the Navy plans to retire legacy mine countermeasures (MCM) systems in the mid-2020s, it has become evident that the U.S. Navy has a need to evaluate its MCM posture for the 2040 timeframe and beyond. This report investigates the current and projected mine warfare (MIW) threat and associated enabling technologies to formulate the 2040 MCM scenario. Analysis of the 2040 scenario identifies several capability gaps that are utilized to formulate two overarching goals for future MCM systems: 1) reduce the MCM timeline and 2) improve the probability of mine detection. To resolve the capability gaps and attain the future MCM goals, a functional architecture is presented and five key technologies that enable significant improvements are examined. To determine how the U.S. Navy will attain the future functional architecture, time-dependent extrapolations of the five enabling technologies determine the expected performance and potential shortcomings that will need to be addressed in order for the systems to mature in stride with future needs.

Keywords: *mine warfare, mine countermeasures*

Background

Sea mines have historically posed a highly asymmetric threat to U.S. Navy operations due to their high level of variation and relatively low expense. For that reason, MIW capabilities have been an integral part of Navy operations. In addition to the historical mine threats, technologies are evolving allowing the types of threats to become more complex and harder to counter. MCM must progress as well.

The future scenario for the 2040 timeframe was developed by researching current types of mine threats including contact mines, influence mines and associated sensors, and maritime improvised explosive devices. To provide a baseline, the current MCM Concept of Operations (CONOPS), which utilizes Avenger class MCM ships and the MH-53E helicopters as platforms for operations, was reviewed. Technology enablers in the areas of command, control, communications, computers, and intelligence (C4I), sensors, weapons, and platforms, and vehicles were studied. To establish the 2040 scenario, the problem was bounded by considering the mining capabilities of adversaries, geographical considerations of mined areas, the type of mine threat, and the U.S. Navy MCM objective. The focus of this study is addressing an advanced mine threat in a narrow strait of water with water depths of forty to two hundred feet. The future scenario includes the concept of the autonomous loitering mine (ALM), envisioned to be capable of continuously moving, holding positions, burying itself, and coordination with other ALMs.

Current and anticipated future MCM capability gaps are described in this study. From the capability gaps, two overarching MCM objectives were established: 1) reduce the MCM Timeline and 2) improve Mine Detection. Five technology growth areas were selected based on the potential to close the gaps and meet the MCM objectives: 1) number of autonomous systems working in a team, 2) energy storage, 3) sensor range and resolution, 4) post-mission analysis (PMA) and automatic target recognition (ATR), and 5) acoustic communications (ACOMMS) bandwidth.

We then examined these gaps and their relationship to MCM objectives and the technology growth areas. For the 2040 timeframe, technology growth can be expected to build from prior success in bold and innovative ways, as captured by Figure 1. In this fashion, MCM operators can combat challenges such as advanced mines with variable ship counts and other MCM technologies. Furthermore, MCM vehicles could also be expected to facilitate operations in subsurface, contested environments. US intelligence and learning are expected to be on the rise during this time frame, spending significant periods of time on-station as a result of full in-sortie power replenishment. As fully autonomous vehicle swarms become a reality, operating new sensors at higher vehicle speeds, and with data analysis being performed on-station within the swarming vehicles, MCM technologies could potentially grow dramatically. With such significant advancements and opportunities in technology, it is anticipated that the acquisition process for MCM technologies will need to be evaluated and potentially altered during this timeframe.

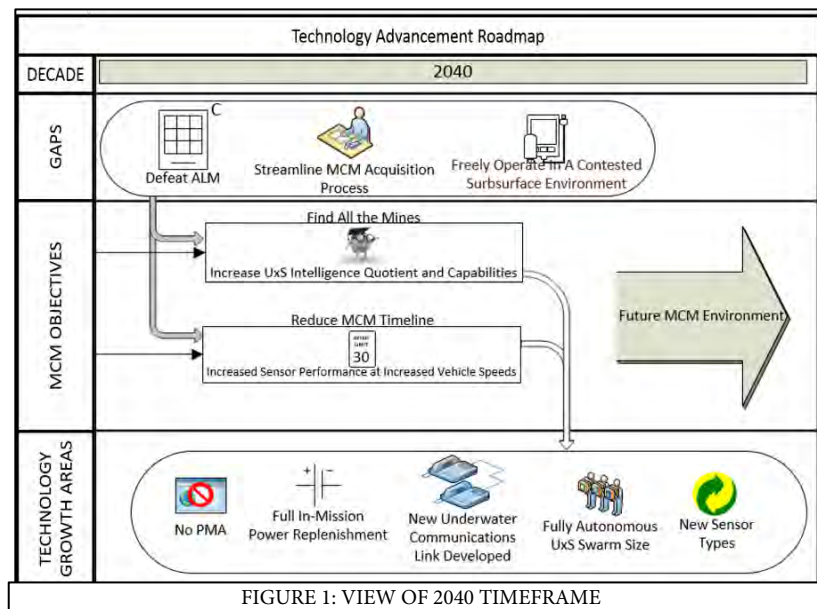


FIGURE 1: VIEW OF 2040 TIMEFRAME

Findings and Conclusions

First, we found that the number of autonomous systems working in a team is strongly correlated with the system autonomy, underwater communications, and localization accuracy. Advances must be made in these areas for swarm architectures to be capable of completing complex mission needs such as MCM. Additionally, energy storage to allow longer missions was determined to be a key consideration for enabling autonomous systems. One study utilized research on lithium-ion batteries to develop a linearly extrapolated trendline to the year 2040 shown in Figure 2. At year 2040, the value for lithium-ion energy density was estimated to be 510 Wh/kg. This increase in energy density will enable autonomous systems to have longer mission durations.

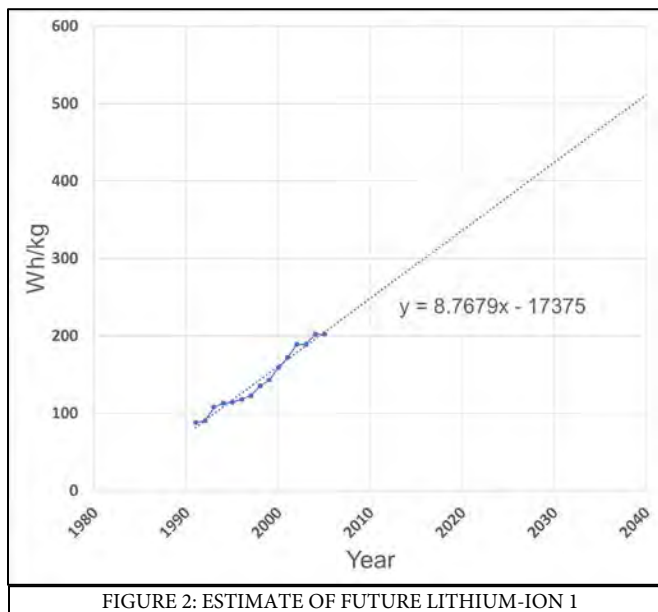


FIGURE 2: ESTIMATE OF FUTURE LITHIUM-ION 1

Recommendations for Further Research

Future studies should focus on the platform integration of a projected future technology sensor package, as well as its use and adaptation according to existing and developing tactics and procedures. In line with that mode of thinking, future studies should delve into how the technology advancements might impact and spark development in mine hunting and mine sweeping tactics and procedures. Future efforts could also investigate the threshold at which mine hunting and neutralization must mature in order to render mine sweeping obsolete. Or, conversely, advancing mine stealth technologies may also advance at such a rate that mine sweeping may be a permanent aspect of MCM operations. Other paths to pursue could also include the identification of specific technological advancement routes that are comparatively more singularly within the Navy's purview to explore, such as mine detection protocols and criteria, as well as those that may be bolstered, or even spear-headed, by industry or other consumer entities. To take another step down this path, future endeavors could evaluate how MCM technological areas and capabilities that fall under Navy funding could be expected to fare when studied against areas and capabilities funded jointly or more exclusively by industry. A wide array of potential topics can stem from the effort dedicated to this study, many with the goal and intent of safeguarding this nation from the silent, lingering threats of mines and mine warfare.

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NPS-17-N341-A: Using the Enterprise Engine (EE) for Building Integrated Fires (IF)

Researcher(s): Dr. Dan Boger and CAPT Scot Miller USN Ret.

Student Participation: Capt Scott Rosa USMC and LT Paul Kim USN

Research Summary

The Navy's Integrated Fires (IF) advanced operational capability imagines integrating data from several legacy stovepipes. The Enterprise Engine (EE) offers an integration approach which appears faster, cheaper, and smarter while enabling semantic interoperability.

Integrated Fires is designed to leverage combat, ISR, and C2 data in combination to improve target acquisition, precision, and persistent targeting. IF is similar in its objectives to the new Navy Integrated Fire Control-Counter Air (NIFC-CA) effort that combines sensors and systems across a network of platforms. While NIFC-CA focuses on air defense, think of IF as focusing on persistent targeting of maritime targets.

Because IF requires complex integration across legacy systems not initially required to work together, IF faces many integrating challenges. Further, to make sense of the proposed onslaught of diverse data requires semantic interoperability.

EE is a semantic integration framework designed and proven to easily, rapidly, and affordably integrate disparate systems, both new and legacy. EE has proved successful in supporting the Marine Corps Warfighting Lab's Marine-machine interdependence project called Unmanned Tactical Autonomous Control and Collaboration (UTACC).

How can such an innovative capability be used to help the Navy build IF, reduce risk, and accelerate new capabilities to the Fleet? Innovation is a process. This research proposed to determine the innovation steps necessary to use EE to support IF development across organizational boundaries, and make recommendations for accelerating IF.

Keywords: *Enterprise Engine, model driven development, NIF-CA, Integrated Fires, persistent targeting*

Background

We present evidence for a compelling transformation: one that promotes doing more, much more, with less. A transformation that starts with advanced modeling techniques, semantic interoperability (the ability of machines and people to understand meaning in context), and adherence to standards (or the development of them when needed) and moves forward from there.

A transformation that makes the users' inputs the fundamental building block of the system.

A transformation that creates the potential for a cyber-immune system that really works; that is dynamic and adaptable.

What is the secret behind this transformation? It is called the *Enterprise Engine*. As a note, the recent 20th anniversary addition of *Fast Company* delivers 20 predictions for the future. The first is: Speed will triumph. ...speed emerges as a business imperative...

In the DoD, connecting systems together is hard. Achieving interoperability, at any level is hard! And it costs money!!! Lots of money! Imagine heaven for a systems engineer, or a large defense systems integrator:

- First, connecting systems together would be as simple as connecting Legos. In fact so simple that operators could do it. And those connections would automatically produce the executable code!
- Second, the connections would occur at the semantic level; one system could exchange meaning with the next; meanings that humans also understand.
- Third, the approach would not only use standards but also promote their development and improvement

EE is all of the above. EE is a model driven development environment, a magnitude of order improvement over current model driven design approaches. EE ensures resultant integrated systems would be secure with a dynamic immune system, active and adaptive around the clock; it enables the integration of legacy systems, not just a clean sheet design; and that this process would be fast; very fast, measured in hours or days, not years. Finally, the end state of EE would include capabilities to directly engage the operators in capturing their needs in such a way that their inputs can become a part of the product. EE succeeds because it seeks to reduce complexity, discover and reuses patterns, and sticks with standards.

For IF to succeed, it needs such a rapid, adaptable, and repeatable set of processes that supports both new systems and legacy systems. Depending on the day and speaker, IF includes the integration of EW systems, ISR sensors, combat systems, and big data reasoning techniques. All represent very complex software codebases.

In the end game, it is very likely that EE offers a new and innovative approach to broad technical and semantic integrations. Since innovation is often defined as a change of practices, the technical maturity and capabilities of EE itself are just a starting point. Engaging the large acquisition and military industrial complex best to move to new practices emerges as likely the biggest challenge.

Findings and Conclusions

The Naval Postgraduate School (NPS) believes that the services and DoD are not taking advantage of recent major breakthroughs in Information Sciences and will not be able to turn around the trend of large software system failures of the last 20 years. These are explained in the following comments:

- 1) Interoperability does not get done because the major systems integrators are building stovepipes which results in major programs not being able to meet warfighter requirements

- a. For instance, an Army project management office estimated that their Leader-Follower program (partly unmanned supply convoys) would cost \$600M, not including the trucks or sensors. We believe with the right tool set that that integration should be executable at one tenth that cost.
 - b. Distributed common ground system (DCGS) developments across services, agencies, and the intelligence community (IC) are all well behind the original envisioned schedule and are rarely interoperable.
- 2) Most (all?!) of the challenges in system integration are now software engineering problems, but software engineering tools have not kept up with other engineering tools.

The Joint Striker Fighter (JSF) is a great example of the differences. The JSF prototype contract was awarded in November 1996. Using advanced aeronautical modeling tools, prototypes first flew Aug 00. The software driven support processes for JSF were not ready until 14 years later!!!

This is changing due to the advent of advanced modeling tools shepherded by the Object Management Group (OMG), an international standards organization for software development tools (which has been working on these tools for over 20 years).

We believe these tools are **necessary** (mandatory) to improve systems development, integration, and interoperability, but are not **sufficient**. These tools need to work in concert with each other. We are proposing an **Enterprise Engine** (EE) framework that enables these tools to work together. If you do not tie these tools together, the chances of failure will not be reduced. A case in point is the Navy's Single Integrated Air Picture of the 00's. It used model based systems engineering with an attempt to automate code, but failed at a cost >\$1B.

We envision six tools: formal modeling, parametric modeling, auto code generation, ontological modeling, rapid integration and platform provisioning, and security development/continuous cyber monitoring.

To achieve success using EE, at first a hand-picked team is required to train the next generation of engineers, developers, ontologists, and security experts. One can't just give these tools and framework to developers and expect them to be successful, since the result might be "power tools for orangutans."

- 3) We've tried an EE based approach on four proofs of concept, all successful. These were parametric modeling in support of Joint Close Air Support (JCAS) activity for the National Air and Space Intelligence Center (NASIC); computer vision, sensor, and alert integrating the National Geospatial-Intelligence Agency (NGA); automated nautical chart update and review process for NGA; and integration of combat system, robots, and Marines for digital fires for the USMC Warfighting Lab (subject of 60 Minutes report). Each was completed in less than three months.
- 4) \$25M has already been invested; the results show that EE works. Best EE practices, and their extensions, generate a two order of magnitude improvement in both time to develop and associated costs in developing complex integrated systems.
- 5) Based on this research and the above experiences with proofs of concepts, we recommend any service desiring to improve their acquisition process to adopt EE. They should start by doing the following:
 - Conduct a follow-on meeting that introduces EE to your top engineers

- Develop a proof of concept where the NPS team and the service team work together. This will again prove the concepts, but yield little in the way of a reusable EE framework and model patterns. What it does do, however, is show competent engineers how much more successful they can be using this EE framework. This will build momentum and enthusiasm for the follow-on longer enduring tasks.
- Start an EE user's group.
- Once the service is familiar with the EE concept and understands the opportunities and risks, then develop the reusable EE framework and development tools. This also enables the start of massive scale reuse, applicable to many programs.
- In the next step the EE framework and development tools are ruggedized, training processes are formalized, and EE user and development certification.
- Tools exist but are cutting edge so the service needs their world-class software engineers who are willing to learn EE. They will be the apostles. NPS succeeded with the proofs of concept because of the quality of the people brought to the effort.

Recommendations for Further Research

None provided.

NPS-17-N343-A: Building Information Assurance (IA)/Risk Management Framework (RMF) into the Enterprise Engine (EE)

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Student Participation: Capt Scott Rosa USMC and LT Paul Kim USN

Research Summary

The Enterprise Engine (EE) offers an integration approach which appears faster, cheaper, and smarter while enabling semantic interoperability. It needs to improve its abilities to accommodate the DoD risk management framework (RMF) and information assurance (IA) directives.

The RMF is an emerging standard practice in industry and DoD which establishes risks to programs, their source, probability of occurrence, and severity. IA is a long standing set of development requirements often addressed poorly within a system's development cycle.

The Model Oriented Development Environment (MODE) is a model driven development environment designed and proven to easily, rapidly, and affordably integrate disparate systems, both new and legacy. MODE proved successful in supporting a very complex NGA nautical chart updating process and was also used with the Marine Corps Warfighting Lab's UTACC project.

EE has not built in risk management capabilities or addressed IA requirements, though a design has been completed. Because of EE's model driven design approach and flexible development environment, it is hypothesized that EE could address RMF and IA in a very innovative fashion, reducing time and costs while improving the quality of risk mitigations. Further, it is presumed that EE could do so continuously thus better adjusting and adapting to emerging threats.

Background

We present evidence for a compelling transformation: one that promotes doing more, much more, with less. A transformation that starts with advanced modeling techniques, semantic interoperability (the ability of machines and people to understand meaning in context), and adherence to standards (or the development of them when needed) and moves forward from there. A transformation that makes the users' inputs the fundamental building block of the system. A transformation that creates the potential for a cyber-resilient system that really works; that is dynamic and adaptable.

What is the secret behind this transformation? It is called the MODE. As a note, the recent 20th anniversary addition of Fast Company delivers 20 predictions for the future. The first is: Speed will triumph. ...speed emerges as a business imperative...

In the DoD, connecting systems together is hard. Achieving interoperability, at any level is hard! And it costs money!!! Lots of money! Imagine heaven for a systems engineer, or a large defense systems integrator:

- [1] First, connecting systems together would be as simple as connecting Legos. In fact so simple that operators could do it. And those connections would automatically produce the executable code!
- [2] Second, the connections would occur at the semantic level; one system could exchange meaning with the next; meanings that humans also understand.
- [3] Third, the approach would not only use standards but also promote their development and improvement

MODE is all of the above. MODE is a model driven development environment, a magnitude of order improvement over current model driven design approaches. EE ensures resultant integrated systems would be secure with a dynamic resilient system, active and adaptive around the clock; it enables the integration of legacy systems, not just a clean sheet design; and that this process would be fast; very fast, measured in hours or days, not years. Finally, the end state of MODE would include capabilities to directly engage the operators in capturing their needs in such a way that their inputs can become a part of the product. MODE succeeds because it seeks to reduce complexity, discover and reuses patterns, and sticks with standards.

Findings and Conclusions

Information Assurance (IA) is the short term that reflects the DoD's efforts to ensure information is protected, defended, corrected, identifiable, etc., as it is used in the DoD. The current DoD program guiding the achievement of IA is called the Risk Management Framework (RMF). It is a follow on to the Department of Defense Information Technology Security Certification and Accreditation Process (DITSCAP), Department of Defense Information Assurance Certification Process (DIACAP), and several other DoD processes dating back to 1985.

RMF is designed to satisfy three information fundamentals (CIA):

- Confidentiality - keep info only to those who need it.
- Integrity - ensure the information is what it intended to be.
- Availability - Given the first two requirements, still make sure that the information is freely available to all those who should need it, and no more.

IA applies not to just information processing technologies and applications, but to all the ancillary equipment and services related to information processing, such as computers, clouds, networks, communications, log ins, etc.. Unfortunately, these devices have issues. When Vint Cerf (one of the inventors of the internet) was asked what he would have done differently, he replied, “Well, they didn’t tell me they wanted it to be secure. I would have done things much differently!” So this is to say that IA and ensuring CIA is even harder because it uses naturally insecure networks to start with.

The 1985 developers of the DoD IA policy already understood and anticipated the future risks the internet would deliver, so they drafted prescient policy – which no one else understood or followed. Thus it has always been! Now owners of IA related applications and equipment know far too well the emerging challenges, as is well documented in relevant papers. Culturally, achieving IA remains hard.

There are two huge reasons and the focus of our research:

First, in the past engineers only “added” IA in after the “real” software engineering was completed. IA was treated as a new and “late” requirement. Systems engineers, as well as dozens of studies, show that this creates poorly engineered IA preventive fixes while adding significant costs. Motivation for program managers to gloss over poorly understood threats was high, since these people are motivated to deliver on time with minimal costs. Building in IA does not appear to add value to a program (until it gets hacked). As an aside, there is a new metric emerging called technical debt that measures the longer term cost of building poor code. This might help get the program managers attention, because besides cost, schedule, and performance, they are also required to consider the total ownership costs for the service.

The second reason is that the cyber environment is dynamic. Programs engineering against known threats will not succeed against newly emerging threats. Continuous monitoring and systems updates are required. This is expensive.

RMF aims to fix these two challenges by requiring IA to be a part of the overall upfront engineering effort and by insisting on continuous monitoring. RMF has six broad steps and a total of approximately 31 supporting tasks. It is thorough, and it is designed to generate an understanding of the various risks that the services face when operating with any information-related devices.

However, as much detail as RMF seeks to provide, RMF offers no real answers on how to engineer in IA upfront or on how to continuously monitor IA performance. Our research seeks to apply emerging systems engineering (SE) capabilities, heretofore known as the Enterprise Engine (EE), to these IA challenges. The goal is to make the RMF process faster, yet more effective, especially in addressing the upfront engineering and the requirement for continuous monitoring.

So what is EE? It is a combination of SE tools, techniques, and processes designed to make software engineering development faster, cheaper, and yet more effective. EE also includes, as byproducts of these tools, other capabilities that we believe are applicable to RMF.

EE consist of six components:

- Formal modeling
- Parametric simulations and analysis
- Semantic enrichment
- Automatic software code generation
- Rapid integration and platform provisioning (RIPP)
- Security services (SS)

An analogy using mechanical engineering explains the intent of EE. In the “old” days, mechanical engineers were given requirements from their sponsors. They would design paper models, develop specifications on drafting paper, and then review these with the machinists who would then actually build the parts. Often, failure was only realized when the new part failed spectacularly as part of a bigger machine, causing death, destruction, injury, and wasting lots of money.

By the 1980s mechanical engineering built their models using computers. That model of the part was tried in a virtual environment or virtual wind tunnel. Failure again occurred. Now the engineers could tell why, and improve their designs, with no death and destruction. Further, that part, once validated by virtual testing, was passed to the machine floor as a digital file. It was entered into a robot, which built the part with reduced tolerances, meaning the part worked better and lasted longer. The result was that machines worked better and took less time and money to construct.

Consider that serving as a test pilot in the 1940s was almost a death warrant. Today it is a far safer job than just driving your car down the street. The engineers not only knew it would work, but how well. While this example uses mechanical engineering, the same approach is now used across the engineering disciplines, except in one area, software engineering. The tools exist, but acceptance has been slow. EE is designed to change that and bring the software engineers into the 21st century.

Recall the six components of EE. The formal models equate to the computer-aided design and manufacturing (CAD/CAM) part design paradigm. The parametric modeling and analysis provides the simulated test environments. The semantic enrichment components is an addition, since software developers often need to make their application work with other applications. The auto code generation is equivalent to the digital parts model being passed to the machine floor and produced by the robots. RIPP is the same as the broader assembly line that produces the overall platform or machine. The SS are the extra tools in EE that ensure that software code equality is best, as well as other functions.

In addition, EE provides a feature called MOF-to-text, where meta-object framework (MOF) is just the acronym for the foundation of the EE toolsets. What is exciting about MOF-to-text is that given the right questions and formats in the formal model construction within EE, EE can create many human readable documents required for DoD processes, such as RMF. Also, in EE’s SS, there is module called the Code Assessment Web Portal (CAWP) that houses many code checkers applicable to most common programming languages. This is crucial, since software code quality has been proven to be directly associated with software security. SS also includes a module that maps specific software quality issues to the common rules, guidance, and directives to the software developer so he or she knows what to fix and why. This also provides better documentation for the services’ risk analysts and decision makers.

Finally, while not yet available in the EE SS, EE anticipates being able to run code checking on software continuously. This would help program managers, network operators, and hardware owners to more easily satisfy the RMF continuous monitoring policies.

Once the applicable EE capabilities were understood, the researchers analyzed all of the RMF tasks for the applicability of EE to those specific tasks. The results are summarized below:

- Tasks that were straightforward and could easily be done by humans, where EE does not add appreciable value.
- Tasks that would benefit from the use of formal models for such purposes as virtual testing or MOF-to-text document production.
- Tasks that would benefit immediately from using the EE SS CAWP.

- Tasks that would benefit from EE's future continuous monitoring capabilities.

In conclusion, it appears that the use of the CAWP would benefit many tasks. Further, we believe the capability of CAWP to support continuous monitoring should be accelerated. Convincing programs to use formal models will take more time, but the benefits are impressive. A formal model of an application or network can be rigorously tested in already existing virtual cyber environments. The MOF-to-text feature allows most documents to be automatically generated. Moreover, there are many other acquisition-related benefits of formal models that can be seen in our sister research, EE for DoD Acquisition.

Recommendations for Further Research

Questions remain about applying EE to the RMF. How much work is really needed to make MOF-to-text work? How much money does a program office spend on documentation? Are there other hidden gems within EE that could benefit the RMF process? How does the technical debt metric actually work, and how can we use it to demonstrate EE's value?

NPS-17-N368-A: Generation of Real-Time Optimal Carrier Landing Trajectories

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Student Participation: LT Aaron Stafford USN

Project Summary

Using simplified ship motion models, helicopter/pilot control models, pilot workload rating and ship airwake models, the purpose of this study is to illustrate that an easy to use MATLAB based tool for rapid computation of Launch and Recovery Envelopes (LREs) can be developed. This tool is intended for use primarily by control development and handling qualities engineers in early stages of helicopter control system development.

The present report summarizes the models used in this study and discusses how these models were employed to develop a tool for rapid computation of LREs. Section 1 includes the nomenclature used in the report. Section 2 introduces the ship motion model. Section 3 discussed the ship airwake turbulence model. Section 4 outlines the pilot model use in the report, and Section 5 presents results obtained by integrating all the models into a tool for rapid computation of LREs. The report ends with Conclusions.

Keywords: *automated landing, optimal control, landing simulations, ship motion prediction*

Background

Today U.S. Navy invests millions of dollars into generating Launch and Recovery Envelopes (LREs): the range of allowable wind over deck (WOD) magnitude and direction for safe helicopter landing aboard a Navy ship. The process for computing LREs requires lengthy at sea testing, and it usually cannot be completed in a single series of tests due to weather constraints and/or ship and helicopter availability [3]. Therefore, quite often LREs issued to the fleet for a particular ship/helicopter configuration are conservative (generic) and result in a reduced operational flexibility of many Navy ships. Examples of existing LREs for V-22 Osprey and H-53 helicopter are shown in Figure 1.

Ship Class	H-53	V-22
CG 47	Not Certified	Not Certified
CVN 68	Minimal Expansion	Spot 6,9 Expanded
CVN 78	No DI Planned	FY 16
DDG 51	Not Certified	Not Certified
DDG 79	Not Certified	Not Certified
FFG 7	Not Certified	Not Certified
LCC 19	H-53D ONLY Generic	Not Certified
LCS 1	Not Certified	Not Certified
LCS 2	Not Certified	Not Certified
LHD 1/LHA 6	Spots 1,2,3,4,8 Minimal Expansion Spots 5,6,7,9 Expanded	Spots 1,3,8 Generic Spots 2,4,5,6,7,9 Expanded
LPD 17	Minimal Expansion	Spots 1,2 Minimal Expansion Spots 3,4,5,6 Generic
LSD 41/49	Expanded	Generic
T-AH 19	Not Certified	Not Certified
T-AK 3005	Generic	Not Certified
T-AK 3008	Generic	Not Certified
T-AK 3015	Generic	Not Certified
T-AK 3016	Generic	Not Certified
T-AK 3017	Generic	Not Certified
T-AKE 1	Generic	Minimal Expansion
T-AKR 300	Generic	Not Certified
T-AKR 312	Generic	Not Certified
T-AO 187	Expanded	Not Certified
T-AOE 6	Generic	Not Certified
T-AVB 3	Generic	Not Certified
T-EPF 1 (JHSV)	Minimal Expansion	Not Certified
T-ESB 3 (MLP AFSB)	FY16	No DI Planned

FIGURE 1: EXISTING LRES [5]

To provide the fleet with a more cost-effective method for computing LREs, the Office of Naval Research funded the Dynamic Interface Virtual Environment (DIVE) program. The objective of DIVE is to "deliver state-of-the-art high-fidelity modeling and simulation (M&S) toolset and a complementary flight/flight simulator testing process to provide timely, reduced cost, and fully expanded ship-helicopter launch and recovery envelopes" [5].

When successfully completed, in addition to its main objective of generating the operational LREs, DIVE will have access to a wide variety of ship airwake, helicopter dynamic, as well as ship motion models for a range of sea states. We believe that one can leverage these models to produce an extremely effective tool for generating preliminary versions of LREs suitable for use by operators, mission planners and control development and handling qualities engineers. To date, however, DIVE models have not been available to us. Instead we have been forced to rely on open literature to obtain all the necessary models required for computing the LREs.

Findings and Conclusions

1 -Nomenclature

L	- ship length at waterline (m)
B_0	- ship maximum waterline breadth (m)
T	- ship mean draught (m)
C_b	- ship block coefficient
GM_T	- ship transverse metacentric height (m)
T_N	- ship roll constant (sec)
θ_s	- ship pitch (rad)
h_s	- ship heave motion (m)
ϕ_s	- ship roll (rad)
h_p	- heap motion of ship's landing pad (m)
y_p	- lateral motion of ship's landing pad (m)
δ_c	- collective input , centimeters of equivalent cockpit controller motion measured at pilot's hand (cm)
δ_a	- lateral cyclic input , centimeters of equivalent cockpit controller motion measured at pilot's hand (cm)
δ_b	- longitudinal cyclic input , centimeters of equivalent cockpit controller motion measured at pilot's hand (cm)
δ_p	- pedal input , centimeters of equivalent cockpit controller motion measured at pilot's hand (cm)
ω_n	- zero mean, unit variance white noise
σ_w	- ship airwake turbulence intensity
σ_{w0}	- nominal ship airwake turbulence intensity
ψ_w	- wind over deck direction (rad)
u, v, w	- components of helicopter inertial velocity vector (m/sec)
p, q, r	- components of helicopter angular inertial velocity vector (rad/sec)
p_x, p_y, p_z	- components of helicopter inertial position vector (m)
τ	- pilot response time constant (sec)

2 - Ship Model

We have used the model of a TMV-114 fast ferry to represent a ship in this study [10]. The ferry is by no means a Navy vessel, and the landing pad shown in Figure 2 is purely fictional, but its dynamic characteristics shown in Table 1 are similar to that of a typical naval destroyer and are available in the open literature. The ship's center of gravity is approximately 3.3m above the water line, and the cruise speed of 25 kts was used in this report.

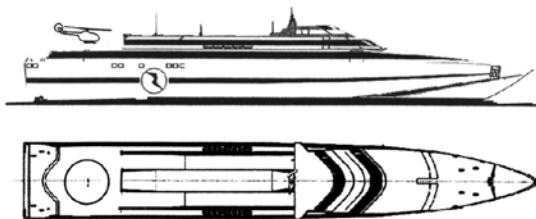


FIGURE 2: A FAST FERRY TMV 114

L	96m
B_0	13.8m
T	2.5m
C_b	2.5m
GM_T	4.9m
T_N	6.3sec

TABLE 1: TMV 114 PARAMETERS

Using the model of TMV 114 developed in [10] the authors of [4] have obtained expressions for the ship's and landing pad's motion in Sea State 5 shown in Tables 2, 3.

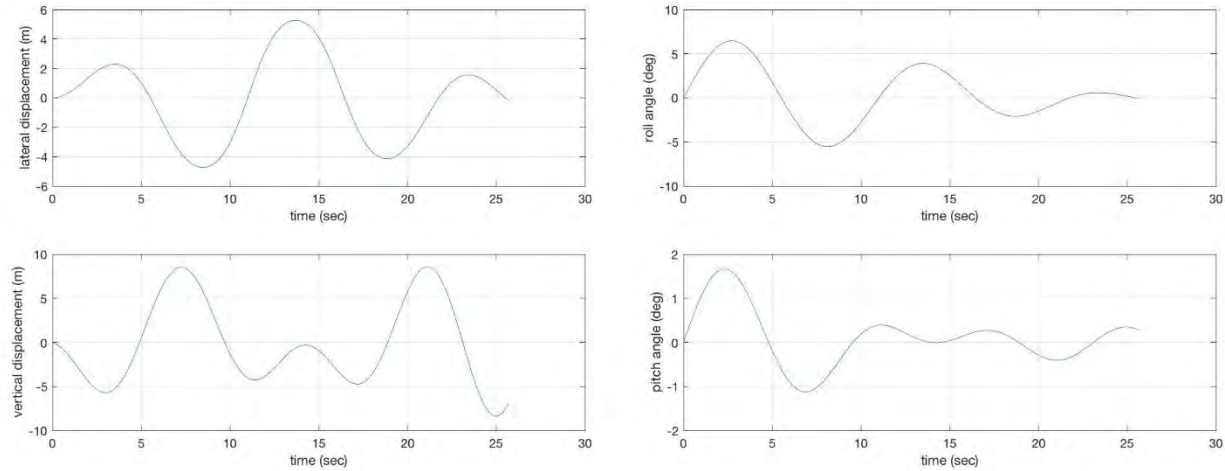
$h_s(t) = 0.2172\sin(0.4t) + 0.4714\sin(0.5t) + 0.3592\sin(0.6t)(m) + 0.227\sin(0.7t) (m)$
$\theta_s(t) = 0.005\sin(0.4t) + 0.00964\sin(0.58t) + 0.3593\sin(0.6t) + 0.227\sin(0.7t) (rad)$
$\phi_s(t) = 0.021\sin(0.46t) + 0.0431\sin(0.54t) + 0.29\sin(0.62t) + 0.0022\sin(0.67t) (m)$

TABLE 2: TMV 114 MOTION IN SEA STATE 5 [4]

Plots of the variables included in Tables 2 and 3 are shown in Figures 3a, 3b

$h_p(t) = 57.11\sin(\theta_s(t)) + 13.2(\sin(0.5\phi_s(t)))^2 + h_s(t) (m)$
$y_p(t) = 6.6\sin(\phi_s(t)) (m)$

TABLE 3: TMV 114 LANDING PAD VERTICAL AND LATERAL MOTION IN SEA STATE 5 [4]



A. LANDING PLATFORM MOTION

(B) SHIP ANGLES

FIGURE 3: SHIP AND PLATFORM MOTION

3 - Turbulence Modeling

In this study we use the turbulence model proposed in [4] with a small modification. In [4] the author argues that adding outputs of a set of transfer functions driven by white noise of unit covariance to the pilot command provides an accurate description of the turbulence effects on the pilot performance during landing. The transfer functions are parametrized by the helicopter rotor diameter, turbulence intensity and wind speed and their outputs contribute to the helicopter/pilot system architecture developed in this study as illustrated in Figure 5. An example of a transfer function used to model turbulence in the lateral cyclic channel [4] is given in Equation (1).

$$\frac{\delta_a}{\omega_n} = \frac{0.17\sigma_w^{0.3735}V_r^{0.5}(s + 0.048V_r)}{s^2 + 0.324V_r s + 0.0195V_r^2} \quad (1)$$

Note that the turbulence intensity w in Equation (1) does not depend on the direction of the wind over deck (WOD). In [6] using computational fluid dynamics (CFD) analysis, the author shows that this in fact is not the case. Indeed, the turbulence intensity changes as a function of WOD direction for the same WOD magnitude. Therefore in this study we have modified w to include dependence of turbulence intensity on the direction of the WOD:

$$\sigma_w = \sigma_{w0}(1 + |\sin(\psi_w)|).$$

Figure 4 includes sample plots of the “turbulence equivalent control outputs” in all four control channels.

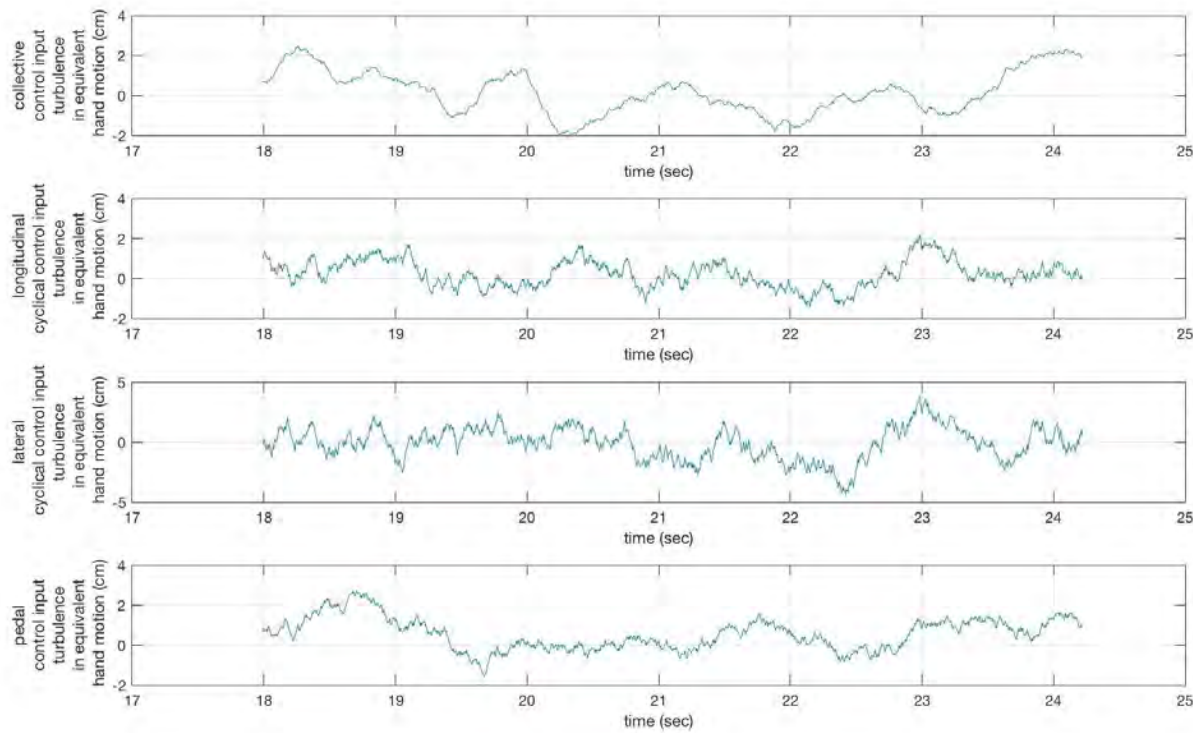


FIGURE 4: TURBULENCE EQUIVALENT CONTROL OUTPUTS DURING FINAL LANDING PHASE

5 - Helicopter/Pilot Model

The complete architecture of the integrated helicopter/pilot model is shown in Figure 5. The helicopter model selected was that of a BO-105 in hover [9]. The sketch of BO-105 helicopter is included in Figure 6. The model includes 12 states x and 4 control inputs u , where

$$\begin{aligned} x &= [u \ v \ w \ p \ q \ r \ \phi \ \theta \ \psi \ p_x \ p_y \ p_z]' \\ u &= [\delta_c \ \delta_b \ \delta_a \ \delta_p]' \end{aligned}$$

Motivated by the discussion in [4], we developed an optimal control model (OCM) of the pilot by employing an integral linear quadratic regulator (ILQR) technique [1] that allows the designer to tune the cost function to achieve desired bandwidth in both command and control loops. This allowed us to guarantee that the bandwidth of each control loop matched the ones suggested by another popular pilot model - crossover model [4, 7].

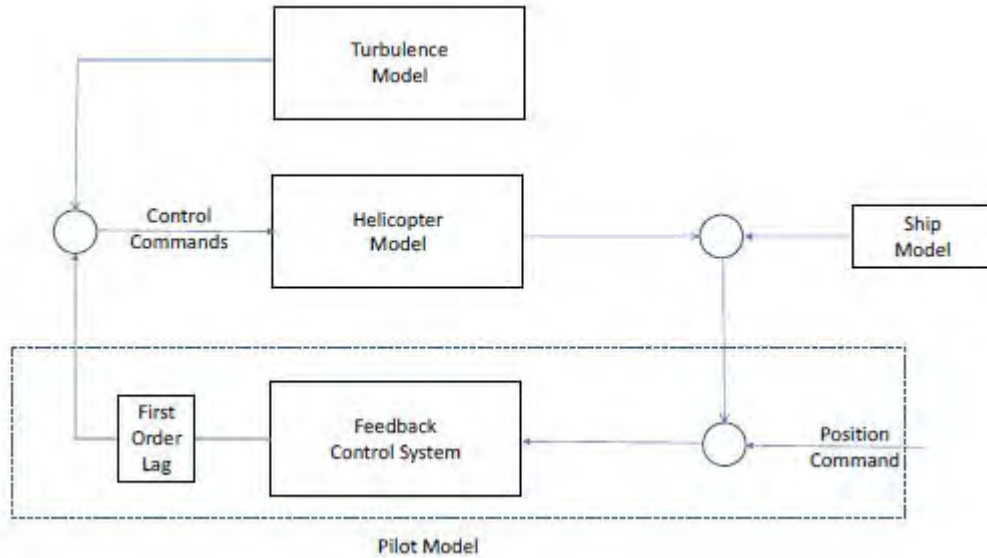


FIGURE 5: HELICOPTER/PILOT SYSTEM ARCHITECTURE

As suggested in [7] we have tuned the ILQR cost function to have a 10 rad/sec bandwidth in each control loop. Figures 7a and 7b include examples of Bode magnitude response in lateral cyclic and rudder control loops. Clearly, the bandwidth in each loop is around 10rad/sec. In addition, the output of the ILQR controller was passed through a first order lag (see Figure 5) of the form $\frac{1}{\tau s+1}$, where the time constant τ represents the skill level of the pilot (τ varies from 0.1 to 0.6, with a smaller value corresponding to a more experienced pilot) [2].

In a typical landing scenario, the helicopter is initialized a 100m from the touch down point on 3 degree glideslope. Prior to touch down the helicopter reaches a point 3m directly above the touch down point and then reduces vertical separation from the deck until touch down. This landing technique was motivated by the discussions the authors held with naval helicopter pilots currently studying at NPS. The plots in this section were generated using an experienced pilot model with $\tau = 0.1$. Figure 8 includes plots of the helicopter horizontal and vertical position with respect to the landing pad in calm seas. On the other hand, Figure 9 show the landing is done in Sea State 5 using the ship motion described in Section 3. Figure 10 includes the plots of equivalent pilot arm and leg motion in each control channel. The coefficients used here for converting the standard control commands into equivalent pilot motion were obtained from [4]. This data is used to compute pilot workload is discussed next.

Reference [8] suggests the following formula for computing pilot workload rating

$$WR = c_1 + c_2s(\delta_a) + c_3s(\dot{\delta}_a) + c_4s(\delta_b) + c_5s(\dot{\delta}_b) + c_6s(\delta_p) + c_7s(\dot{\delta}_p), \quad (2)$$

where $s(\cdot)$ represents standard deviation of a particular pilot equivalent control input or of its derivative with respect to time during the last phase of the landing. Using the expression (2) workload rating for the pilot control activity shown in Figure 10 is 5.53.

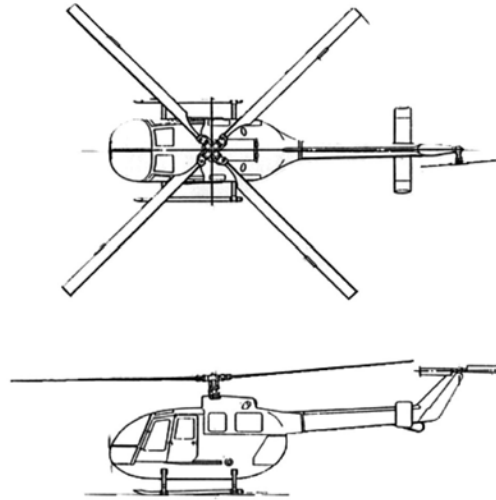
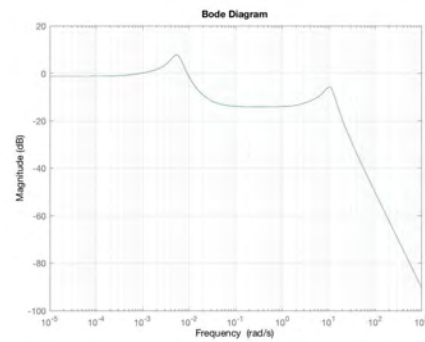
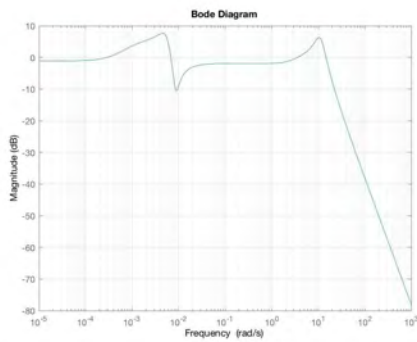


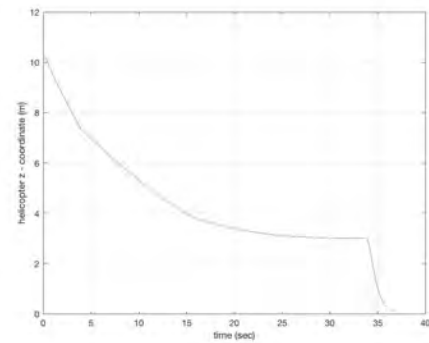
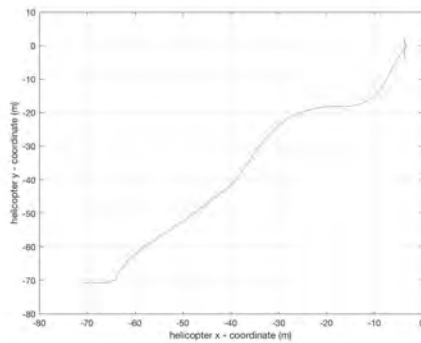
FIGURE 6: BO-105 ROTOCRAFT



- BODE PLOT OF THE LATERAL CYCLIC CONTROL LOOP (B) BODE PLOT OF THE RUDDER CONTROL LOOP

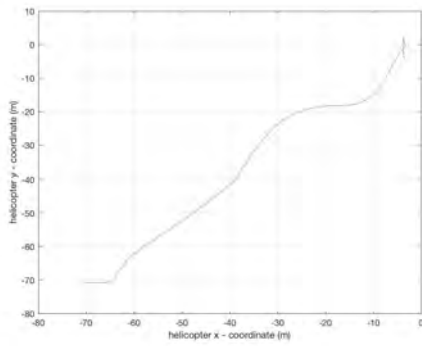
FIGURE 7: BODE MAGNITUDE PLOTS IN LATERAL CYCLICAL AND RUDDER CONTROL LOOPS

According to [8] this value exceeds a threshold of 5 - considered maximum acceptable pilot workload.

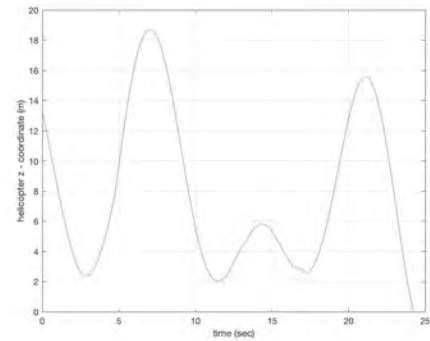


- HORIZONTAL MOTION (B) VERTICAL MOTION

FIGURE 8: HELICOPTER MOTION WITH RESPECT TO LANDING PLATFORM IN CALM SEAS IN THE PRESENCE OF WIND



(A) HORIZONTAL MOTION



(B) VERTICAL MOTION SEA STATE 5

FIGURE 9: HELICOPTER MOTION WITH RESPECT TO LANDING PLATFORM IN SEA STATE 5 IN THE PRESENCE OF WIND

c_1	2.1238
c_2	0.624
c_3	7.2237
c_4	-0.7879
c_5	0.8214
c_6	-0.47042
c_7	8.8116

TABLE 4: REGRESSION COEFFICIENTS IN WORKLOAD PREDICTOR [8]

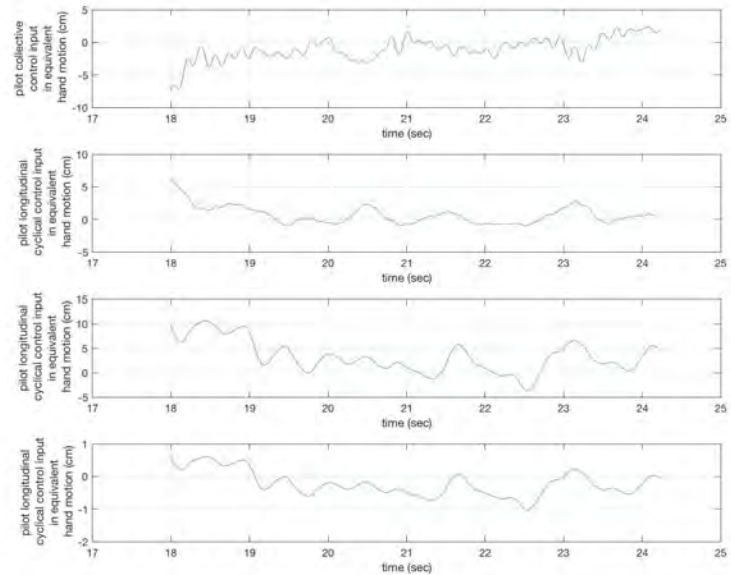


FIGURE 10: PILOT EQUIVALENT CONTROL INPUTS DURING THE FINAL LANDING PHASE

6 - Computation of Launch and Recovery Envelopes

A detailed procedure of how Launch and Recovery Envelopes (LREs) are computed by U.S. Navy can be found in [3]. In the fleet the pilot workload rating is generated by analyzing evaluations of the landing by both helicopter and ship crews. In this study we attempt to model this approach by using the pilot control and workload models described above. Figure 11 includes an LRE for the TMV-114/BO-105 ship/helicopter combination for landings performed by an expert pilot ($\tau=0.1$, see Section 5). The maximum acceptable workload rating was set to 5.0. The basic shape of the LRE makes sense: the range of WOD directions exceed 180 degrees for wind speeds

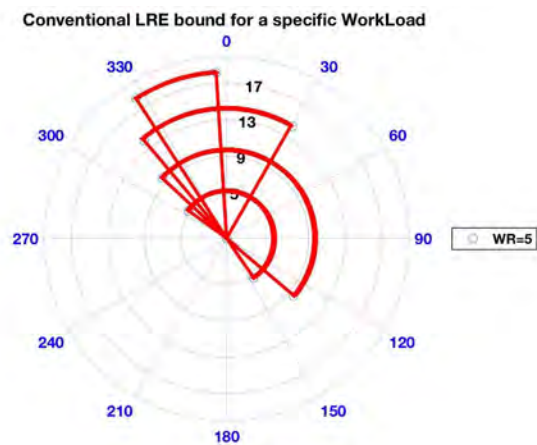


FIGURE 11: LRE FOR TMV-114/BO-105 SHIP/HELICOPTER COMBINATION PERFORMED BY AN EXPERT PILOT

up to 10 knots and then decreases as the wind speed increases. The general shape of the LRE shown in Figure 11 is similar to the one in Figure 12 [3]. A more detailed comparison is of course impossible since in fact the ship/helicopter combination in Figure 12 is unknown. Clearly, a more apple to apple comparison is warranted.

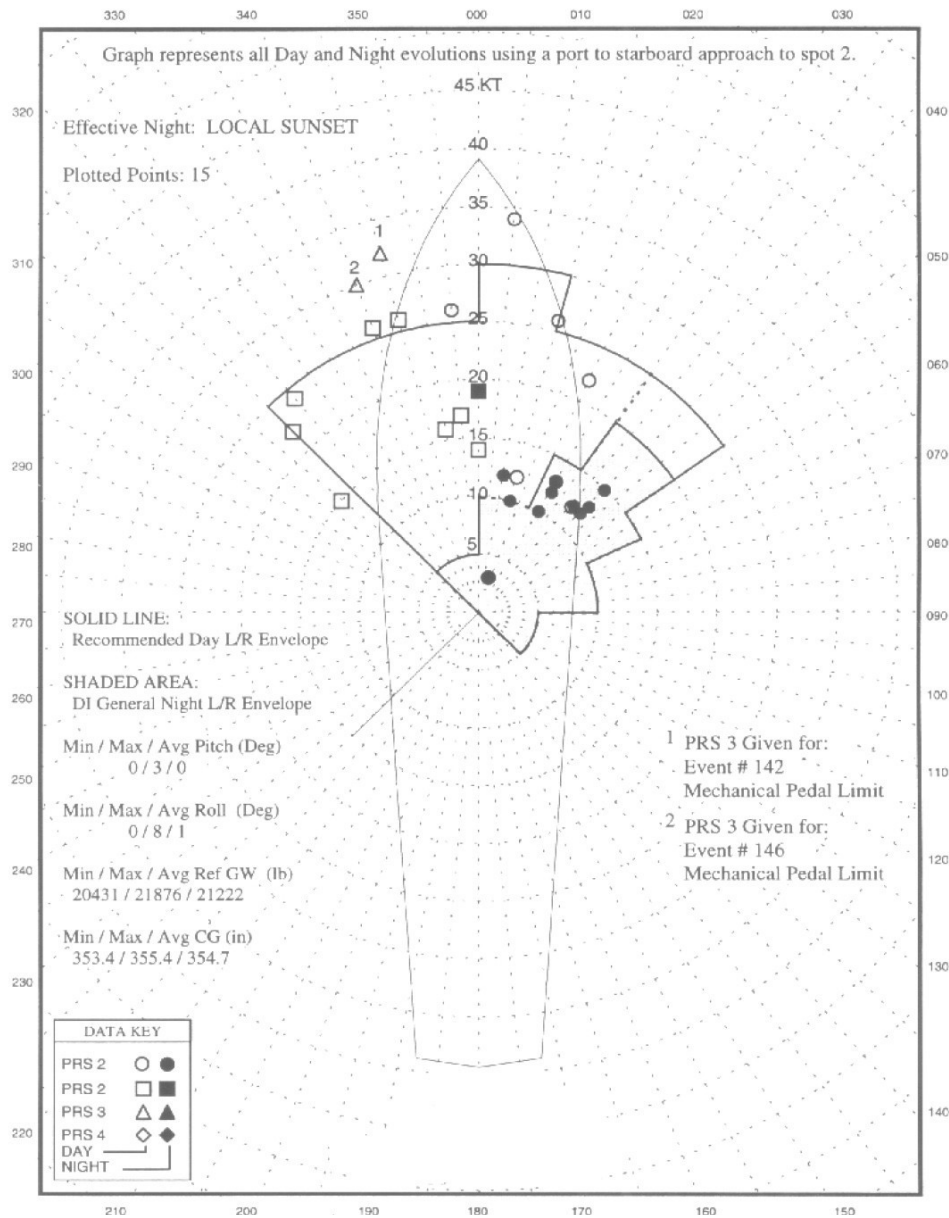


FIGURE 12: EXAMPLE LRE [3]

Findings and Conclusions

This report summarizes the work done under 2017 NRP topic NPS-N368-A. Over the past 16 months we have developed a MATLAB based tool for rapid computation of Launch and Recovery Envelopes, whose target users include operators, mission planners and control and handling qualities engineers. In the process we have integrated a variety of models for ship and helicopter motion as well as pilot and airwake models to produce a MATLAB based tool for rapid computation of Launch and Recovery Envelopes. All of the models were obtained from open literature.

Recommendations for Further Research

The key contribution of our work, we believe, is integration of these models into one tool that can produce LREs. To date, to the best of our knowledge, this has not been reported in open literature.

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NPS-17-N370-A: A Robust Approach for Budgeting Effect Chains

Researcher(s): Dr. Moshe Kress and Dr. Roberto Szechtman

Student Participation: Dor Kronzilber IDF

Project Summary

The U.S. Navy air-wings are required to be capable to execute 20 different types of missions, each comprises a series of actions called kill chains. These kill chains need assets such as sensors, air-platforms and weapons. In addition to the obvious effectiveness objectives regarding the results of kill chains' executions, budget constraints require also efficiency. In this study we develop two models -- one deterministic and one probabilistic -- that optimize the utilization of assets over the range of possible kill chains.

Keywords: *kill chains, robust optimization, uncertain budget*

Background

The U.S. Navy has 10 air-wings. Each air-wing may be required to execute 20 different types of kill chains (KCs) (also called effect-chains) over the next 10 years. A KC consists of three general tasks: find the target (detect), fix (acquire and track), and finish (fire, kill and perform BDA). The 20 types of KCs are divided among four mission areas, Strike, Counter Air, ASW and Anti-Surface Warfare.

While a KC is an operational concept that describes a sequence of three tasks -- Find, Fix, Finish -- needed for executing a certain mission, its implementation depends on physical assets. For example, a counter-air KC against an enemy aircraft may comprise, E-2 Hawkeye (Asset 1) to Find, F-18 (Asset 2) to Fix, and AIM-120D (Asset 3) to Finish. Each one of the three tasks may require more than one asset, and there may be several sets of assets that can facilitate a certain KC. For example, the E-2 Hawkeye in the aforementioned KC could be replaced by a certain unmanned aerial vehicle (UAV). Each such set of assets that can execute a certain KC is called a package. Each KC has a unique set of packages, a package-set, where each package in the set can be used to execute the KC at different cost and various levels of effectiveness.

One of the challenges in our problem is to determine, for each KC, the optimal package(s), when also considering all other KCs and their interdependencies. The interdependence among KCs can be studied from two angles: assets and KCs.

Assets: A certain asset may belong to more than one package and therefore may take part in multiple package-sets serving a number of different KCs. For example, a group of satellites on the same orbit can be used for the Find task in several package-sets and several KCs involving surveillance, detection, and tracking. Another example is F18 aircraft that can perform the Fix task in multiple KCs in multiple mission areas such as Strike, Counter Air, and Anti-Surface Warfare. However, unlike satellites that may be able to perform multiple tasks in multiple KCs simultaneously, a single F18 aircraft cannot perform, simultaneously, multiple different KCs. Thus, the number of F18 aircraft needed depends on the prevalence and intensity of the relevant KCs, as described in the next section. At the extreme, we have assets exclusively dedicated to the execution of a certain KC; for example, there is a one-to-one correspondence between an Advanced Medium-Range, Air-to-Air Missile (AMRAAM) missile and the execution of a KC using it. A fired AMRAAM missile cannot be reused. Hence, the number of AMRAAMs needed is proportional to the number of executions of the relevant KCs.

KCs: The feasibility of executing kill chains depends on their temporal and spatial distributions. KCs that are sparsely distributed over time in a small area generally need fewer assets when compared to the same KCs whose executions are frequent or over a disparate area. If, for example, all KCs involving F18 aircraft are executed one month apart, then probably one squadron would (theoretically) be sufficient for all. Since such a time restriction cannot be guaranteed, and some KCs may be executed simultaneously or soon after each other, more F18 squadrons will be required.

In the models described below we capture these two perspectives via an effective utilization parameter (EUP). The EUP of an asset as part of a package that serves a KC is the proportion of assets required to execute the KC over a given window of space-time. For example, if an asset participates in three KCs that are co-located and are sparsely distributed in time, then the EUP = 1/3. If all three KCs are concurrent,

and each instance of the KC requires a unit of this asset, then the EUP is 1. In other words, the smaller the value of the EUP, the higher the efficiency of the asset.

To summarize, a KC is associated with a package-set comprising packages of assets capable of executing the KC. Packages share assets and the challenge is to select packages such that assets are utilized efficiently, and KCs are executed most effectively. We assume a binary situation: an execution of a KC is either successful or it fails, and the probability of success depends on the package chosen.

These are major sources of uncertainty when dealing with KCs:

1. The completion (successful or not) of a specific KC: The probability of a successful completion depends on the package selected to serve the KC, and ultimately on the assets that make up the package.
2. The number of KCs that need to be executed during the planning horizon: The simplest way to handle this uncertainty is to maximize the expected number of successful KCs. The downside of this approach is that the risk is not captured. A more sophisticated approach attempts to maximize the probability that a certain fraction (say, 90%) of the KCs execute successfully.
3. Another, indirect, source of uncertainty relates to the available budget for procuring and supporting assets needed to serve a KC.

Each asset has a fixed cost that is incurred by simply selecting it for executing KCs (e.g., R&D) and a variable cost that depends on the number of assets procured.

Findings and Conclusions

In this project we developed an initial framework for the efficient funding of assets employed in kill chains. The idea is that money can be spent towards assets, which make up packages that can be used to execute a kill chain, and a kill chain may be executed by several different packages. Importantly, the probability that an asset performs without flaw depends on the funding allocated to it. We formulated two models: one deterministic, and another probabilistic. The deterministic model takes as an input the money spent on each asset and the resulting probability of good performance and formulates and solves an assignment optimization problem to find the optimal asset/package/kill chain assignments. The probabilistic model assumes that each package is made up by assets connected in series, so that that a package does not execute correctly if at least one asset fails. The latter occurs with a probability that depends on the funding allocated to each asset. The model is a mixed integer optimization problem that outputs the optimal level of funding to each asset and the optimal assignment of packages to kill chains. Last, we extended the basic framework to capture budget uncertainties.

Recommendations for Further Research

In this project we developed a framework to:

1. Allocate packages to kill chains
2. Find good budget allocations for assets employed in packages that execute kill chains
3. Capture budget uncertainties

As such, our models can be employed as a basis to develop more sophisticated models that use real input data, and to implement these models in professional level optimization solvers. Other possible improvements are: to refine variables (e.g., split assets into their components), and to include network configurations for the packages other than assets in series (as we did in this work).

NPS-17-N374-A: Representing the Value of Carrier Aviation Presence

Researcher(s): Dr. Kyle Lin and Dr. Jeffrey Appleget

Student Participation: CDR Roger Huffstetler USN

Project Summary

This project develops a game-theoretic framework to quantify how the presence of a carrier strike group (CSG) can deter aggressive military actions from opposing forces. We develop a conceptual framework to describe the conflict between a regional power, a global power, and the other nations in the operational theater, when tension escalates. Based on the framework, we take two approaches to study deterrence by focusing on these nations' diplomatic, information, military, and economic (DIME) powers. First, we design a war game, which concerns a scenario based in South China Sea, where China wants to expand its influence while the United States wants to deter China's aggression. Second, we formulate and solve a Markov game model, which treats the global power and the regional power as two selfish players. The Markov game proceeds in rounds, and each player chooses among several actions in each round to achieve his own goal. The solution to the Markov game model informs the probability of an eventual conflict, which can be used to assess the deterrence value of CSGs.

Keywords: game theory, wargaming, carrier strike group, deterrence, DIME.

Background

"If deterrence fails, the Navy will conduct decisive combat operations to defeat any enemy." The final line from the mission in the Chief of Naval Operations' Design for Maintaining Maritime Superiority describes a clear measure of effectiveness that aligns with the Joint Publication 1.02 definition of risk—the probability and severity of loss linked to hazards. While the calculation of combat losses is meticulously determined through combat simulations, the other side of the risk product probability is not calculated. This uneven treatment of risk often minimizes investments to maintain presence that prevent conflicts.

The Navy needs a tool to assess the deterrence value of CSGs. If the tension escalates in a region, how does the presence of United States CSGs help deter aggression from an adversarial force? Specifically, how does the probability of an eventual force-on-force combat change if the United States sends CSGs to the region? This project seeks to represent the value of CSG presence through a risk framework that complements current Navy combat modeling.

Findings and Conclusions

To assess the deterrence value of a CSG, we develop a conceptual framework to describe the conflict between a regional power, a global power, and the other nations in the operational theater, when tension escalates. Based on the framework, we take two approaches to study deterrence by focusing on these nations' diplomatic, information, military, and economic (DIME) powers.

First, we design and carry out a war game. A team of four M.S. students in the Operations Research Department at Naval Postgraduate School leads this effort under faculty supervision. The war game concerns a scenario based in South China Sea, where China wants to expand its influence while the

United States wants to deter China's aggression. The game was played on 8–9 June, 2017, by military, civilian, and international players.

Second, we formulate and solve a Markov game model. The game treats the global power and the regional power as two selfish players and treats the actions of the other nations as random events. The Markov game proceeds in rounds, and each player chooses among several actions in each round to achieve his own goal. The solution to the Markov game is implemented in Python, while the input and output are handled by Microsoft Excel. By feeding the model with input parameters provided by subject matter experts, the solution to the Markov game model informs the probability of an eventual conflict, which can be used to assess the deterrence value of CSGs.

Through the war game and the Markov game model, we find that:

1. CSG presence alone does not provide effective deterrence. A strong diplomatic relation with the other nations in the regional is critical, which amplifies the deterrence value of CSGs.
2. In some instances, it is advantageous for the global power to seize the initiative and strike first, if it has a military advantage and a diplomatic advantage, before the regional power has a chance to increase force presence.
3. Finding out the regional power's objective significantly improves the global power's ability to choose the best action. Finding out the regional power's real-time action provides only marginal benefit.
4. The output of the Markov game model is sensitive to various input parameters, such as each nation's military strength and its attitude. Effective intelligence and assessment of these parameters is essential to properly analyze and interpret the model's output.

Recommendations for Further Research

Both the war game and the Markov game model provide useful insight into the deterrence value of CSGs. We demonstrate both approaches via a scenario in South China Sea. While the Markov game model can be used to assess the deterrence value of CSGs for conflicts in other parts of the world—assuming model input parameters can be assessed by subject matter experts—the war game based on a scenario in South China Sea cannot be directly reused to study a different conflict.

Our case study on the scenario in South China Sea uses open source data and subjective assessment to define the input values. Subject matter expert opinion or intelligence estimates could provide better resources to assess model parameters. Our war game and Markov game model both assume two active players. An interesting extension is to allow for three or more active players in the game.

ASN (M&RA): MANPOWER AND RESERVE AFFAIRS

NPS-17-N083-A: The Hatch LLA Data Depiction with MMOWGLI

Researcher(s): Dr. Ying Zhao

Student Participation: Capt Jennie Bellonio USMC

Project Summary

In order to help Navy to maximize the potential of crowdsourcing, we demonstrated in this project to leverage a deep learning method named Lexical Link Analysis (LLA) to select high-valued and innovative information from crowd-sourced data collection such as Hatch and Massive Multiplayer Online Wargame Leveraging the Internet (MMOWGLI). LLA is a deep learning method for text analysis and depiction to discover high-value information. The definition of high-value information can vary depending on the applications; however, we can apply the LLA to categorize any information into popular or authoritative, emerging and anomalous ones. Such categorization can greatly facilitate the discovery of high-value information. We demonstrated the LLA applications using two use cases.

Keywords: *Lexical Link Analysis, unsupervised learning, high-value information, crowdsourcing, innovation*

Background

Today's workers are much better able to find information, but they must put much more effort into assessing the accuracy, quality, and context of the information – an information literacy skill. We must examine new ways of visualizing real time information about co-workers, work activities, and worker information exchanges during collaborative work. Workflow visualizations can improve team member perceptions of their organizational role, show how their work fits into the overall workflow, and improve their motivation and productivity. Within the Department of the Navy small networks of expertise exist but are often unconnected. We must determine ways and provide tools to promote improved and effective collaboration.

The Defense Business Board was recently tasked to review and make recommendations on options for the DoD to engage its workforce and inspire effective collaboration. Crowdsourcing and distributed collaboration are becoming increasingly important in driving production and innovation in a networked world. In the past, the Department of the Navy (DoN) Innovation Hatch project served as a virtual innovation community (<https://doninnovation.ideascale.com>). Yet, there are certain limitations that lead decision makers to seek alternative crowdsourcing platforms such as a MMOWGLI game.

In order to help Navy to maximize the potential of crowdsourcing, the goal of the project is to leverage a deep learning method named Lexical Link Analysis (LLA) to select high-valued and innovative information from crowd-sourced data collection such Hatch and MMOWGLI. LLA is a form of text mining in which word meanings represented in word pairs and are treated as if they are in a community of a word network. LLA can provide automated awareness for analyzing text data and reveal previously

unknown, data-driven themes and topics. The results from the analysis can then be used to assess and depict the potential solutions to the research questions such as:

1. Can high-valued or innovative ideas be selected automatically?
2. Can crowd-sourcing platforms such as Hatch and MMOWGLI provide efficient ways to generate high-valued and innovative ideas for the Navy?

Traditionally in social networks, the importance of a network node as one form of high-value information, for example, the leadership role in a social network [1][2] is measured according to centrality measures [3]. Among various centrality measures, sorting and ranking information based on authority is compared with page ranking of a typical search engine. Current automated methods such as graph-based ranking used in PageRank [4], require established hyperlinks, citation networks, social networks (e.g., Facebook), or other forms of crowd-sourced collective intelligence. Similar to the PageRank algorithm, HITS algorithm [5], TextRank [6] and LexRank [7] have been used for keyword extraction and document summarization. The authority of each node is determined by computing an authority score that equals the number of times cited by the other nodes [4].

However, these methods are not applicable to situations where there exist no pre-established relationships among network nodes. For example, there are few hyperlinks available in military application data or public social media data. This makes the traditional centrality measures or PageRank-like methods difficult to apply. Furthermore, current methods mainly score popular information and do not rank emerging and anomalous information which might be more important for some applications; for instance, resource management professionals may need to identify emerging information to best allocate resources, anticipate and forecast upcoming events, and maximize the return of investments. Another example is that crowdsourcing and distributed collaboration are becoming increasingly important in driving production and innovation in a networked world. It is important to identify innovative ideas using crowdsourcing.

Findings and Conclusions

We will demonstrate a novel distributed recursive method, i.e., Lexical Link Analysis (LLA) to discover high-value information [8][9]. The definition of high-value information can vary depending on the applications; however, we can apply the LLA to categorize any information into popular or authoritative, emerging and anomalous ones. Such categorization can greatly facilitate the discovery of high-value information in different application domains.

We demonstrated the methodology using two use cases.

Use Case 1: We analyzed the data from the Department of the Navy (DoN) Innovation Hatch project which served as a virtual innovation community (<https://doninnovation.ideascale.com>). The Hatch project is part of the Department of the Navy Innovation website (<http://www.secnv.navy.mil/innovation/Pages/Home.aspx>), a platform of an open forum for soliciting innovative ideas from all Navy personnel. Each idea is viewed and then analyzed manually now by the domain experts and assigned with a “vote up” score. The “vote up” score can be viewed as a value assessment for each input idea to the Hatch system. We extracted a sample data set around April 30, 2016 for one active campaign about 255 ideas. Table 1 shows that the 255 ideas are categorized into anomalous, emerging and popular categories using LLA.

- The anomalous and emerging ideas have higher total “vote up” scores (1828), higher average “vote up” scores (11.5), and higher percentage of the ideas with a “vote up” score > 10 (17.6%).
- More interestingly, Figure 1 shows if one looks at the time series on how these ideas are evolved, anomalous and emerging information tend to spread more over time.

These validate that emerging/anomalous information discovered using Lexical Link Analysis/Collaborative Learning Agents (LLA/CLA) are correlated with the high-value information sought by human analysts (i.e., ideas with higher “vote up” scores from human analysts).

Type	Total Vote Up Score	Average Vote Up Score	Percentage of Vote Up > 10	Number of Ideas
Anomalous	1828	11.5	17.6%	159
Emerging	544	10.9	14.0%	50
Popular	312	6.8	10.9%	46
Data set as whole	2684	10.5	15.6%	255

TABLE 1: CATEGORIZED IDEAS FOR THE HATCH DATA SET

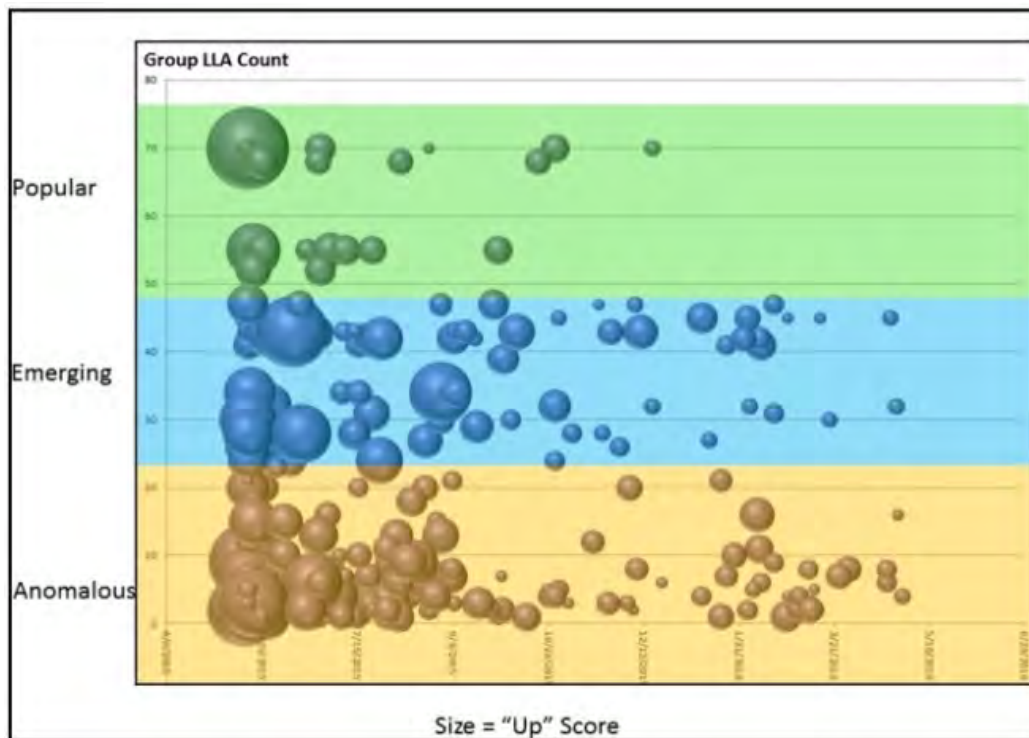


FIGURE 1: ANOMALOUS INFORMATION SPREAD OVER TIME.

Use Case 2: NPS has performed a Massive Multiplayer Online Wargame Leveraging the Internet (MMOWGLI) named Singularity in order to crowdsource answers to the questions:

- What concepts for human-machine teaming might we develop as we approach the Singularity?
- As complexity rises all around us, what new organizational constructs should we consider?

There are more than 1000 players, ~9,000 idea cards played and 45 action plans developed by participants. Post-game workshop was documented in <http://www.secnaw.navy.mil/innovation/Pages/2017/11/PostMMOWGLI.aspx>.

The pre-processing steps are summarized as follows:

1. We focused on the 9,000 idea cards, and each idea was extracted as a separate text file. Meta data links each file to the attributes of the file such as the time (day), level, type and superinteresting that are used by human analysts to assess whether ideas in the file are interesting.”
2. We first identified multiple indicators in this data set, for example:
 - The "level" field in an idea card indicates the depth in which the idea was discussed.
 - An idea can be turned into an action plan where players discussed more in depth how to make the idea feasible. The decision of an idea into an action was decided manually by human analysts.
 - The overall goodness of an idea sometimes receives “superinteresting” tag, however, there were three of 9,000 ideas in this data set with the tag.
 - The overall goodness of an action plan also receives a degree of “thumbs.” We also calculated the numbers of comments for each action plan.
 - One or more idea cards can be tied into an action plan.
3. We also linked the players’ profiles including fields of affiliation, location and expertise, highest badge number, total badges, authored plans and cards played.
4. The next step was to see if there are correlations between the LLA categorizations and the indicators.

For example, Figure 2 shows a distribution of popular, emerging and anomalous idea over time for the MMOWGLI game. Table 2 shows the categorized statistics for the data set. The average “level” measures for anomaly and emerging categories are higher than the popularity categories.

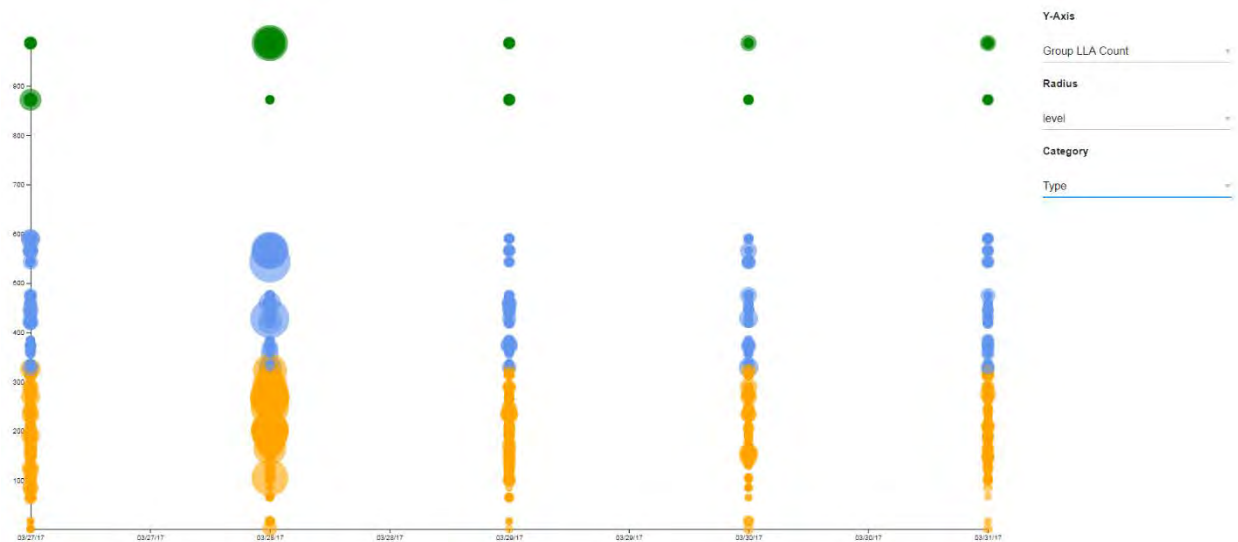


FIGURE 2: DISTRIBUTION OF POPULAR, EMERGING AND ANOMALOUS IDEA OVER TIME FOR THE MMOWGLI GAME

	Level average	Number of Idea Cards
Popularity	2.8	793
Emerging	3	3151
Anomaly	3.3	3752

TABLE 2: CATEGORIZED “LEVEL” MEASURE FOR THE MMOWGLI DATA SET

Recommendations for Further Research

Although future research is needed to improve the accuracy and provide evidence that LLA indeed select good ideas, it is feasible and helpful to apply LLA to a Navy innovation or crowdsourcing platform to automatically select innovative, high-valued and interesting ideas.

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NPS-17-N084-A: Excess Capacity

Researcher(s): Mr. Anthony Kendall and Ms. Sharon Runde

Student Participation: No students participated in this research project.

Project Summary

The federal government purchases more supplies and materials than any other entity in the world. Financial Management Regulation (FMR) and associated regulations require agencies, to the maximum extent practicable, fill requirements for personal property by using existing agency property or by obtaining excess property from other federal agencies. There is no unified system, user friendly application for the efficient utilization of all excess property within DoD, and we believe it would be difficult and expensive to design such a system. There are enterprise logistics systems such as GSAXcess and the Federal Excess Personal Property Utilization Program, but not an easy-to-use mobile application. There is also the Navy's Enterprise Resource Planning (ERP) which could also be a common source for excess property inventory. We propose a peer-to-peer federated system (we call FindEX a mobile app and a web site) that matches the supply (excess) with a demand similar in concept to Uber, Lyft, and Airbnb. FindEx would initially have a copy of excess data from GSAXcess and other sites through an extraction transformation loading (ETL) process from GSAXcess.gov and the Defense Logistics Agency (DLA) Defense Disposition Services which would be to provide a "clearing house" for those looking to dispose of an item (or bulk) and one who may want to procure the item (or bulk). This extracted (updated daily) information would be presented via a mobile app or through a web site with social networking tools. This opportunity for exchange of government using FindEx presents a value proposition or question to both parties. The "demander" could simply buy new the item, but his or her consideration could be budget constraints, or the "demander" simply would like to save the government money or need a part not available new. The data layer would be updated through the ETL process as well as holding peer-to-peer excess information for local organizations. FindEx would push/pull this information using rapid application development (RAD) software such as Swift to minimize development and maintenance costs and allow iOS, Android, and web platforms using the same data. FindEX extracts databases and would be spiral developed with RAD which would reduce complexity and maintenance costs. We have concluded that this could be implemented in one year and for a cost under \$100,000 and even less as a thesis project.

Keywords: *supply, logistics, Swift, iOS, mobile applications, relational database, DRMO, DoDAAC, Navy ERP, spiral development, Android, RAD, agile development*

Background

DLA Disposition Services reported that in the last four years more than 2.2 billion dollar's worth of property was reused each year in addition to supporting disaster relief and humanitarian assistance. There are still opportunities to better utilize excess property. For example, the DoD Inspector General (January 23, 2017), concluded that the Navy did not maximize the use of existing consumable material in the Fleet Logistics Center (FLC) and held consumable material rather than use the material to fill requisitions or offset purchases. This occurred because Naval Supply Systems Command (NAVSUP) guidance did not require customers to first use the Navy Enterprise Resource Planning (ERP) system when requisitioning material and missed opportunities to for unique item numbers valued at \$306,454. Bit-piece part non-

availability which can seriously impact military readiness could be partially solved by the use of excess material but requires visibility through user friendly interfaces.

Findings and Conclusions

Our goal was to propose an inexpensive and easily maintained system for a more efficient utilization of excess property. For such a system to be inexpensive it must avoid complexity and leverage existing capabilities that seek to repurpose excess property. Any “governance” issues should be minimized to reduce administration and maintenance costs. There is no unified or universal system for the efficient utilization of excess property, and we believe it would be difficult and expensive to design such a system. We propose a peer to peer federated system (we call it FindEX) that matches the supply (excess) with a demand similar in concept to Uber, Lyft, and Airbnb. FindEx would initially excess an extraction of the excess data using proven and inexpensive ETL technologies, to process records from GSAXcesss.gov to FindEx which would then provide a “clearing house” for those looking to dispose of or procure an item. This would mean that on a daily or other time period, ETL would extract the relevant records and data fields from GSAXcesss.gov into the FindEx data repository where it could be accessed by the FindEx website, an Android, or iOS (Apple) smart phone. We see the initial proof of concept as a match maker between GSAXcesss.gov and the “demander.” Basically, FindEx would extend the power of GSAXcesss.gov or similar repositories by providing push information to the “demander.” In addition, FindEx could have logistics algorithms to inform the demander if it would be worth the cost to order the item(s). We believe the potential value initially would be ordering large quantities of material/products. FindEx could also immediately notify the demander when a product or item is available on GSAXcesss.gov and provide point of contact information. For the first iteration FindEx would not allow a direct order to GSAXcesss.gov but would go through GSAXcesss.gov.

Two example general use cases are given to illustrate the use of FindEX.

- The seeker/demander is looking for a generator and goes to FindEX where either he or she sees the item listed from local and national sources. FindEX would estimate the overall cost to the government. Updates will be pushed to the user on a daily basis.
- The provider if other than DLA/GSAXcess would post the item to excess, and this will be immediately checked against the FindEX. The provider would be immediately notified if there is an approximate match, and if the cost estimate is favorable, a POC of the seeker(s) will be provided to the provider. In some cases, cost would not be a factor it is effective a mission essential (an item that cannot be procured anywhere else).

The starting page (or view in a smart phone application) is shown below. Further views would include such standard fields as Item Control Number, Item Name, FSC/National Stock Number, etc. These fields and others would be extracted and copied.

Main Page

ITEM INFORMATION	
Search	Goes to Form, similar to Fields from Search Report
Your Excess Equipment	Goes to Form, Item Information
Push Request	Goes to Form similar to Item Information Form

TABLE 1: NOTIONAL FIRST PAGE OF FINDEX

Our research has found that many organizations have their own local methods to try to repurpose excess material including email announcements, websites, and posting on SharePoint. FindEx would not seek to replace these local information repositories but make the information more visible to the potential demander. FindEX in addition to providing a virtual extension of GSAXcesss.gov (or other DoD repository) could be a focal point for these local efforts to more efficiently reuse excess property. FindEx would provide standard relational tables in a database that local organizations could use as a means for local redistribution of property. These local entities could decide to be part of the FindEx search and/or limit some items by geographic regions, such as furniture, which would not be a cost-effective proposition to send across the country. In additional, there is potential for social networking tools to share knowledge among local “providers” on best practices to more effectively dispose of excess property.

Our literature review and discussion with supply and logistics experts confirmed our belief that the complexity of the problem of universally disseminating excess property information is complex with legal and logistics issues which would prevent us from our goal of providing a low-cost application to more effectively use excess capacity. Our goal would be to have a thesis student with faculty assistance able to create an application using RAD and spiral development to reduce risk. For example, we looked at the Navy’s Enterprise Resource Planning (ERP), and the complexity of such a system would be beyond the scope of a low cost, quick effort, although as part of spiral development ERP as the data source may be a better long-term solution. For the first iteration, extracting data from GSAXcesss.gov we believe, would be a good first effort for the FindEx. As a demonstration we were able to use Apple’s Swift programming language with Xcode as the interface development environment (IDE) which is the RAD approach to quickly work up a partially working iPhone approach to connect to a database. Swift is a powerful and intuitive programming language for iOS. Writing Swift code is interactive and the syntax is concise yet expressive. Xcode uses a type of model view controller (MVC) as the pattern for development which makes it easier to design and implement a data driven application such as is needed for FedEx. We found it is easy to learn and to develop smart phone applications. Swift code is safe by design, yet also produces software that runs lightning-fast. The ETL process could be easily be used to copy the GSAXcesss.gov to the FindEx data store and then access it at the application layer via smart phone (iOS or Android) or a basic website which could also use Oracle’s Web Center or Adobe Experience Manger. ETL is proven technology so the main focus was on the practicality of developing smart phone applications in addition to standard website applications. Our experience with Swift to develop a working mockup shows that an application could be developed that would:

- Access an extracted database such as from GSAXcesss.gov
- Could push information to the user
- Could provide logistics algorithms to obtain the total cost of the item
- Would be a low cost, low risk solution and avoid risky major system development with uncertain return on investment
- Would minimize any governance, legal issues and security/information assurance issues and no personally identifiable information (PII)

One limitation in our research procedures is our assumption of “buy in” by GSAXcesss.gov or an alternative data provider. Our previous research does indicate such repositories as Navy’s ERP values reuse of data. The ETL process has been used in previous projects so from a technical perspective the issue would be convincing GSAXcesss.gov the low cost and low risk to their platform. ETL has been used before to extract data from government repositories so we do not believe it’s a major limitation. We believe that a federated system as we propose would be a low-cost solution to improve utilization of excess property and

with spiral development features would grow as driven by the community. Also, if local organizations see value, they will want to use FindEX as an easy way to list excess property. This would be done by the ETL process or creating a simple, standard relational database located on the FindEX server. Alternatives to FindEX or similar architectures using agile development methods would most likely be expensive and take a long time to develop, especially any solution that would want to modify the enterprise systems such as the Navy's ERP. We would leverage existing databases and thus not have the cost to maintain the database since we would extract copies for read only access. We think FindEX would be inexpensive and leverage both national and local systems and would initially run on two servers or virtual machines such as in Amazon's AWS. Our scope didn't allow us to thoroughly investigate the logistics algorithms, but our architecture would easily incorporate costing models and even offer alternatives to users. For our cost models there are available API's for Google maps, FedEx, and UPS which would provide cost information to provide the user with information as to whether the transfer would really save the government money. The cost is not to just the user, but overall cost to DoD. Without the overall cost sub optimization can occur and encourage users to maximize savings at the expense of DoD as a whole.

Swift software for iOS would allow you to connect, for example, to FedEx to compute costs as well or provide user input, and Android Studio would provide similar capabilities. Our focus for this stage was on the feasibility of implementing these capabilities and features, and they can be implemented on the three platforms (web, iOS (using Swift), and Android (Android Studio)). We did not create a test application for Android but believe that for this iteration an iOS test was sufficient to prove the concept of a logistics app. The key is the data layer, and that is made simple through ETL.

Two other potential issues:

1. Why would a supplier post?
2. Why would a demander visit the site or app?

Would "demanders" use the system? For the web version of FindEX social networking capacities can easily be added such as forums and discussion groups. The FindEX ultimately would have to provide value or our app or any app would not be used. Since we recommend a low-cost spiral development, we would have time to evolve the app to one that would be used, or if not, the risk and cost would be low. It was beyond the scope of the project to study the marketing strategy, but we do think that if the application provides value, it will be used since it would be simple.

Recommendations for Further Research

Investigate the data architecture needed to use GSAXcess (or alternative) as a source for FindEX and develop a web and/or smartphone application. Also, investigate the logistics algorithms that would advise the user to acquire excess property or buy new. Another area for further research is the issue of computers and e-waste. Most computers and servers excessed require their hard drives to be removed; could that issue be resolved and is it repurposing functional but older servers/computers?

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NPS-17-N088-A: Scaled Approach to Open Sourcing Department of the Navy Produced Software

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Student Participation: Capt Donovan Holloway USMC, and Capt Julian L. Garcia USMC

Project Summary

The life cycle costs of software continue to grow for the Department of the Navy (DoN), and the fear is these costs will be unsustainable. This research will be applied to the DoN to determine the benefits and risks (including cybersecurity risk) to open-sourcing for all software, including the implications for classified systems. Costs trends and the key drivers will be identifiable from the research. The knowledge of the trends and drivers of the successful efforts will inform the development of potential courses of action for the DoN. Given potential limitations due to cybersecurity or legal requirements, a scaled approach may be more prudent approach. Cybersecurity is a concern for all system development efforts, and although no type system should be excluded from using open source software (OSS), some systems may require more attention to security than others. There are also new development cultures arising that capitalize on the use of OSS such as DevOps, a development environment where the software developer works closely with software operations. Recommended areas for use of OSS would be in the business or administrative applications, particularly with new development efforts that would provide the opportunity to maximize the gains resulting from using OSS and the new techniques, such as DevOps.

Keywords: open source software (OSS), Free Open Source Software, (FOSS), Free/Libre Open Source Software (FLOSS,) open sourcing, scaled, application program interface (API), DevOps

Background

The life cycle costs of software continue to grow for the Department of the Navy (DoN), and the fear is these costs will be unsustainable. In 1985, the Free Software Foundation (FSF) was founded to support the development of free software that they defined as “software that gives you the user the freedom to share, study and modify it (Free Software Foundation).” The FSF coined the term Free Open Source Software (FOSS). The use of open source software (OSS) has been an interest of many in the community since the “open source” label was created in 1998 (Open Source Initiative, www.opensource.org). It cannot be assumed that open source software is totally free because the developers could charge for developing or

maintaining it, yet still make it available to copy, modify, or share it (What is open source?). Some communities use the term Free/Libre OSS (FLOSS) rather than FOSS. OSS, FOSS, and FLOSS are used synonymously in the DoD (DoD CIO).

The use of open source software in the Department of Defense (DoD) has been studied for over a decade (see (The MITRE Corporation, 2003)); yet, the DoD and the DoN continue developing code at an incredible expense. The latest source of guidance for use of open source software (OSS) in the DoD can be found in the Frequently Asked Questions at the DoD website (DoD CIO). Yet, articles have been published providing reasons NOT to use open source software (Rubens, 2014) or claiming it's not really free, that is you pay either way (Sabhlok). There remain perceptions by some DoD managers that use of open source is not a feasible option due to concerns with infrastructure, cybersecurity or life-cycle costs; consequently, code development continues. Given the potential cost benefits of using open source software, this research focused on its use in the DoN. A scaled approach may remain cost effective enough to consider for some applications.

Findings and Conclusions

The approach to this research included literature and website reviews, attendance at conferences, and review of policies. Although, neither the DoD nor the DoN precludes the use of OSS, its use did not accelerate until recently. According to The Mitre Report from 2003, there were already 115 FOSS applications in use in the DoD (The MITRE Corporation, 2003). According to the DoN Application and Database Management System (DADMS) database, there is OSS being used in the DoN, with Red Hat Linux being one of the more common ones. According to Forbes magazine, open source solutions provide “plenty of innovation, an ability to move fast and dramatically lower cost” (Fruehe). Because of the standardization in application program interface (API), integration of open source solution modules has become easier and faster (Fruehe). Somewhat based on our experience with applications (apps) on smart phones, we have come to expect rapid release of applications.

Because of the DoD's concern with cybersecurity, it was noted that the consensus of the people participating in the OSS conference consider OSS to be more secure than proprietary software. They thought that because the number of people having access to the source code was higher, the malicious code would be found. And, because checking the code in and out of a library was required to change it, that it would be done in a controlled manner by someone who is trusted. Yet according to the Skynk report, developers review their code for different reasons and may not find the vulnerabilities or they lack to expertise to find the vulnerabilities and these vulnerabilities may remain undiscovered for a long time (Skynk, 2017). Also, some code may require more attention to security than others as discussed in the report by the Institute for Defense Analysis (IDA) (Wheeler & Khakimov). The quantitative approach used by IDA could be applied when deciding which applications should be developed.

A related concept, DevOps, surfaced in the research. According to Wikipedia (<https://en.wikipedia.org/wiki/DevOps>, 2017), DevOps is a software engineering culture that focuses on shorter development cycles in which the software developers work more closely with operations software operations and is tightly aligned with the business objectives, thus producing software that should satisfy the users, or if not, could be changed rapidly (<https://en.wikipedia.org/wiki/DevOps>, 2017). According to TechBeacon, open-source development has always been an integral part of DevOps (Open source software leads to DevOps success) (<https://en.wikipedia.org/wiki/DevOps>, 2017) (Open source software leads to DevOps success).

As mentioned in the blog, “DevOps enhances customer satisfaction by providing quick feedback-enabled efficiency and qualitative deliverables (How DevOps helps enhance Customer Satisfaction, 2017).” DevOps is expected to reduce costs and time to market (metaware) (metaware; <https://en.wikipedia.org/wiki/DevOps>, 2017; <https://en.wikipedia.org/wiki/DevOps>, 2017).

The research concluded that the DoN should move forward, taking maximum advantage of the use of OSS. With SoftwareForge, the DoD has established an infrastructure to support the development, fielding, and use of OSS (FAQs about SoftwareForge).

Recommendations for Further Research

This research provided enough evidence that open source software is the wave of the future. Given the general expectation among people for new applications that are innovative, easy to use, and delivered rapidly, research suggests that a legacy DoD applications that is not user friendly be re-written totally using a DevOps approach and as much OSS as possible. Further research is needed to choose the appropriate application to rewrite.

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NPS-17-N097-A: Analysis of Navy Innovation Network

Researcher(s): Dr. Wayne Porter, Dr. Camber Warren, Mr. Albert Barreto, and Mr. Rob Schroeder

Student Participation: LT William Huff USN

Project Summary

NPS researchers coded and developed *social network analysis* matrices of U.S. Navy personnel (nodes) who are currently linked together through various events, social media fora, and topics of interest, that contribute to the *Naval Innovation Network*. Through the use of commercially available social network analysis software, the matrices (of members, events, organizations, topics) were used to develop graphical two- and three- dimensional topologic/sociogram depictions of the sub-networks that connect these nodes through strong and weak ties. These matrices were dynamically updated by *open source databases* with information related to events being scheduled, organizations, fora available, topics, and progress being made in specific areas of interest to the Navy. *Community detection algorithms* and *metrics of centrality, density, cohesiveness/structural holes, and clustering* were used to identify *authorities and hubs*.

The Common Operational Research Environment (CORE) Lab constructed a sociogram of nodes and ties within an identified Naval Innovation *Event Network*, based on a number of different events that took place to encourage innovation. To supplement the Event Network, social media connections were analyzed by looking at those accounts connected to The Athena Project's Twitter account. A community detection algorithm used the pattern of ties to identify subgroups within a *Followers, Retweets, and Mentions Network*. Finally, documents from different websites, including eight from different parts of the social media network, were analyzed based on their content using latent Dirichlet allocation (LDA) as a method for extracting topics from the text. The resulting *Topics Network* was then aligned with the previously identified Events and Followers, Retweets, and Mentions networks in order to determine where potential additional collaboration could occur. This analysis was intended to determine how best to increase the Naval Innovation Network's effectiveness to more efficiently capitalize on innovative ideas and technologies.

Keywords: *Naval Innovation Network; open source databases; community detection algorithms; metrics of centrality, density, cohesiveness/structural holes, and clustering; authorities and hubs; Event Network, Followers, Retweets, and Mentions Network, Topics Network*

Background

In *A Design for Maintaining Maritime Superiority* (2016), the Chief of Naval Operations, ADM Richardson, identified, "the increasing rate of technological creation and adoption" as one of the three major interrelated global forces shaping today's strategic environment. To achieve "high velocity learning at every level," the paper cited the need to "Adapt processes to be inherently receptive to innovation and creativity." Over the last decade, an unprecedented number of innovation cells have emerged throughout the Navy. Many of these innovation cells are interconnected, with members possessing attributes that include high levels of trust, adaptability, knowledge-seeking behavior, loyalty, openness, transparency, and a willingness to navigate an often daunting Navy bureaucracy.

Innovation nodes (sailors, Navy civilians, organizations, fora, events, initiatives) have self-organized over time, creating an evolving and dynamic social network. The informal Naval Innovation Network includes (or has included) the Chief of Naval Operation (CNO)'s Strategic Studies Group (SSGs), Deep Blue, Disruptive Thinkers, the CNO's Rapid Innovation Cell (CRIC), Tactical Advancements for the Next Generation (TANG), the Consortium for Robotics and Unmanned Systems Education and Research (CRUSER), The Athena Project, Defense Entrepreneurs Forum (DEF), and its offshoot DEFx, the Secretary of the Navy (SECNAV)'s Strategy and Innovation Department, Task Force Innovation (TFI), the Naval Innovation Advisory Council (NIAC), Defense Innovation Unit Experimental (DIUx), FabLabs, ROBO Dojo, Fleet Readiness Center Mid-Atlantic (FRCMA) Junior Innovation Think Tank (JITT) and Senior Innovation Think Tank (SITT), the Bridge, the Constellation, and many others yet to be formally identified. Collaboration and brain storming methods have inspired new possibilities, critical thinking skills, and collaboration through Design Thinking (DT), User Based Design, experimentation, rapid prototyping, and intrapreneurship. By identifying and connecting the nodes in this social innovation network using open source data and voluntarily provided information, the Navy can amplify effects in areas such as unmanned vehicles, additive manufacturing, knowledge management (to include big data), wearable technology, codes and algorithms, virtual and augmented reality, and many other areas of operational interest.

A significant body of research has been conducted in the area of leveraging social networks to enhance innovation by connecting communities of interest. This work involves the study and coding of member attributes, behavior, motivations, relationships, and social media that attract new members into self-organizing clusters that constitute communities of interest (Backstrom, Huttenlocher, Kleinberg, & Lan, 2006). Further research has explored emergent behavior that can be applied as a potential strategy to increase a positive epidemic of desired behaviors within a complex organization (Horgan et al., 2010). A study of human and organizational behavior in the military provided insights into the use of electronic media and social media analysis to model human behavior, infrastructure, and information exchange in order to increase military readiness and effectiveness (National Research Council, 1998). These studies followed earlier work that sought to identify barriers to, and catalysts of, new discoveries through the mobilization of social movements (Klandermans & Oegema, 1987).

In today's hyper-connected environment of young professionals, social network analysis provides a method and tools for identifying, mapping, and measuring the emergent network of sailor-innovators eager to contribute their knowledge and Fleet experience in the pursuit of technology and process improvement through innovation. Once network membership, structure, and behavior are qualitatively analyzed and quantitatively measured, strategies can be developed to better connect sailors, command-initiatives, naval warfare centers, and labs in order to drive creative insights toward innovative and actionable solutions.

The Naval Innovation Network may be analyzed through either one mode or two mode matrices: one mode analysis ties individuals to individuals for example, and two mode analysis ties, for example, individuals to fora, events, organizations, and topics they have in common. Both methods were employed in this research. While data is routinely collected on the attributes (characteristics) of individuals and stakeholders which might be helpful in link analysis, less attention has been paid to the collection of relational data. This can be achieved through algorithmic searches designed to sort large data sets from dynamic, open source (technological, news, military, and industry) databases (Franzese, Hays, & Kachi, 2012; Hays, Kachi, & Franzese, 2010; Robins, Snijders, Wang, Handcock, & Pattison, 2007). The use of

social network analysis that integrates attribute data with relational data provides metrics for network analytics (e.g. eigenvector centrality, density, clustering, cohesiveness/structural holes) not possible with link analysis (Borgatti, Everett, & Johnson, 2013; Freeman, 2016; Granovetter, 1973; Kadushin, 2012; Prell, 2012; Watts, 2004).

NPS researchers coded and developed social network analysis matrices of U.S. Navy personnel (nodes) who are currently linked together through various formal and informal blogs, social media fora, information exchanges, technical fora, and command-sponsored innovation initiatives aimed at improving Navy combat systems, human resource polices, acquisition policies, tactical, and operational approaches. Through the use of commercially available social network analysis software (Organization Risk Analyzer (ORA), University of California Irvine Network (UCINET)), the matrices (of members, events, organizations, etc). were used to develop graphical two- and three-dimensional topologic/sociogram depictions of the Naval Innovation Network that connect these nodes through strong and weak ties. These matrices were dynamically updated by open source databases with information related to events being scheduled, organizations, fora available, topics, and progress being made in specific areas of interest to Naval Innovation Network members. Metrics of centrality, density, cohesiveness/structural holes, and clustering were used to measure the network. Thesis student LT Huff, USN will use this analysis to determine how best to increase the network's effectiveness and integration with ongoing Navy research and development in order to more efficiently capitalize on new ideas and technologies to improve effectiveness in a variety of subject areas of interest.

Findings and Conclusions

This research sought answers to the following the questions:

- A - What are the key nodes and networks in the Naval Innovation Network?
- B - What are the ties that link together members of the informal network?
- C - How could we more effectively bridge together individuals and clusters within the social network of Navy innovators (from the deck plates up)?
- D - How can we measure the growth and effectiveness of Navy innovation networks to enhance collaboration?
- E - Can we longitudinally measure the impact Navy formal and informal innovation networks have on enhancing the Navy's effectiveness and rapid prototyping capabilities?
- F - What strategies would be best suited to move innovation from the deck plates to those best placed to adopt new ideas for rapid prototyping?

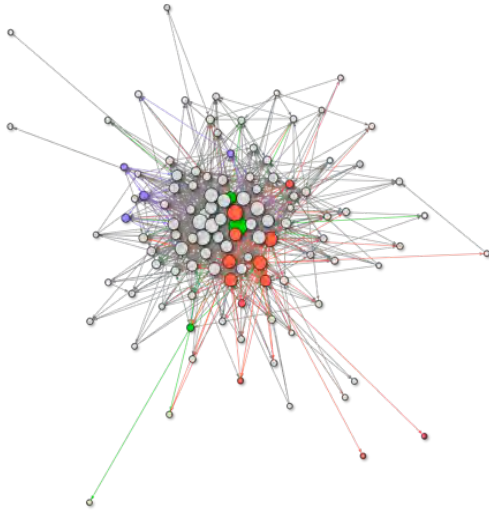
Based on the research discussed above, the following findings are provided in response to the research questions:

A - What are the key nodes and networks in the Naval Innovation Network? While there are several institutional offices within the Navy that serve as hubs for innovation (such as the Office of the Deputy Under Secretary of the Navy (Management) (DUSN(M))/NIAC/Strategic Innovation Office, Navy RDT&E Strategic Cell, and others cited earlier) and in the Department of Defense (such as the Defense Entrepreneurs Forum, the Armed Forces Communications and Electronics Association (AFCEA), and DIUx) provide areas for both events and a social media presence. This brings together various individual sailors, who themselves can be central in bringing new ideas from one event to another or be influential for spreading knowledge via social media or other public forums. Regional events can create clusters of

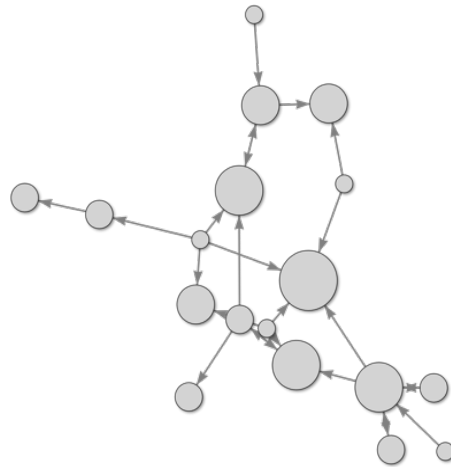
local innovation networks, with larger events, social media, and publishing articles via blogs or websites playing a role in spreading the information across the greater community.

Based on subgroup analysis the following key nodes and hubs were identified through Twitter analysis: @AthenaNavy (events and official twitter account) to access Navy innovation subgroup (Subgroup 4); @DEFConference, for accessing DoD innovation subgroup (Subgroup 1); @USNavy and @NavyInnovation, to access the upper levels of the Navy (Subgroup 3); @CIMSEC and @NavalInstitute, for accessing policy and specific areas of the Navy (Subgroup 6). (see Figures 1, 2 below)

Subgroup 1



Subgroup 2



Subgroup 3



Subgroup 4

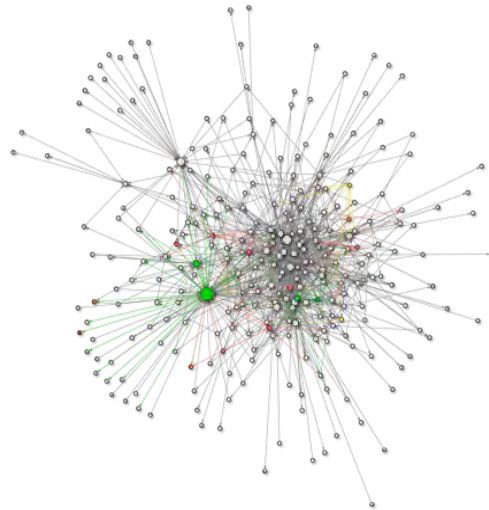
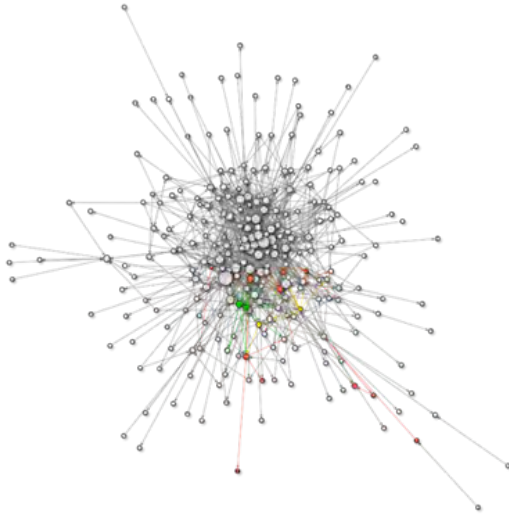


FIGURE 1: GRAPHS BASED ON SUBGROUPS FROM LOUVAIN ALGORITHM. NODES COLORED BY ACCOUNT TYPE AND SIZED BY IN DEGREE.

Subgroup 5



Subgroup 6

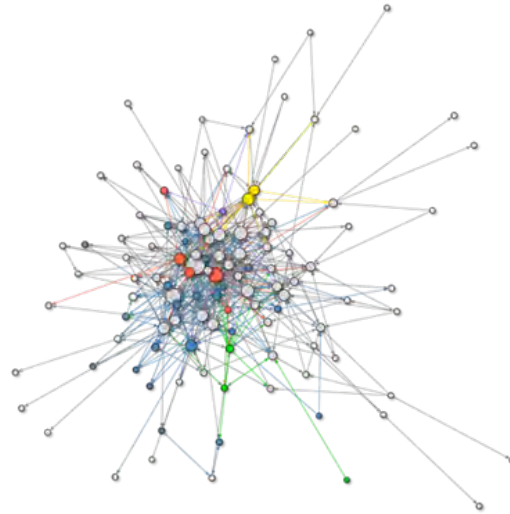


FIGURE 2: GRAPHS BASED ON SUBGROUPS FROM LOUVAIN ALGORITHM. NODES COLORED BY ACCOUNT TYPE AND SIZED BY IN DEGREE.

Our research found that official, or organizational, accounts can play a role as key hubs or brokers of information, while individuals can serve as authorities, or sources of information. We identified several of these.

B - What are the ties that link together members of the informal network? This research used the Louvain algorithm for extracting subgroups from a Twitter network by determining whether the ties between nodes are internally dense and externally sparse. This algorithm maximized the modularity score to identify five different subgroups. The location of nodes and their ties within the layered core of the network provided the means for community detection. It was found that in many cases, ties were stronger among nodes that belonged to both the Twitter network and the events network. Of the seven subgroups identified, subgroups three, four, and six were of particular interest to the Navy. The third subgroup (Figure 1 above) contains 84 accounts. The majority of official Navy Twitter accounts in this network are included in this subgroup. These Navy accounts are also relatively central in this subgroup. The fourth subgroup (Figure 1 above) is the subgroup that contains @AthenaNavy. This subgroup is where many accounts that are highly involved in innovation in the Navy are likely located. The sixth subgroup (Figure 2 above) contains 114 accounts. This is the subgroup that contains different regional or specialty areas for the Navy. Also of note, the first subgroup identified (Figure 1 above) contains 114 accounts and is the subgroup with the largest number of accounts by people who attended events in the initial network. It is visualized on the top left of Figure 1 above. The most central accounts, in terms of in-degree centrality, are people and events from the Event network. While there are no official Navy accounts in this subgroup, it seems to be the area where people and organizations are engaged regarding innovation in the entire DoD. Engaging this subgroup would be useful for either incorporating relevant ideas from the rest of the DoD, or injecting ideas from the Navy into the larger DoD.

C - How could we more effectively bridge together individuals and clusters within the social network of Navy innovators (from the deck plates up)? Based on community detection analysis, it would seem logical that the Navy may benefit from using official Navy accounts in Subgroup 3 (Navy leadership) to pass along information generated in Subgroup 4 (Navy innovation subgroup). This information could be

targeted towards accounts in Subgroup 6 (as conduits for Navy topics of interest). This could be accomplished by institutionalizing outreach to better connect the Network in Network (NIN) to other groups in the Navy through networks of events, organizations, and social media. Additionally, the outreach could also be institutionalized to the larger DoD in order to capture the information generated by individuals already engaging with other parts of the military.

D - How can we measure the growth and effectiveness of Navy innovation networks to enhance collaboration? It is apparent from the preliminary social network analysis conducted at NPS, that it is possible to dynamically update and periodically measure and assess the NIN network and the number and strength of ties to the wider innovation community.

E - Can we longitudinally measure the impact Navy formal and informal innovation networks have on enhancing the Navy's effectiveness and rapid prototyping capabilities? By monitoring the number of innovations originating in the NIN that subsequently result in Fleet implementation and/or rapid prototyping, and conducting correlation analysis, it should be possible to longitudinally assess the impact the NIN is having on the enhancement of Navy capabilities over time.

F – What strategies would be best suited to move innovation from the deck plates to those best placed to adopt new ideas for rapid prototyping? Thesis student LT William Huff, USN is exploring strategies to institutionalize the adoption of innovation through rapid prototyping. His thesis will be completed in Mar 18 and will be provided to DUSN(M).

Recommendations for Further Research

It is apparent from the preliminary social network analysis conducted at NPS, that it is possible to dynamically update and periodically measure and assess the NIN network and the number and strength of ties to the wider innovation community. Further research is needed to measure the impact the Naval Innovation Network is having on prototype development and fielding. Further research should also focus on social network analysis within specific technology areas of research (e.g. unmanned systems (UxS), robotics, 3-D Manufacturing, acquisition reform).

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Stakeholders and Sources Identified:

- 1) Defense Entrepreneurs Forum
 - a. Website
 - i. www.defenseentrepreneurs.org
 - b. Facebook
 - i. <https://www.facebook.com/DefenseEntrepreneurs/>
 - ii. <https://www.facebook.com/DEFxSD/?fref=ts>
 - iii. <https://www.facebook.com/DEFxSV/?fref=ts>
 - iv. <https://www.facebook.com/events/932254493568327/>
 - v. <https://www.facebook.com/groups/1470527806557261/?fref=nf>
 - c. Twitter
 - i. www.twitter.com/DEFConference
 - ii. www.twitter.com/DEFannapolis
 - iii. www.twitter.com/benningagora
 - iv. www.twitter.com/uk_def
- 2) Athena Project
 - a. Website
 - i. <http://athenavy.com/>
 - b. Facebook
 - i. <https://www.facebook.com/athenavy/>
 - c. Twitter
 - i. www.twitter.com/athenavy
- 3) LinkedIn
 - a. Naval Innovation Network
- 4) Bunker Labs
 - a. Facebook
 - i. <https://www.facebook.com/thebunkerlabs/>
 - ii. <https://www.facebook.com/bunkerlabssiliconvalley/?fref=ts>
 - iii. <https://www.facebook.com/bunkerlabsjax/?fref=ts>
 - iv.
- 5) CNO's Rapid Innovation Cell (CRIC)

- a. Facebook
 - i. <https://www.facebook.com/NavyCRIC/>
- 6) SECNAV's Strategy and Innovation Department
 - a. Website
 - i. www.secnavy.navy.mil/innovation
 - b. Facebook
 - i. <https://www.facebook.com/NavalInnovation/>
- 7) Tactical Advancement for Next Generation (TANG)
- 8) Strategic Studies Group
- 9) Navy Warfare Development Command's (NWDC) Navy Center for Innovation
 - a. http://www.navy.mil/submit/display.asp?story_id=75060
- 10) Task Force Innovation (SECNAV)
 - a. <https://www.navytimes.com/story/military/2015/04/15/navy-secretary-mabus-unveils-task-force-innovation-sea-air-space/25816721/>

NPS-17-N102-A: A Plan for Big Data Management

Researcher(s): Dr. Neil C. Rowe

Student Participation: Mr. Jeffrey S. Dean CIV USAF, LT Keith W. Nelson USN, and 2LT Ryan J. McCaughey USA

This project addressed big-data challenges for management of information-security data, in particular reports of new suspicious activity. Early warning of new cyberattacks is possible by analyzing traffic over a network and files left in secondary storage of computers and devices to look for anomalous activity. However, thorough application of these principles would result in a huge amount of data. Most of the interesting analysis requires correlating data seen at different locations, and that could be a large number of comparisons. Centralization of the comparisons on collection nodes would require large amounts of network traffic for just the collection alone. Thus, it is essential to summarize and filter data before trying to analyze it.

This project, with student help, looked at three ideas that may help with the big-data challenges of security monitoring. One idea is to focus on the most basic aggregate data of networks, "flow" data, and try to find patterns using ideas of machine learning. Another idea is to use machine learning try to generalize details of past cyberattacks to recognize new attacks that, while not identical, have similarities to what you have seen. A third idea is to develop deceptive honeypots that can collect a smaller but richer set of attack data.

Keywords: *big data, information security, cyberattacks, intelligence, flows, machine learning, honeypots*

Background

A wide variety of methods are used by organizations to monitor their networks for cybersecurity threats. Besides the well-known techniques of antimalware scanning and intrusion-detection systems, they include anomaly analysis using data such as flow records (Internet addresses, ports, bytes transmitted, and timestamps), explicit warnings issued by security experts, and data collected by decoy targets (honeypots).

Findings and Conclusions

Flows are sequences of packets sent between two network nodes. Analysis of flow data has advantages over signature-based monitoring of systems and networks in that it is much faster since it looks at only aggregate data and does not raise privacy concerns. We found that users and their usages could be characterized to some extent by their flow data (Dean, 2017). However, it is often (but not always) important to exclude automatic flows such as protocol-initialization communications, certificate checks, Domain Name Servers (DNS) directory lookups, and automatic refresh methods to better distinguish what users are doing. They can be detected by regular timing (such as every 10 minutes) and known site identifies. Then we can assign the remaining flows to different categories of users (in our cases, students versus teaching staff versus managerial staff) using a wide range of metrics. This is helpful in detecting possible insider threats whose behavior is atypical for their job descriptions. We did careful tests and provided results showing the benefits of this approach. These methods are well suited to distributed-processing methods for big-data analysis because our methods consider flows in isolation of their surroundings, and we showed this was sufficient for good classification.

We also investigated the generalization of network alert messages about cyberattack campaigns (Nelson, 2017). This was done in the context of an individual Navy ship that does not always have time to wait for complete and precise information about cyberattacks. Instead, and especially during active conflict, it needs to make some analogies to previous cyberattacks and knowledge of what countermeasures worked. We built a demonstration system for testing using the Microsoft Azure framework (Microsoft, 2017) and showed it could predict new things, and do so quickly.

A third area of our research was our work with honeypots, decoy cyberattack targets. We have a set of connections outside the school's firewall which we use for this kind of research (McCaughey, 2017). The experiments in FY17-FY18 involved first document-delivering honeypots modeled on our school's library collection, then a secure-shell honeypot for monitoring attempts to subvert our operating systems, and then an industrial-control-systems honeypot simulating a power plan. Honeypots can be more effective if they use a variety of deception (Rowe and Rrushi, 2016) because cyber attackers want to avoid honeypots when they recognize them. This means that honeypots can either try to not look like honeypots (encouraging cyberattacks, allowing for more collection of data) or can try to look like honeypots (scaring attackers away, helping protect systems). Our experiments with real attackers over a period of time showed definite tendencies of certain deceptions to either decrease or increase traffic.

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NPS-17-N125-A: Analysis of Innovation Communities of Interest for Technology Transfer and Development

Researcher(s): Dr. Wayne Porter and Mr. Rob Schroeder

Student Participation: LT Todd Coursey USN

Project Summary

In *A Design for Maintaining Maritime Superiority* (2016), The Chief of Naval Operations, ADM Richardson, identified, “the increasing rate of technological creation and adoption” as one of the three major interrelated global forces shaping today’s strategic environment. Researchers in the NPS Common Operational Research Environment (CORE) Lab coded and developed *social network* matrices of US Government agencies, contracting offices, and vendors (nodes) who are currently linked together through *communities of interest* within and outside the Navy pursuing technologies aimed at improving *Navy additive manufacturing capabilities*. Through the use of commercially available social network analysis software, the matrices (of agencies, contracting and requesting offices, vendors, and topics) were populated and used to develop graphical two- and three-dimensional *topologic/sociogram depictions* of the additive manufacturing innovation community of interest network that connects these nodes. These matrices were dynamically updated by *open source databases* with information related to contracts, vendors, areas of technology, and agencies in the area of additive manufacturing (with a focus on research, development, and production contracts awarded as well as with topics of interest). Metrics of *centrality, fragmentation, constraint, cohesiveness/structural holes, and clustering* can then be longitudinally measured to determine how best to increase the network’s effectiveness and integration with ongoing commercial research in order to more efficiently capitalize on collaboration, new ideas, and technologies to improve additive manufacturing capabilities for the Navy.

Keywords: *social network analysis, Small Business Technology Transfer (STTR), topologic/sociogram depictions, centrality, fragmentation, constraint, cohesiveness/structural holes, clustering, communities of interest, Navy additive manufacturing capabilities, open source databases*

Background

In a 2015 report entitled *DoD Needs to Systematically Track Department-wide 3D Printing Efforts*, the Government Accounting Office (GAO) found that, “DoD has taken steps to implement additive manufacturing to improve performance and combat capability, and to achieve cost savings. GAO obtained information on multiple efforts being conducted across DoD components. DoD uses additive manufacturing for design and prototyping and for some production, such as parts for medical applications; and it is conducting research to determine how to use the technology for new applications.” The report goes on to state, “However, DoD does not systematically track additive manufacturing efforts, to include (1) all activities performed and resources expended by DoD; and (2) results of these activities, including actual and potential performance and combat capability improvements, cost savings, and lessons learned. DoD has not designated a lead or focal point at a senior level to systematically track and disseminate the results of these efforts, including activities and lessons learned, department-wide. Without designating a lead to track information on additive manufacturing efforts, which is consistent with federal internal control standards, DoD officials may not obtain the information they need to leverage ongoing efforts.” (Merritt, Z. D. (2015). *DoD Needs to Systematically Track Department-wide 3D Printing Efforts*. GAO Reports, I-44. Retrieved from <http://www.gao.gov/assets/680/673099.pdf>)

In *A Design for Maintaining Maritime Superiority* (2016), The Chief of Naval Operations, ADM Richardson, identified, “the increasing rate of technological creation and adoption” as one of the three major interrelated global forces shaping today’s strategic environment. To achieve “high velocity learning at every level,” the paper cited the need to “Adapt processes to be inherently receptive to innovation and creativity.” The *Department of the Navy Additive Manufacturing Implementation Plan* states that, “The U.S. Navy and Marine Corps are realizing the potential of additive manufacturing to transform the Department of the Navy through innovation in design, rapid prototyping, and future applications that enable warfighter readiness and self-sustainment during operations.” Through the Department of the Navy’s Small Business Innovation Research (SBIR) Program, small businesses of 500 people or less have the opportunity to address naval needs in more than 30 science and technology areas. SBIR provides the fleet with innovative advances in technology developed by small firms. SBIR participants benefit both from program awards as well as the further development and commercialization of the resulting products. In addition, the Navy Small Business Technology Transfer (STTR) program is intended to foster transitions of joint efforts between qualified small businesses and research institutions to Navy and Marine Corps, in particular navysbir.com. Collaboration and brain storming methods have inspired new possibilities, critical thinking skills, and collaboration, through Design Thinking (DT), User Based Design, experimentation, rapid prototyping, and intrapreneurship. By identifying and connecting the nodes in these social innovation networks using open source data and voluntarily provided information, the Navy can amplify effects generated within additive manufacturing communities of interest to increase warfighter readiness and self-sustainment.

Findings and Conclusions

Researchers gathered data from various government sources in order to understand how the U.S. Navy and other Services/Agencies are funding additive manufacturing research and development. Initial data was gathered from the Small Business Innovation Research database (Small Business Administration, 2017) and the USASpending.gov database (USASpending.gov, 2017) for Prime Awards and Sub-awards that contained any of the following search terms: “Additive Manufacturing”, “Direct Digital Manufacturing”, or “3-D Printing.” The datasets were then combined using the identification numbers associated with the Prime Awards and Sub-awards, and additional searches were performed in order to supplement missing information from the initial searches.

Researchers at NPS collected 302 different additive manufacturing-related contracts for financial assistance (direct grant or cooperative agreement), 464 different contracts for Prime Awards, and 93 for Sub-awards covering the government fiscal years of 2008-2017. Twenty-five different agencies or bureaus and 119 different contracting and requesting offices were involved by either funding a Prime Award or Sub-award or by requesting funding for a specific project that was fulfilled through a Prime Award or Sub-award.

Social network analysis was used to longitudinally analyze funding for projects in order to see how the community of government offices and vendors working on additive manufacturing evolved over time. Networks were initially created by graphing connections of project requests and funding sources to Prime Awards and Sub-awards, and also by connecting Prime Awards and Sub-awards to the vendors receiving them. Agencies were connected to their contracting offices and requesting offices. Sub-awards were also connected to their Prime Awards. Overall, the additive manufacturing network has been increasing in size and decreasing in fragmentation (a measure of disconnectedness within a network). The periods when the network size increased the most tended to have a decrease in the clustering coefficient, but this is to be

expected when new vendors or contracting and requesting offices become involved in additive manufacturing. Over time, these vendors or contracting and requesting offices should be expected to have a higher level of clustering due to increased coordination and cooperation within the additive manufacturing community.

Key nodes were identified by analyzing the entire network across all time periods (2008 – 2017) and identifying nodes that spanned “structural holes” or gaps within the network. This analysis evaluates each node’s constraint, a brokerage measure for each node that calculates how infrequently a node lies in triadic brokerage positions (Burt, 1992; Everton, 2012). Nodes with low constraint have high brokerage, thereby spanning more structural holes (gaps in connectivity), and tend to be areas where new ideas or innovation may occur.

In addition to establishing contracting connections through funding requests or funding as discussed earlier, abstracts for the Prime Awards and Sub-awards were analyzed using latent Dirichlet allocation (LDA), a machine-learning algorithm that extracts sets of words that correspond to a common topic (Blei, Ng, & Jordan, 2003). This topic analysis was applied to the abstracts or product descriptions in order to determine whether the evolving communities coalesced around specific topics, or where there were potential areas for collaboration. Analyzing network topography measures over time, such as fragmentation and the local clustering coefficient, as well as measuring clustering associated with specific topics of interest could enhance the Navy’s ability to improve efficiency by optimizing resources.

This would potentially contribute to the rapid prototyping of additive manufacturing technologies. Structurally, nodes with low constraint have the most potential to facilitate the exchange of ideas or information about additive manufacturing by coordinating with a variety of different agencies, contracting and requesting offices, and/or vendors. The nodes with lowest constraint can be agencies, contracting and requesting offices, or vendors, because each of these different node types plays a different role in the network. Among the agencies with least constraint were the National Science Foundation, the Department of Defense, the Department of Energy, the Department of the Air Force, and the Department of the Navy. Among contracting and requesting offices with least constraint were National Aeronautics and Space Administration (NASA) Shared Services Center, FA8650 Air Force Materiel Command (AFMC) Air Force Research Laboratory Contracting Division (AFRL RQK), Office of Naval Research, the Defense Advanced Research Projects Agency (DARPA), and the DLA Enterprise Support Defense Supply Center Philadelphia (DES DSCP) Contracting Services Office. Among vendors with least constraint were: Ues, Inc; Materials & Electrochemical Research Corp; Nscrypt, Inc; Calram, Inc; and Questek Innovations LLC.

Clusters were identified within the overall additive manufacturing network by analyzing contractual connections among agencies, contracting and requesting offices, and vendors and by extracting sub-networks based on project topics. Abstracts for the Prime Awards and Sub-awards were analyzed using latent Dirichlet allocation (LDA). Overall, the additive manufacturing network has been increasing in size and decreasing in fragmentation.

Increasing clustering of individual innovators as well as agencies, contracting and requesting offices, and vendors around specific topics of interest across the whole of government could help eliminate redundancies or increase cost effectiveness. Searching out those who are working on similar ideas and

encouraging partnerships (when practical) would help bridge individuals and organizations to clusters within the network.

Recommendations for Further Research

Further work should be done to evaluate how best to institutionalize or encourage connectivity among agencies, contracting and requesting offices, and vendors by aligning them with shared topics of interest, in order to enhance the adoption and rapid prototyping of additive manufacturing technologies.

Further analyzing the additive manufacturing network topography measures over time, such as fragmentation and local clustering coefficient, as well as measuring clustering associated with specific topics of interest could enhance the Navy's ability to improve efficiency by optimizing resources.

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NPS-17-N318-A: A Comparative Study of Truths and Myths of Military Millennials

Researcher(s): Dr. Kathryn Aten, Ms. Anita Salem, and Ms. Sally Baho

Student Participation: No students participated in this research project.

Project Summary

Millennials will soon account for over half of the U.S. workforce. Organizations may need to adapt their practices to attract, motivate and retain top Millennial talent. Research shows that work-life balance, meaningful work and attention and recognition contribute to Millennial loyalty and *retention*. Further, Millennials are particularly concerned with relationships, in particular those with superiors. Millennials expect feedback, praise and guidance. Other common perceptions of Millennials (e.g., that they are needy and disloyal) may stem from differences in work values and motivations between generations. Researchers reviewed existing literature on Millennials in the workplace and conducted interviews of Millennials in the military to provide a context specific understanding of the work values, motivations and expectations of military Millennials. Data was compared across age groups, rank and gender.

Keywords: *Millennials, attraction, retention*

Background

The Secretary of the Navy's vision for 21st century Sailors is to improve readiness and maintain the resiliency of the force, as well as to maintain combat effectiveness by improving the health and well-being of Sailors and Marines, and acknowledges that to achieve this, the Navy needs a strong organizational culture that instills loyalty, rewards performance, and offers work-life balance. Ongoing changes in our nation's and the Navy's demographics, including evolving social attitudes toward work, job satisfaction, and family life, will influence best talent management practices and the Navy's ability to recruit, develop and retain sufficient high value talent.

If widely held assumptions about inter-generational differences are correct, then differences among Boomers, Gen Xers, Gen Yers (aka Millennials), and Gen Zers will likely have a pronounced impact on retention. But – *are* inter-generational differences as profound as the literature suggests? Particularly when it comes to high value talent in the Navy? And, if so, what are the implications of these differences? Importantly, whether real or perceived, generational differences, affect leadership and communication styles, values, and beliefs.

The literature can be divided into several streams. Some authors see distinct inter-generational differences between Boomers and Gen Xers, and Gen Xers and Millennials (or Gen Yers). Others think that where individuals are in terms of their stage of life is more important than which generation they belong to. And yet others contend that any perceived differences are best explained by societal trends that have impacted everyone. Further, although approximately 50% of Navy personnel are said to be Millennials, scholars note that it is too early to generalize about Millennials accurately; not enough data has yet been collected.

Findings and Conclusions

This study investigated, “How do Navy Millennials perceive themselves (self perceptions), how do they believe that others perceive them (theorized perceptions), and how do Gen X leaders perceive Millennials (leaders’ perceptions)?”

Many inside and outside of the U.S. Navy believe that differences between Millennials and younger generations, will require that organizations adapt their practices to attract, motivate, and retain top Millennial (GenY) talent. A review of research on generational differences found that although there are some differences between Millennials and other generations—Millennials increased familiarity and use of technology and greater self-focus—there are few differences between the generations’ expectations of leadership, incentive preferences, and work ethic. However, although generational differences are slight and are confounded with cohort, age, and period effects, there is a *perception* of difference. This study investigated self, theorized, and leaders’ *perceptions* of Millennials and how *perceived differences* may affect Navy work and life.

The research team conducted eighteen interviews at the Naval Postgraduate School in Monterey, CA. Interviews were conducted by one or two researchers. Nine of the interview participants were Millennials (born 1980-2000) and the other nine were Gen Xers (born 1960-1980). Demographic information was collected prior to the interview. Interviews were semi-structured and followed an initial guide focused on their experiences of as a Millennial and their perceptions of stereotypes of Millennials. Participants were encouraged, however, to elaborate and to discuss issues they believed to be important. Interviews lasted approximately 30 minutes. Interviews were audio recorded and transcribed, resulting in 202 pages of transcripts. The researchers conducted interviews with nine GenY (Millennial) sailors and nine (GenX) leaders. The interviews centered on five categories of difference identified in the previous literature review (shown above). Researchers analyzed the data using qualitative data analysis software to code group the data and generate word clouds. The analysis resulted in themes related to each initial category, which were compared across the two generational groups.

Interviews indicated the following shared theorized and leader perceptions: Navy Millennials are adept at socializing and communicating with technology, are more self-interested than other generations, are stereotyped as lazy, required different leadership styles, and have similar motivations for joining and staying in the Navy. Navy Millennials, however, perceived themselves as exceptions to some of these characterizations. Five global and societal trends are more likely to be enduring influencers of Navy culture than generational differences. Navy talent management policies and practices should focus on these trends, rather than generational differences.

This explorative study of self, theorized and leader perceptions of Millennials suggests that more nuanced factors than generational differences should be considered when assessing workforce trends and related Navy policies and programs. The stereotype of the lazy, self-focused Millennial was resisted by both age groups we studied because it was viewed as an oversimplification and not useful for guiding leadership or policy. Other factors were seen as much more important—societal changes, the economy, and personal differences. Both GenX and GenY participants noted two mitigating factors in the military that may explain participants’ resistance of the stereotype. One mitigating factor is that the military is a unique environment that may supersede slight generational influences. Another mitigating factor is that generational differences are confounded with other trends influencing modern life. Participants noted that maturity and the changing societal culture are more important influencers of behavior than the date one was born.

Recommendations

The two prominent beliefs about generational stereotypes—that the military is unique and that the stereotypes are oversimplified—drove many participants to focus on factors that they felt *did* affect recruitment, promotion, and retention of service members. These factors include maturation effects, the rise of informationalism, changing geopolitics, changing work places, and the role of culture.

This is good news for the Navy. Instead of chasing the tail of Millennials, and then Generation Z, and then Generation 2050, the Navy can focus its policies on the arc of change. For instance, recognizing the rapid pace of technology change, we can predict and plan for the integration of machines and humans, the use of manipulatable virtual environments, the growth of artificial intelligent agents, the development of extreme networks, the collapse of networks due to cyberattacks, and the appropriate use of 'big data'. The Navy can then plan for the 'likely' by developing future scenarios that are based on researched trends and are evaluated regularly. The result is focused contingency plans that allow the Navy to plan, yet adapt. For instance, in the case of technology, the Navy may move towards specialized skill sets, encourage peer-to-peer communications, offer continuing education options, and/or decentralize and virtualize training.

By understanding the trends that are in play, and by making contingency plans for mitigating risks and leveraging opportunities, the Navy can avoid a reactionary cycle of personnel management.

Recommendations for Future Research

This was an exploratory study designed to identify and describe *perceptions* of Navy Millennials. The exploratory nature of the study supported the use of interviews and purposeful sampling. This approach, however, results in some limitations. The study relied on a small number of interviews (18) and although participants varied across many demographic characteristics and rank, they were not selected randomly and are not representative of the diversity of Navy personnel. Participants were predominately white, male, educated, and middle class. In addition, Marines are not represented in this study.

This study suggests that social, technological, and political trends are important influencers of work attitudes likely to affect all generations. These trends are evolving and most likely enduring for all age groups. Future research should test and confirm these exploratory findings using random survey data and quantitative analysis techniques to assess perceptions across the identified themes and a broad cross-section of the Navy. If this study's exploratory findings are confirmed, education and policies should focus on larger social, technological, and political trends that affect all ages, rather than on generational differences. Additionally, research should track these trends over time.

ASN (RDA): RESEARCH, DEVELOPMENT & ACQUISITION

NPS-N16-N242-A: Surface Combatant High Energy Laser Weapon Viability in Various Marine Atmospheres

Researcher(s): Dr. Keith Cohn and Dr. Joseph Blau and Mr. Paul Frederickson

Student Participation: LT Rene Martin USN, LT Herbert Heaney USN, LT Joseph Collins, USN, LT Joshua Valiani USN, LT Daniel Martell USN, LTJG Hayati Emir TNF and ENS Donald Puent USN

Project Summary

Continuing our past research into directed energy (DE) weapons and modeling, we have analyzed the performance of a notional 30 kW to 400 kW laser weapon integrated onto a surface combatant. This analysis modeled the laser from the source, through a turbulent atmosphere, toward a target at various ranges and altitudes using the laser performance tool ANCHOR (developed by the Physics Department) integrated with the optical turbulence model NAVSLaM (developed by the Meteorological Department). We have conducted additional modeling using the full diffraction code WaveTrain (from MZA Associates Corporation). This study also focused on characterizing the turbulent characteristics in different operational theaters, investigating the interplay between turbulence and thermal blooming on laser performance, measuring the severity of ship-induced turbulence and modeling its impact 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, ship-induced turbulence

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 is near the laser source. 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, the Assistant Secretary of the Navy 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 tasks. We will discuss each one separately. Much more complete descriptions of each task are available in the corresponding student theses relating to that task.

Task 1: Characterization of Turbulence

Students: LT Daniel Martell and LT Herbert Heaney

This task encompassed two main objectives: to model the turbulence over geographical regions surrounding potential operational theaters, and to evaluate turbulence over the deck of the ship. The former objective helps establish the expected range of turbulence values at different locations and different times of the year. The latter objective required performing an experiment aboard the Self Defense Test Ship to acquire actual turbulence data.

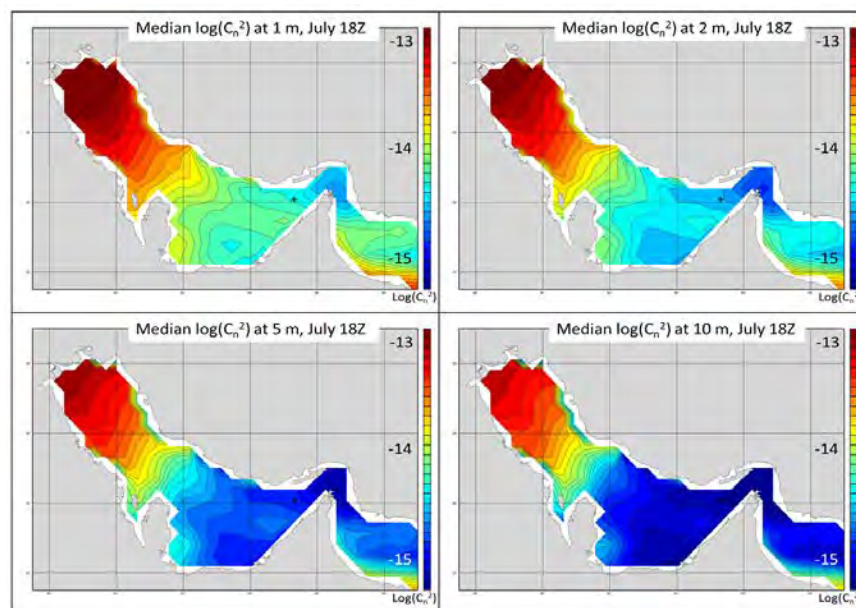


FIGURE 1: TURBULENCE PROFILES AT DIFFERENT ALTITUDES ABOVE THE SURFACE OF THE ARABIAN GULF.

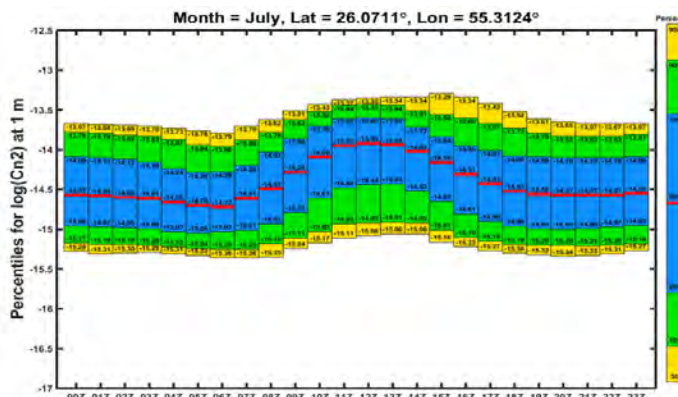


FIGURE 2: PERCENTILE TURBULENCE PLOTS AT DIFFERENT TIMES THROUGHOUT A SUMMER DAY NEAR THE STRAIT OF HORMUZ.

Turbulence in potential theaters was estimated using climatological data from the Climate Forecast System Re-analysis database and the Navy Atmospheric Vertical Surface Layer Model (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, which illustrates the level of turbulence at various altitudes above the Arabian Gulf on a median July day at 1800Z.

Furthermore, percentile plots were produced that characterized mean turbulence values and likely spreads in those values over the course of the day and year. Figure 2 shows a turbulence percentile plot, generated in a similar manner as described before, near the Strait of Hormuz throughout a summer day. It illustrates the anticipated range of C_n^2 values for different times of the day, where the median value is indicated by a red stripe. These sorts of plots can then be used to generate turbulence profiles relevant for weapons modeling in regions of interest.

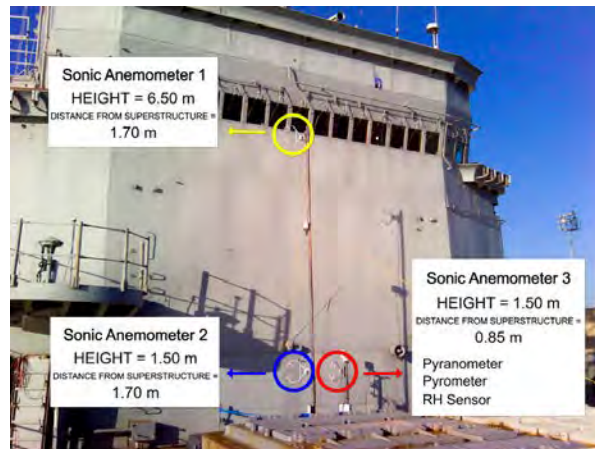


FIGURE 3: LOCATION OF THE SONIC ANEMOMETERS AND OTHER SENSORS ABOARD THE SDTS.

For the second objective, we measured turbulence profiles aboard the Self Defense Test Ship (SDTS). This study, conducted in coordination with Space and Naval Warfare Systems Command (SPAWAR) Pacific, involved installing nearly a dozen sensors at multiple locations to measure sonic temperature, ship bulkhead temperature, humidity, and solar irradiance. Specifically, three sonic anemometers were placed just forward of the pilot house at different heights above the deck and distances from the bulkhead (see figure 3). This was to gauge the influence of those surfaces on turbulence. The anemometer data, in conjunction with the other sensors, was converted to C_n^2 values.

The results of these measurements are limited distribution and not available for public release.

Task 2: Implement New Thermal Blooming Models into ANCHOR

Students: LT Joseph Collins and LTJG Hayati Emir

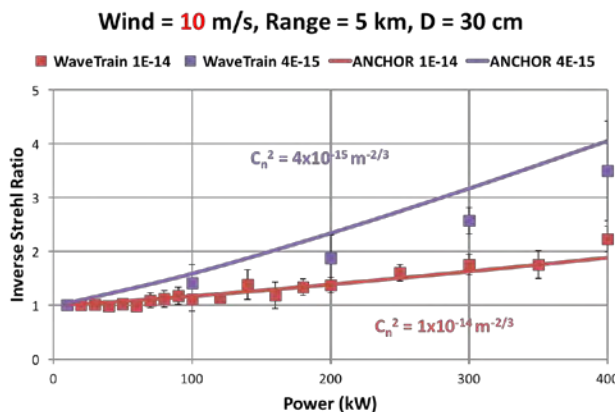


FIGURE 5: COMPARISON OF ANCHOR'S ENHANCED THERMAL BLOOMING MODEL (SOLID LINES) WITH THE FULL DIFFRACTION CODE WAVETRAIN (DOTS WITH ERROR BARS) FOR TWO DIFFERENT TURBULENCE LEVELS. THE STRONGER TURBULENCE VALUE (IN MAROON) SHOWS LESS VARIATION WITH OUTPUT POWER, AS EXPECTED.

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. Specifically, strong turbulence disrupts the focus of the beam; as result, this can reduce the impact of thermal blooming. Full diffraction codes model the turbulence and thermal blooming in a self-consistent way. Analytic codes like ANCHOR, while much faster to execute, attempt to account for the relationship between turbulence and thermal blooming in a more *ad hoc* manner.

To do this, we used a self-consistent diffraction code (WaveTrain) 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 large parameter space between all of the variables. Finally, we incorporated these models into ANCHOR.

Figure 5 shows a comparison between the enhanced ANCHOR thermal blooming model (solid lines) and WaveTrain (dots) for two different levels of turbulence. ANCHOR correctly predicts that the influence of thermal blooming is smaller for stronger turbulence; it also correctly predicts the Strehl ratios up to a laser output power of 400 kW (within the margin of uncertainty of the WaveTrain results).

Further enhancements to ANCHOR were provided to account for the varying amounts of effective crosswind along the propagation path of the laser. Effective wind is the vector sum of the actual wind and the slew velocity between the source and the target at each point along the path; an effective wind of zero indicates the location of a stagnation zone that can result in strong thermal blooming. Thus, the effective motion between the target and ship plays a vital role in the amount of blooming. Again, the Strehl ratios predicted by ANCHOR were compared to the output of WaveTrain; an example of the results are shown in Figure 6. In these radial plots, the ship is located at the center, and the Strehl ratios are plotted as a function of azimuth. The motions of the ship, target, and wind are listed in the caption. The asymmetry of the Strehl ratio from both codes is due to the changing location of the stagnation zones at different azimuths.

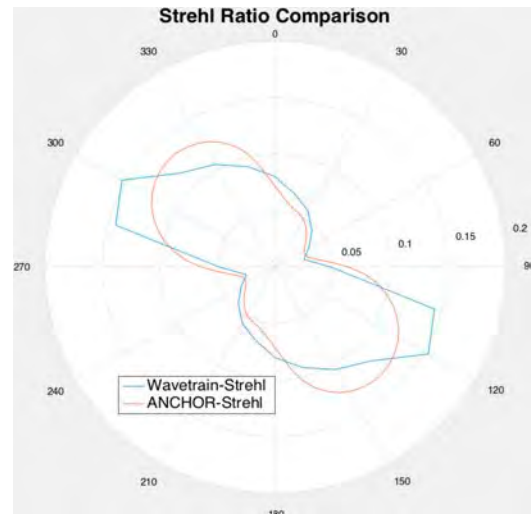


FIGURE 6: COMPARISON OF ANCHOR AND WAVETRAIN FOR A 100 KW LASER WITH THE SHIP TRAVELING NORTH (TO THE TOP) AT 10 M/S, THE TARGET TRAVELING EAST (TO THE RIGHT) AT 10 M/S, AND THE WIND BLOWING TOWARD THE NORTHEAST AT 14 M/S. THE RADIAL AXIS IS THE STREHL RATIO AND THE ANGULAR AXIS IS AZIMUTH.

Tasks 3 and 4: Evaluate Laser Performance Using ANCHOR and WaveTrain

Students: *LT Joshua Valiani and LT Rene Martin*

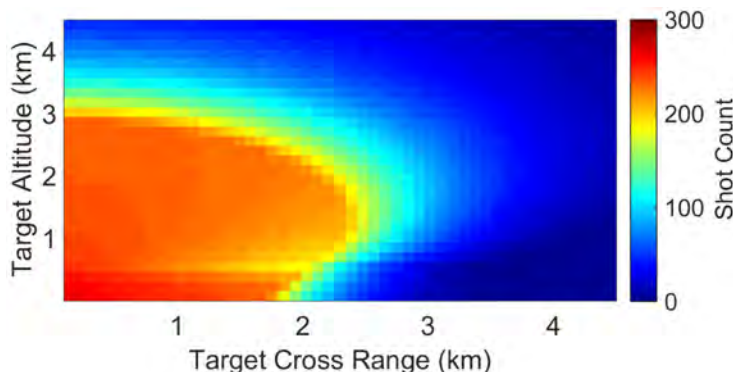


FIGURE 7: NUMBER OF SHOTS AVAILABLE FROM A NOTIONAL 500 KW LASER WITH A LITHIUM ION BATTERY ENERGY STORAGE DEVICE. THE LASER PLATFORM IS LOCATED AT THE ORIGIN OF THE PLOT, THE TARGET POSITION IS INDICATED BY THE HORIZONTAL AND VERTICAL AXES, AND THE COLOR REPRESENT THE NUMBER TARGET KILLS BEFORE THE BATTERY REQUIRES RECHARGING.

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. An example is shown in figure 7. Here, ANCHOR has been modified to provide the number of shots available in a given energy storage configuration based upon the target's range and altitude, the laser parameters, and the atmospheric conditions. This particular study indicated that if the goal is to

maximize shot count before depleting the available energy storage, it may be advantageous to dial back the laser's output power in certain situations.

Additionally, we used the turbulence data from the SDTS experiment in task 1 to estimate the influence of ship-induced turbulence on target irradiance. Since we only experimentally measured turbulence over the ship, we used NAVSLaM to estimate turbulence over the water based on nearby buoy data. For this analysis, we used WaveTrain, varying the turbulence along the beam depending on whether the path was over the ship (where we used experimentally observed turbulence values) or over water (where we relied upon NAVSLaM). The results from this study are limited distribution and not available for public release.

Task 5 and 6: Incorporate Atmospheric Compensation into ANCHOR

Student: ENS Donald Puent

Atmospheric compensation techniques may be implemented to mitigate the harmful effects of turbulence on laser propagation. However, these techniques can significantly increase the cost and complexity of the laser system. Therefore, it is imported to establish (1) whether atmospheric compensation will be necessary for realistic engagement scenarios, and (2) to what extent it will improve performance.

Fortunately, several astronomical telescopes have used adaptive optics (AO) for years; members of the astronomy community have developed several simple techniques to estimate the improvements imparted by AO that can be applied to laser weapons. These methods account for the number of actuators in the deformable mirror, the bandwidth of the AO system (related to the update frequency of the deformable mirror), and the signal-to-noise ratio of the wavefront sensor. Examples of different AO implementations are shown in figure 8.

Student Thesis Involvement

LT Daniel Martell, USN, Applied Physics (December 2015), "Atmospheric Characterization of the Marine Boundary Layer for a Submarine-Based High Energy Laser."

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."

LTJG Hayati Emir, Turkish Navy, Applied Physics (June 2016), "Effects of Relative Platform and Target Motion on Propagation of High Energy Lasers."

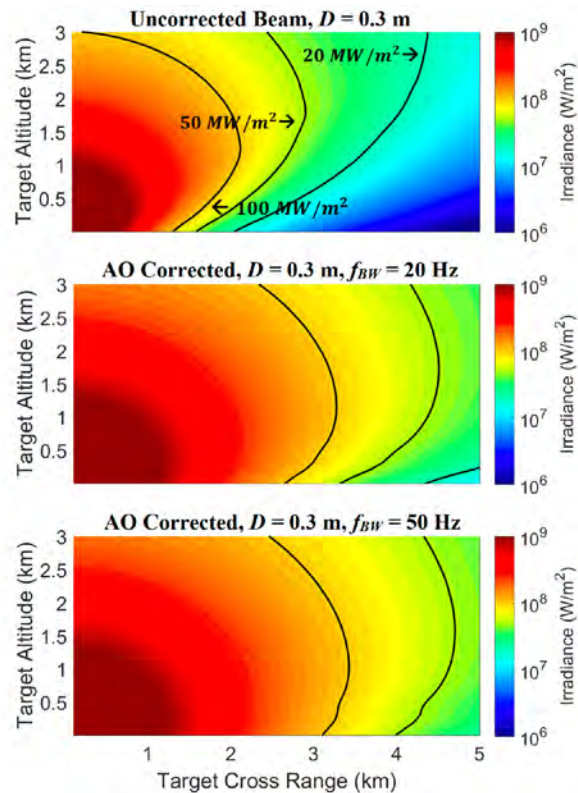


FIGURE 8: Peak irradiance plots for a system with no AO (top), an AO system with a bandwidth of 20 Hz (middle), and one with a bandwidth of 50 Hz. The contours represent different peak irradiances, as indicated at top.

LT Herbert Heaney, USN, Applied Physics (June 2017), “Investigation of ship-induced turbulence effects for the laser weapons system demonstrator.”

LT Rene Martin, USN, Applied Physics (June 2017), “High energy laser performance based on ship-induced turbulence effects.”

ENS Donald Puent, USN, Applied Physics (June 2017), “Integration of adaptive optics into high energy laser modeling and simulation.”

Recommendations for Further Research

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. We also recommend further improvements to ANCHOR, including incorporation of the Navy Atmospheric Vertical Surface Layer Model (NAVSLaM) 2.0, further validation with experiments and wave propagation models, and possible incorporation into a future simulation experiment (SIMEX).

NPS-17-N003-A: Reference Architecture Model Demonstrating Model Centric Systems Engineering

Researcher(s): Dr. Kristin Giammarco, CDR Christopher Wolfgeher USNR, Ms. Marianna Jones, Mr. Bruce Allen, and Dr. Mikhail Auguston

Student Participation: Mr. William Carlson, NUWX Division, Keyport, Mr. Ernest Lemmert, NUWX Division, Keyport, SI4022 Students of Cohort 721-171, SE4151 Students of Cohorts 311-163A and 721-161, and SE4935 Students of Cohort 721-161

Project Summary

This research aims to improve the development and analysis of architecture models throughout the Program Executive Office, Unmanned Aviation and Strike Weapons (PEO U&W) based on the Unified Modeling Language (UML) Profile-based Integrated Architecture (UPIA)-inspired Generic Model guidance published by the Architecture Modeling for Systems Engineering Working Group (AMSEWG). To test its tool-neutrality, the Generic Model language is reproduced in tools other than Rational Software Architect (RSA), the native tool in which the Generic Model was developed. In the course of this research, the Generic Model language was successfully reproduced in Alloy, a formal language, and in Innoslate, a model-based systems engineering (MBSE) tool. The results of this research include new patterns, templates and style guidance for architecture-level model views, which can be used to inform the continued evolution of Generic Model guidance with practical lessons from the architecture modeling research community. We show graphical templates for structuring executable behavior models using the Lifecycle Modeling Language (LML), and discuss the benefits and limitations of these templates. The results also found that Monterey Phoenix (MP) tools MP-Firebird and MP-Python are capable of representing aspects of the Generic Model language that pertain to behavior, bridging the Generic Model language to the scenario generation capabilities of MP. The graphical templates and MP modeling in this research lay the groundwork for follow-on work to automate the translation of graphical behavior models into MP to leverage its scope-complete scenario generation, emergent behavior identification, verification, and validation capabilities.

Keywords: MBSE, LML, UPIA, Monterey Phoenix, architecture patterns, behavior modeling, formal methods

Background

In 2016, a model reference architecture and development guide (Generic Model) was created by the AMSEWG for use by PEO U&W programs of record at the U.S. Navy Naval Air Systems Command (NAVAIR). This reference model provides examples of Department of Defense Architecture Framework (DoDAF) views that seek to normalize the structure of views throughout the PEO, regardless of which program they are developed in, so that all PEO U&W architecture models share a common look and feel, minimizing ambiguity and facilitating stakeholder reviews. Two needs have been recognized to promote the broader adoption of the Generic Model: 1) the Generic Model needs to be tool-agnostic, so that it may be used as guidance by architects using various tools, and 2) the Generic Model needs to contain guidance for executable architecture modeling, which is increasingly being recognized as an important capability for the early verification and validation of static DoDAF models being used as a specification for detailed design.

NPS has a competency in architecture modeling research that will be used to address these needs. Identification of tool-agnostic patterns in architecture models was the subject of Giammarco's PhD dissertation in 2012, which identifies recurring patterns of entities and relationships using a high-level DoDAF and Unified Profile for DoDAF and MoDAF (UPDM) –based conceptual data model, culminating in the definition of non-interoperability patterns against which architecture models may be tested. Preliminary and follow on publications (Giammarco, 2010) (Giammarco, Xie, & Whitcomb, 2011) (Giammarco, 2014) (Lew & Giammarco, 2014) (Rodano & Giammarco 2014) describe the approach in general terms. The tool-independent Lifecycle Modeling Language (LML) is used for its ability to express generic patterns that can be reused throughout different system architectures. The Monterey Phoenix language is also relevant in that it promotes the early exposure of modeling errors and unwanted behaviors. MP has a demonstrated ability to expose incorrect, hazardous, unsecure, or otherwise undesirable behaviors in processes and system designs so that they can be removed or mitigated before they manifest in an actual system (Auguston, Whitcomb, & Giammarco, 2010) (Giammarco & Auguston, 2013) (Giammarco et. al, 2014) (Auguston et. al, 2015).

In response to the needs expressed by NAVAIR, we established the following research objectives:

- [1] Assess the reproducibility of the RSA-native Generic Model in other tools, specifically in Innoslate and Monterey Phoenix
- [2] Produce tool-agnostic patterns and style guidance
- [3] Test the executability of successfully reproduced Generic Model behavior views in Innoslate and Monterey Phoenix
- [4] Provide tool-agnostic instructions for creating and analyzing executable activity models

Findings and Conclusions

The research employed a methodology starting with data collection on the Generic Model, and a request for a NAVAIR architecture model already expressed using the Generic Model for use as a verification and validation (V&V) case study. Exports from the RSA tool were provided by NAVAIR and used as the primary source data to reproduce the Generic Model. Upon inspection of the source data, it became clear to the research team that the Generic Model is in fact comprised of a collection of example templates for an architecture model using the UPIA conceptual data model as a language. The team then proceeded with modeling classes of the UPIA present in the Generic Model in Alloy, to create a single, integrated

formal model of the Generic Model schema since only example instances exist. The Alloy language was chosen because the Alloy Analyzer tool can generate example instances of the Generic Model automatically, supporting the research objective to test tool neutrality of the Generic Model. By representing the Generic Model in Alloy, we effectively re-generated the contents of the provided source data (minus some classes that were not modeled due to schedule constraints), plus additional possible scenarios that were not present in the original file. This work is described in Chapter 3 of the technical report.

The next step was to review existing patterns and style guidance for architecture models, which led to the formalization and publication of new and existing heuristics and corresponding analytics expressed at the level of a conceptual data model language. The preliminary work used the LML since it has a deliberately high level of abstraction. As the project progressed, we translated the LML expressions into UPIA (Generic Model), DoDAF Meta Model (DM2), and System Description Language (SDL) conceptual data models. We then developed some examples of well-formed architecture models that adhere to the defined heuristics. This work is described in Chapter 2 of the technical report.

Since a model of an actual system expressed in Generic Model language was not available, an existing Unmanned Aerial Vehicle (UAV) model from a different project supporting the same sponsor was substituted. The UAV model is represented in Innoslate and Monterey Phoenix. Since Innoslate uses LML, the Innoslate entities were labeled according to UPIA conceptual data model equivalents to provide a mapping to the Generic Model. These mappings are available natively in the Innoslate model accompanying the deliverables.

Innoslate was used to develop most of the architecture views (connectivity, hierarchy, traceability, functionality, behavior) while MP-Python (a Monterey Phoenix tool) was used to test the executability of system behavior in particular. This work is described in Chapter 5 of the technical report.

In order to facilitate analysis of graphical behavior models, executable behavior models were developed in Innoslate. A number of generic behavior model templates showing good modeling practices were developed to supplement the Generic Model. This work is described in Chapter 4 of the technical report.

Finally, we evaluated the findings from the research and summarized these as conclusions and recommendations in Chapter 6 in the technical report. The conclusions are summarized as follows.

We had the objective to assess the reproducibility of the RSA-native Generic Model in other tools, specifically in Innoslate and Monterey Phoenix. We accomplished this objective as follows. The Generic Model, as a set of example architecture instances using class and relationship names from the UPIA, contained all the elements needed to formally specify and graph a metamodel, or conceptual data model. As shown in Chapter 3, we found that the Generic Model was easily modeled in the lightweight formal methods language Alloy, and that we could graph the UPIA-based conceptual data model automatically from the provided example instances. We further found that we could reproduce the example instances in the source data along with many more examples, automatically, using the Alloy Analyzer tool. Having formalized the Generic Model in Alloy, we found straightforward mappings between the UPIA-based Generic Model language and the LML used by Innoslate. The Alloy Generic Model contains relevant signature mappings to LML classes, and an Innoslate model containing the example patterns in Chapter 2 has relevant mappings of LML classes to their counterparts in UPIA. The Monterey Phoenix models in Chapter 5 are behavior models, and we found that root events typically map to the UPIA CapabilityRole class (LML Asset class), and that composite and atomic events typically map to the UPIA OperationalTask

class (LML Action class). Since MP's capability focuses on generating behavior scenarios, it follows that only the behavior-related classes carry over to the MP models.

We had the objective to produce tool-agnostic patterns and style guidance. We accomplished this objective as follows. We created, updated and translated LML architecture heuristics and analytics into three other conceptual data model languages: DM2, UPIA, and SDL. The expressions in Chapter 2 of the technical report show the conceptual data mappings across these four languages (LML, DM2, UPIA, and SDL), and by extension, any tool that implements any of these languages. Furthermore, we present additional examples of well-formed architecture models as patterns, which formally capture best modeling practices of experienced architects. The patterns in Chapter 2 are ready for transition to extend the Generic Model specification.

We had the objective to test the executability of "successfully reproduced" Generic Model behavior views in Innoslate and Monterey Phoenix. The interpretation of this objective changed as we learned more about the intent of the Generic Model, to provide examples of well-formed views based on a UPIA schema. We pursued this objective by discussing executable models in Innoslate and Monterey Phoenix, which were already shown to contain mappings to the Generic Model concepts. The Ingress phase of the Innoslate UAV model was discussed in Chapter 2, notional (generic) patterns for executable models in Innoslate were discussed in Chapter 4, and all four MP UAV model phases (Ingress, OnStation, Egress, and Postflight) were discussed in Chapter 5. The models were executable in simulation, each providing a timeline of events that could, in future work, be configured with durations and other attributes.

We had the objective to provide tool-agnostic instructions for creating and analyzing executable activity models. We accomplished this objective in Chapter 4, with instructional content about the executable logic constructs available in LML and eight templates for executable action diagram structures. These templates have some pronounced strengths and limitations. A major strength of the templates is that their diagram structures enable expression of behaviors in multiple systems or different parts of the same system, and in the environment. The triggering input/outputs are used to create dependencies between actions on different branches. They show how to expand behavior descriptions beyond simple system behavior, to include system of systems behaviors and dependencies. We discovered a limitation when using "or" and "sync" action pairs inside loops. The "sync" action depends on the timing of its preceding activities, so if nested inside a loop, caution must be used in applying durations to the sync branch actions such that they keep pace with the triggers being sent to them from the corresponding "or" action. Otherwise, a sync branch from a previous loop iteration can be still running during a current loop iteration.

NPS Master's and PhD students participated throughout the research, bringing valuable insights to the project in exchange for gaining modeling experience. Chris Wolfgeher, a Systems Engineering PhD student, was instrumental in the digestion and modeling of the Generic Model source data. Students taking courses SE4151 System Integration and Development (Curricula 311, 721, 581), SE4935 Formal Methods for System Architecting (Curricula 581, 721), and SI4022 System Architecture (Curriculum 721) developed, verified, and/or validated the UAV model used as examples for the templates. Two PD21 students in particular, Ernest Lemmert and William Carlson, have adopted thesis topics that supported the templates and patterns aspect of this research. Lemmert summarizes the strengths and weaknesses found in various languages. Taking a domain-specific bottom-up approach, Carlson explores process

model structure impact on the decision process for the operation of an acoustic range conducting an underwater vehicle test, which generalize to systems of interest to NAVAIR.

The advancements delivered from this project are intended to support NAVAIR's mission accomplishment, especially in improving and promoting the ideas behind the Generic Model, to have uniform standards for the quality and presentation of both static and executable architecture models, and to make design errors and issues easier to detect across programs.

Recommendations for Further Research

Since the inception of this project, NAVAIR has made language and tool selections beyond the scope of those used in the research, including SysML, MagicDraw, and Cameo. We recommend that follow on research include extending the translations of the work herein to include these languages, and testing the translations operationally in the tools being used. Translating the heuristics and analytics into the preferred ontology, as well as generating templates for static and executable architecture models in the preferred tools, should be among the tasks of future work. The templates have many common logic constructs found in other languages, making them transferable, reusable, and valuable beyond the language and tool in which they were developed.

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NPS-17-N004-B: Development and Validation of SE-Based T&E Methodology for Assessing UxS Autonomy

Researcher(s): Dr. Oleg Yakimenko

Student Participation: See Table 1

Project Summary

This research applied the Systems Engineering (SE) methodology to explore different aspects of planning, instrumenting, conducting and reporting the results of the developmental tests and early operational assessments of unmanned systems (UxS) possessing different levels of autonomy (LoA). UxS autonomy is defined by its ability of sensing, perceiving, analyzing, communicating, planning, decision-making, and acting/executing to achieve its goals as assigned by its human operator through designed human-robot interaction. This research considered different classifications of UxS, LoA, and transfer them into the domain of novel capabilities. These capabilities formed a framework for the functional analysis and decomposition and served as a basis for developing SE verification and validation procedures including metrics, processes, and tools for evaluation/measurement. In total this project involved 30 students. Twenty-five distance-learning students were working in six groups and developed test and evaluation plans for six different notional systems based on a variety of individual UxS and their combinations. One of the major top-level functions for these systems was identified as assuring continuous situational awareness. As a result, four resident students continued working of utilizing available passive electro-optical and infrared sensors to assess the current technology level in terms of using image processing and neural networks to execute scene segmentation and object classification. Several computer algorithms were developed for different applications / missions and tested in computer simulations. Some of them were then converted into real-time code and tested using enhanced commercial-of-the-shelf UxS.

Keywords: *unmanned systems, test and evaluation, autonomy, capabilities, scene recognition, object classification*

Background

Increasing capabilities of and roles the unmanned systems (UxS) are supposed to play in the future warfare [1]-[7] poses significant and unique challenge to the Department of Defense (DoD) test and evaluation (T&E) community.

The current UxS assuming remote control, simple automation, scripted missions, or simple decision making will soon to be replaced with more sophisticated systems allowing more autonomy including responding to changing operational environment, adaptation to dynamic mission change, multi-mission reasoning, and networking in heterogeneous multi-agent operations with centralized and decentralized control architecture.

T&E of manned aircraft has a long history and is now well established. It tests aircraft performance assuming that it is operated by a qualified and capable operator. T&E procedure, therefore, does not test operator's capabilities relying on his judgement and typical set of skills. To date, the same more or less standard methods and approaches (including execution of specifically planned scenarios) have been utilized to evaluate performance of the current UxV as well. It is done under the same basic assumption that there is a human being capable of operating the airframe and its systems even though he/she resides

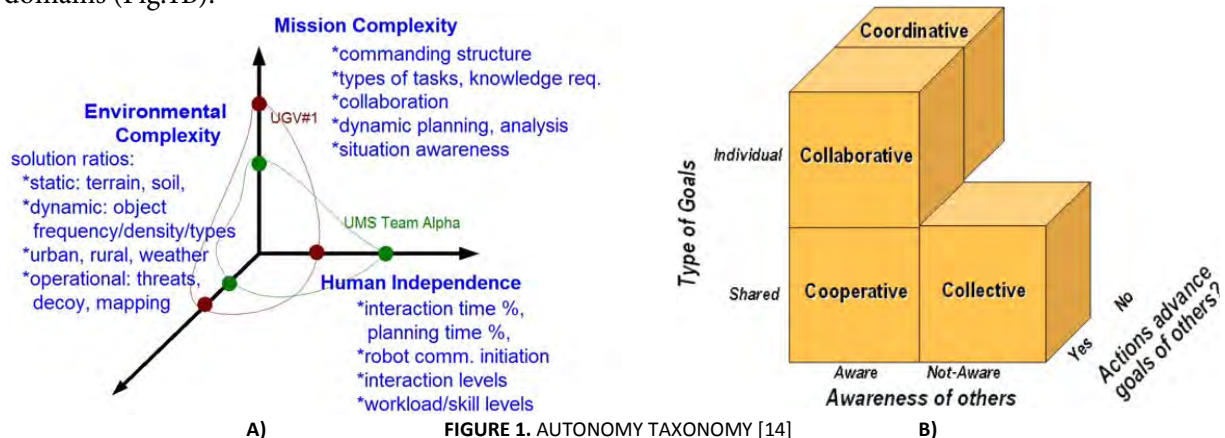
on the ground. Increased capabilities are therefore associated not necessarily with onboard software being able to execute complex missions (or typical tasks) autonomously, but on the multi-person ground operator teams working in shifts. On the contrary, fielding the future UxS will require evaluating not only their standard performance, but understanding and validating their non-scripted decision making process in response to a dynamic environment, i.e. their autonomy characteristics. Hence, maturation of the autonomy should be parallel to the development of the processes to properly assess it.

Findings and Conclusions

This project aimed to develop a T&E methodology to properly assess performance and autonomy of existing and future UxS. The developed methodology is based on the Systems Engineering (SE) approach trying not to deal with the fuzzy definition of the level of autonomy [8]-[12], but rather establish and document novel capabilities that future UxS should bring to the table. As such, it specifically addressed the existing DoD gap presented in the Defense Science Board (DSB) Task Force Report on the Role of Autonomy in DoD Systems [13],[14].

Autonomy of UxS is defined by its own ability to sense, perceive, analyze, communicate, plan, make and effectively execute decisions, to achieve its goals as assigned by its human operator through designed human-robot interaction (HRI). As such, a straightforward approach establishes four levels of autonomy (LoA) as perception, modeling, planning, execution, and aims at treating (assessing) these autonomous levels separately from autonomous performance. Hence, this approach does not provide an evaluation of UxS' autonomous performance, but rather encapsulates its potential to operate autonomously.

A more sophisticated approach, ALFUS, considers aforementioned autonomy enabling functions in an integrated manner [8],[9]. As such it deals with an unmanned aircraft system (UAS)'s contextual autonomous capability characterized by the missions that the system is capable of performing, the environments within which the missions are performed and human independence that can be allowed in the performance of the missions (Fig.1A). This approach is referred to as the Contextual Autonomous Capabilities (CAC) model. Each of the aspects, or axes, namely, mission complexity (MC), environmental complexity (EC), and human independence (HI) could be further attributed with a set of metrics to facilitate the specification, analysis, evaluation, and measurement of CAC of particular UxS. Fig. 1A illustrates that a specific UxS can possess different levels of “autonomy” in each dimension, and therefore it is difficult to characterize its non-context “autonomy” level as a whole. In fact, there may be even more dimensions that need to be characterized. For example, looking along the Mission complexity axis in Fig.1a the “collaboration” item can in turn be broken into a three-dimensional subspace representing a variety of missions that can be executed by a group of (heterogeneous) UxS operating in the different domains (Fig.1B).



The CAC model facilitates the characterization of UxS from the perspectives of requirements, capability, and levels of difficulty, complexity, or sophistication. This model also provides ways to characterize UAS's autonomous operating modes. The three axes can also be applied independently to assess the levels of MC, EC, and HI (the latter axis is also referred to as the axis for LoA).

Despite of obvious disadvantages of this approach in that it does not provide the explicit tools to decompose the tasks, assess interdependency between metrics, develop objective scoring scales and consequently integrate multiple metrics, this research attempted to do the first steps in understanding the high-level requirements, converting them into functions and farther to novel capabilities for several notional systems that would possess certain LoA in at least one of multiple dimensions.

The SE approach allowed to analyze UxS autonomy via transferring a problem into the capabilities domain. Specifically, six systems considered within the first part of this research were supposed to provide some basic (must-to-have) autonomous capabilities as followed:

- See and avoid for a single unmanned aerial vehicle (UAV)
- See and avoid for a single unmanned surface vehicle (USV)
- Search and rescue (SAR) for a small team of cooperative UAVs
- Broad area intelligence, surveillance and reconnaissance (ISR) for UAV swarm
- ISR for a system comprised of UAV and unmanned ground vehicle (UGV)
- ISR for a system comprised of UAV and USV

Twenty-five MS students from the Systems Engineering (311) curriculum (Table 1) worked on developing notional T&E master plans for the aforementioned systems. The analysis started from analyzing and formulating the operational mission needs followed by establishing novel operational requirements to the aforementioned systems. Functional decomposition and capabilities dendritic scheme enabled to define critical operational issues (COIs), measures of effectiveness (MOEs) and performance (MOPs). The latter defined notional operational scenarios, T&E vignettes and suggested required instrumentation.

TABLE 1. SYSTEMS TEST AND EVALUATION CLASS.

Student	Site	Rank/Service/Country
Alexandris, Alexis	Jacksonville, FL	Civilian
Araya, Kahsay	Patuxent River, Maryland	Civilian
Armstrong, Paul	Cherry Point, NC	Civilian
Black, Jerick	Patuxent River, Maryland	CDR, USN, U.S.A.
Cook, Amber	Patuxent River, Maryland	Civilian
Cudd, David	Patuxent River, Maryland	Civilian
Griffin, Carl	Orlando, FL	Civilian
Haas, Leah	China Lake, CA	Civilian
Hoeschen, Sadie	Lakehurst, NJ	Civilian
Holden, Sean	Patuxent River, Maryland	Civilian
Kiang, Kelly	Cherry Point, NC	Civilian
Kowalski, Thomas	Patuxent River, Maryland	Civilian

Letwinsky, Justin	Patuxent River, Maryland	LCDR, USN, U.S.A.
Misner, Joan	Patuxent River, Maryland	Civilian
Misner, Sean	Patuxent River, Maryland	Civilian
Moon, Allison	Patuxent River, Maryland	LCDR, USN, U.S.A.
Muse, David	Cherry Point, NC	Civilian
Piedmont, Otto	Patuxent River, Maryland	LCDR, USN, U.S.A.
Rodriguez, David	St. Inigoes, MD	Civilian
Shaffer, Blake	Patuxent River, Maryland	LT, USN, U.S.A.
Sran, Dylan	Lexington Park, MD	Civilian
Steinbach, Rozier	Patuxent River, Maryland	Civilian
Tanveer, Harris	Patuxent River, Maryland	Civilian
Tortorice, Jeanelle	Patuxent River, Maryland	Civilian
Walker, Joseph	Milton, FL	Civilian

The analysis involved drafting different views within the Department of Defense Architecture Framework (DoDAF). As an example, Fig. 2 shows one of these views for the first of the aforementioned systems.

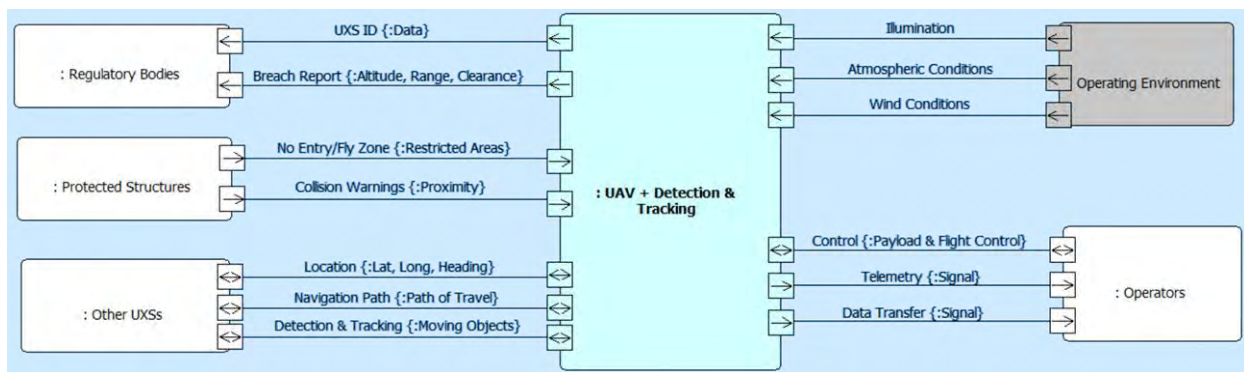


FIGURE 2. EXAMPLE OF THE DODAF VIEWS

The second part of this research effort was to demonstrate the developed approach using UxS available at NPS (Fig.3). Specifically, the intent was to evaluate the overarching capability (common for all future UxS) to use passive sensors to reliably detect, classify, and track multiple targets within the camera field of view. This is a single enabling capability that prevents a full integration of UxS into the manned environment (e.g., see [15]).

Towards this end, four Master students from the Systems Engineering, 580, and Mechanical and Aerospace Engineering, 570, curricula (Kiong Ang, Leong Lai, Marvin Tan, Benjamin Toh) worked on instrumenting the Pioneer ground robot (Fig.3a) and DJI Matrice 100 aerial developmental platform (Fig.3b) to obtain video footage of dynamic environment with multiple heterogeneous vehicles operating in a relatively compact space. (It should be mentioned that one more SE MS student, Juan Castillo, was also working on this project but got into a terrible life-threatening car accident and could not continue supporting this project.)



A)



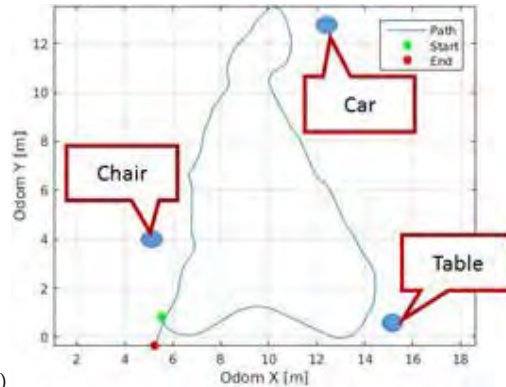
B)

FIGURE 3. UGV (A) AND MULTIROTOR UAV IN A CLUTTERED ENVIRONMENT (B).

Within their theses [16]-[19, students] developed and tested a variety of algorithms. For example, Fig.4 demonstrates a real-time code running on UGV and allowing to detect multiple objects and properly classify them using a simple low-resolution web camera and trained convolutional neural network (Fig.4A). A priori known information about these objects (their size) allowed to execute a feature based navigation (Fig.4B).



A)



B)

FIGURE 4. TARGETS DETECTION AND CLASSIFICATION (A), FOLLOWED BY FEATURE-BASED NAVIGATION (B) [16].

Figure 5 demonstrates the effectiveness of algorithm developed and implemented on UAVs. This algorithm allows to detect and track multiple heterogeneous moving objects including ground objects (Fig.5A) and aerial objects (Fig.5B) regardless background.



A)



B)

FIGURE 5. REAL-TIME DETECTION AND TRACKING OF MULTIPLE HETEROGENEOUS GROUND (A) AND AERIAL (B) TARGETS / THREATS [17].

Figure 6 illustrates the developed algorithm enabling finding surface vehicles using the day (Fig.6B) and night (Fig.6B) cameras. The algorithm further compares a detected surface vehicle with its model and based on this information tries to assess vehicles relative pose.

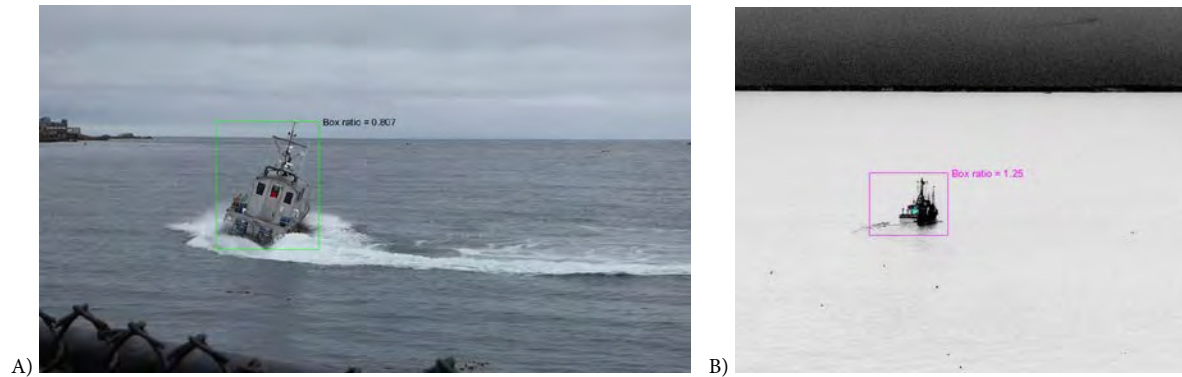


FIGURE 6. TARGET DETECTION AND THREAT ASSESSMENT USING EO (A) AND IR (B) SENSORS [18].

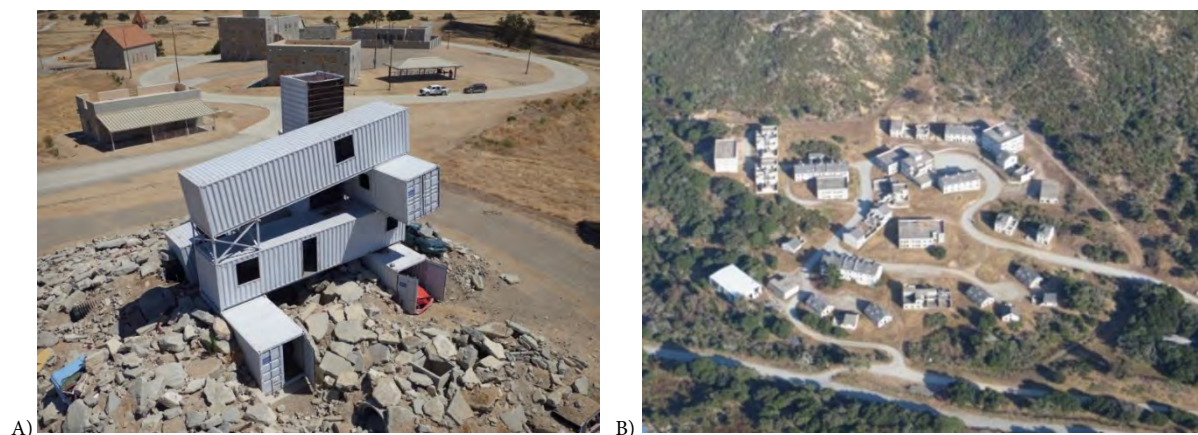


FIGURE 7. TESTING SITES AT CAMP ROBERTS (A) AND IMPOSSIBLE CITY (B) [19].

Recommendations for Further Research

Within this research a SE-based methodology for UxS, T&E was proposed and partially validated in the field experiments involving 30 students from multiple curricula. A SE DL PhD student (581 curricula), Matthew Sheehan, joined the research team and continues working on the theoretical aspects of proposed methodology. A natural continuation of this research effort includes following the developed methodology and drafting more complete T&E plans for assessing other capabilities that are currently under development for different-domain UxS. Field experimentation of the UxS prototypes could be executed in more realistic operational environments, like shown in Fig.7A and Fig.7B, that are now available to NPS students and researchers. Having a hand-on experience of exploring different aspects of planning and instrumenting prototype UxS to test their novel capabilities along with actual execution of these tests and reporting their results would have a significant impact of preparing T&E community to assess future combat systems with novel autonomous capabilities.

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NPS-17-N053-A: Surface Ship Port Loading Model Development

Researcher(s): Dr. Kyle Lin and CDR Peter Ward

Student Participation: LCDR William Buffington USN and LCDR Matthew Schaefer USN

Project Summary

The Navy contracts out surface ship maintenance availabilities to private shipyards. If the workload of these availabilities fluctuates a lot over time, then the private shipyards may have a hard time to complete these availabilities on time when workload is high, and struggle to train and retain a skilled workforce when workload is low. This project develops a port loading model for surface ship maintenance availabilities to estimate their realistic completion times to help the Navy better assess the delay risk. The inputs of the model include the start date and period of performance of each availability, and its labor requirement for each trade skill, as well as the regional shipyard labor capacity for each trade skill. The outputs of the model include projected labor execution and an estimation of each maintenance availability's completion time. Besides the port loading model, we also run statistical hypothesis tests—based on 24 availabilities performed in Southwest Regional Maintenance Center from December 2014 to October 2017—to conclude that an availability's labor requirement alone is not sufficient to predict its delay. The port loading model, which accounts for the start dates and labor requirement of the other availabilities, offers a better prediction.

Keywords: *maintenance availability, level loading, logistics, scheduling*

Background

Port loading is the capacity of available or committed resources specific to the industrial bases within a port. The ship repair industry requires workload stability to efficiently hire, train, and retain a capable workforce, plan the use of facilities, and keep subcontractors and supplier bases employed. The surface Navy is heavily dependent on the private industrial base for surface ship maintenance. Performance of the private ship repair industry directly influences the cost and schedule of ship maintenance.

In an ideal world, the Navy would schedule surface ship maintenance availabilities based on individual ship's maintenance requirements and the Optimized Fleet Response Plan. In the real world, however, the private industrial base does not have unlimited labor pool and facilities to support the maintenance of surface ships. If the workload fluctuates, then the private shipyards may not be able to properly train and retain the necessary workforce or industrial capacity. The problem becomes more challenging since the Navy does not have direct insight to the labor exact capacity of each private shipyard, so it is difficult to plan the maintenance tasks to support level port loading.

Findings and Conclusions

This project develops a port loading model for surface ship maintenance availabilities to estimate their realistic completion times to help the Navy better assess the delay risk. The inputs of the model include the start date and period of performance of each availability, and its labor requirement for each trade skill, as well as the regional shipyard labor capacity for each trade skill. The outputs of the model include projected labor execution and an estimation of each maintenance availability's completion time. The inputs and outputs are both handled by Microsoft Excel files, and the port loading model is coded in

Python. We demonstrate the model by running a case study using data from maintenance availabilities performed by BAE Systems in San Diego, California, from August 2014 to October 2018. The port loading model is the topic of M.S. thesis by LCDR Matthew Schaefer. The thesis won the Surface Navy Association Award for Academic Excellence in Surface Warfare Research in September 2017.

In addition to the port loading model, we study whether the labor required for each trade skill can be used to predict potential delay of a maintenance availability. We use the Spearman rank correlation to run the statistical hypothesis test based on 24 availabilities performed in Southwest Regional Maintenance Center from December 2014 to October 2017. Based on our dataset, we do not find sufficient statistical evidence to reject the null hypothesis that the labor required for each trade skill and the schedule delay are independent. This study is the topic of M.S. thesis by LCDR William Buffington.

Recommendations for Further Research

Our port loading model has many potential uses that require further investigation. Besides projecting realistic completion times of maintenance availabilities and identifying the trade skill that causes delays, the model can be used to identify how new work and growth work affect delays by running the model with and without new work and growth work. In addition, the model can be used to evaluate a contractor's proposal and assess its risk of execution. By running the model with future availabilities, we can optimize the schedule of future availabilities to minimize their impact on delays of ongoing availabilities. Finally, expanding the model to account for critical resource such dry docks could improve the projection an availability's completion time.

NPS-17-N100-A: Networked Undersea Autonomous Sensing and Tracking

Researcher(s): Dr. Kevin B. Smith

Student Participation: LT Robert Vann USN, LT Steven Seda USN, Mr. Thomas Deal CIV
NUWCDIVNPT and LT Leander van Schriek RNN

Project Summary

The overall goal of this project was to evaluate the performance of various components of a passive acoustic tracking system based upon directional acoustic vector sensors integrated into distributed platforms. Two types of platforms were investigated – unmanned underwater vehicles (UUVs) and drifting buoys. Various processing approaches were investigated with emphasis placed on low-power and faster-than-real-time data products. Data transfer via underwater acoustic modems to a gateway buoy was investigated with the UUVs, while the drifting buoys tethered the sensor at depth and provided their own gateway for transmission via Iridium or high-speed radio (RF) transmitter.

Keywords: *autonomous platforms, acoustic vector sensors, underwater acoustic modems, gateway buoy, passive acoustic tracking*

Background

From 2012-2017, NPS managed a set of autonomous UUVs under the guidance and support of ONR Code 321MS. The UUVs served as platforms for testing various sensors, the development of new data acquisition systems, and the integration of networking systems such as acoustic modems, Wi-Fi

(802.11b), radio frequency (RF, Freewave), and Iridium satellite. Numerous sea tests were conducted in Monterey Bay in order to evaluate sensor capabilities. Initial testing with single acoustic vector sensors mounted off the nose of the UUVs revealed a number of limitations with these types of platforms. Data processing was performed post-exercise and included scaling various acoustic channels appropriately, extracting separate data from orientation sensors to perform coordinate transformations to the Earth's frame, and finally acoustic data processing to estimate the absolute bearing of a sound source of interest

The processing techniques evaluated included multiplicative acoustic intensity processing, coherent linear processing, and coherent adaptive processing of various types. For a variety of recorded signals, including surface craft, marine mammals (humpbacks), and impulsive signals from fishing vessels (seal bombs), all methods were able to provide reasonable bearing estimates. The performance of the coherent methods suffered from inexact calibration data for the sensors, although in-situ calibrations seemed to provide some improvement. The work concluded that such bearing estimations could be run on-board in real-time using either coherent linear (Bartlett) or adaptive (MVDR only), with each giving reasonable bearing estimates towards sources of sufficient amplitude.

Multiplicative acoustic intensity processing produced similar results to the coherent methods. This method would not be expected to provide the same gain when coherently processing data from a well-designed and well-calibrated vector sensor. However, the software required to implement is easier and faster than the coherent methods, and the bearing estimates were generally consistent at similar SNR levels.

Issues related to submerged navigation, data exfiltration, and remote command and control of the UUVs were previously investigated using state-of-the-art acoustic modems. While improved tracking and navigation were achievable, the additional drain on batteries to power the acoustic transducers significantly reduced the operational time available.

Findings and Conclusions

In this study, we set out to evaluate if such directional sensors integrated into distributed platforms could provide useful data in an efficient manner in order to successfully develop target motion analysis (TMA) tracks for sources of interest. This was built upon the previous work done with UUVs and surface gateways, and extended the study to evaluate alternative platforms that included drifting or moored buoys with constant surface expression.

The initial goal was to collect data from two separate platforms simultaneously in order to provide minimal target tracking information. Two UUVs were deployed in Feb 2017, but the test was unsuccessful due to on-going issues with UUV reliability. While other UUV platforms would be expected to perform better, we can extrapolate previous findings with those reported here to infer some conclusions about this approach.

Multiple (4) drifting buoy platforms were updated/modified to include a new COTS data acquisition system and the integration of the same type of vector sensors used on the UUVs. The sensors were mounted compliantly in a new frame that was tethered at depth from the buoys. The tops of the buoys were outfitted with GPS and radio tracking, and are currently being upgraded to include a high-data-rate RF comms antenna.

A test was conducted at the NUWC-Keyport tracking range on Dabob Bay, WA in Sept 2017. Minor issues with the sensors' orientation data was identified and resolved post-test. Good quality acoustic data was still collected, though, and post-processing showed similar performance to tests conducted with UUVs. Furthermore, surface craft target data was collected simultaneously on two separate systems, allowing for the TMA study.

As in the previous work, both multiplicative acoustic intensity processing and coherent (linear and MVDR) were utilized. All methods appeared to perform similarly. Therefore, future work could take advantage of the simplicity and efficiency of either intensity processing or linear processing.

This work suggests that most any system capable of properly deploying such sensors may be considered viable from the perspective of calculating bearing estimates for tracking purposes. However, other platform limitations must be considered. The two primary issues would be power and data exfiltration, while a third issue of concern is sensor placement (especially depth). While the use of UUVs is attractive from the perspective of stealth and the ability to move a sensor in depth, UUVs suffer from considerable self-noise, power limitations, and the ability to rapidly transmit data of interest to the surface or a shore command. The introduction of acoustic modems onto the UUV platforms helped mitigate some navigational issues and improved data exfiltration, but at a significant cost to the power budget.

An alternative explored here was the use of a drifting buoy platform (could potentially be moored). This had the advantage of being able to support larger battery packs for extended deployments, and even the integration of energy harvesting through solar panels. Such a platform also allows for constant GPS fixes and regular position updates to a shore command. Comms are also improved by maintaining the surface gateway, either through low-data-rate Iridium satellite or high-data-rate RF links. The scale of the buoys also supports larger payloads than are typically realizable on UUVs. Still, such platforms are generally limited by the depth to which sensors can be deployed due to challenges with transmitting low-power data over long electrical cables. A moored system may permit sensors to be placed at deeper depths, however such approaches would eventually be limited by the data transmission to the gateway on the surface.

Much of this work was conducted by previous and current MS thesis students at NPS, including Robert Vann, Steven Seda, Tom Deal, and Leander van Schriek. Support was also provided by NUWC Division Keyport primarily through Dr. Mark Paulus and his group in Code 21E.

Recommendations for Further Research

As of the writing of this report, the capabilities of such drifting buoys are continuing to be explored and system enhancements are being implemented. In FY18, we intend to complete the integration of RF comms onto the buoy with a link created to a command center ashore, and to generate on-board pre-processing strings that will reduce the data transmitted to a manageable size.

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NPS-17-N127-A: MEMS Direction Finding Acoustic Sensor

Researcher(s): Dr. Gamani Karunasiri

Student Participation: LT William Swan USN

Project Summary

The objective of the proposed research is to explore the possibility of developing direction finding acoustic sensor based on the ears of the fly *Ormia ochracea*. The ears of the fly are separated by less than a millimeter yet it has remarkable sensitivity to direction of sound. The sensor was designed using microelectromechanical system (MEMS) technology. The sensor consists of two wings (1x1 mm² each) made of 25 μm thick Si layer that are coupled in the middle and connected to the substrate using two torsional legs. Nanometer scale vibrations of the wings under sound excitation were probed using comb finger capacitors attached to the edges of the wings. The sensor response showed cosine dependence to incident direction of sound with good sensitivity. The cosine dependence is due to interaction of sound from both front and back sides of the wings generating a pressure gradient which has cosine dependence to the incident angle of sound. A sensor assembly consisting of two sensors was used to unambiguously determine the direction. Field testing carried out at Camp Roberts showed that the sensor can determine the direction of sound within two degrees similar to that of the fly. Based on the data an estimated detection range was found to be over a kilometer.

Keywords: MEMS, acoustic, sensor, underwater, directional

Background

The ability to find the direction of a sound source arises from the different distances sound travelled to each ear resulted in a phase difference, analogous to an amplitude difference for periodic sound waves. In animals with a relatively large ear separation compared to sound wavelength, the delay of the sound arrival and variation in the pressure field between ears allow for direction finding. Humans use this principle to determine sound direction with up to 2 degrees accuracy. However, there are insects such as the parasitic fly *Ormia Ochracea* with much smaller separation of ears have developed unique approach to direction finding. The female of this species seeks out chirping crickets to lay their eggs on, and do so with an accuracy of less than 2 degrees. The two eardrums of the fly are separated by a mere 0.5 mm yet it homes in on the cricket chirping with a nearly two orders of magnitude longer wavelength. The previous studies of fly's hearing system [1] found that the two ear drums are mechanically coupled as shown in Fig. 1A and have two normal modes correspond to the eardrums moving in phase and out of phase as schematically illustrated in Fig. 1B. These modes, caused by the mechanical link between

eardrums, give the *Ormia Ochracea* remarkable sensitivity to the direction of an incident sound stimulus. The fly employs the coupling between the two modes at the chirp frequency of cricket to sense the direction making use of the unequal vibrational amplitudes of the two eardrums.

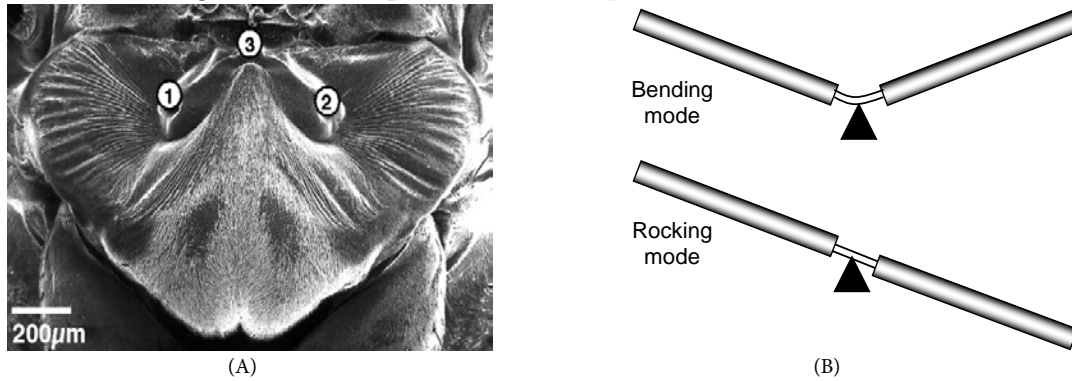


FIGURE 1. (A) SEM IMAGE OF FLY'S EARS AND (B) TWO MODES OF OSCILLATION OF EARDRUMS.

Findings and Conclusions

During the course of research, a MEMS directional sound sensor operating in air was designed (see Fig. 2A) based on operation principle of the fly's hearing organ. The sensor consists of two wings (1x1 mm² each) made of 25 μm thick Si layer that are coupled in the middle and connected to the substrate using two torsional legs. Nanometer scale vibrations of the wings under sound excitation were probed using comb finger capacitors attached to the edges of the wings [2,3]. Figure 2B shows the comparison of actual and simulated directional responses of the sensor when excited at the bending frequency. The cosine dependence shown in Fig. 2B is due to interaction of sound from both front and back sides of the wings generating a pressure gradient which has cosine dependence to the incident angle. The symmetric directional response shown in Fig. 2B around the normal incidence (zero degree) makes the determination of bearing ambiguous.

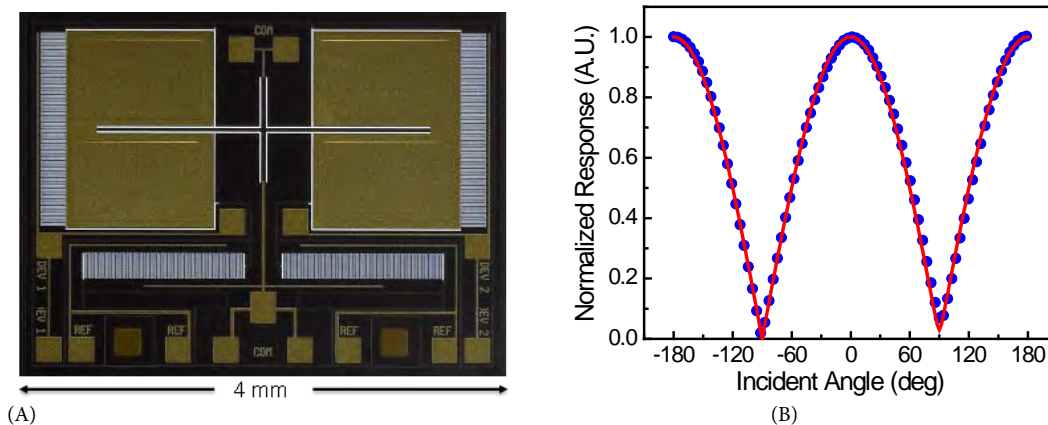
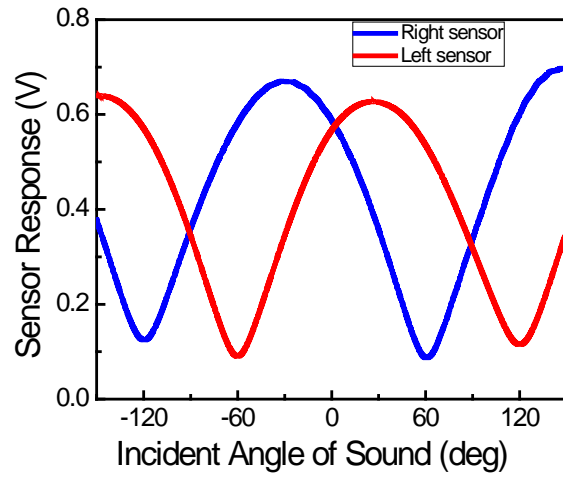


FIGURE 2. (A) SENSOR DESIGNED TO OPERATE IN AIR WITH COMB FINGER CAPACITORS AND (B) ACTUAL AND SIMULATED DIRECTIONAL RESPONSES OF THE SENSOR AT 1.5 KHZ.

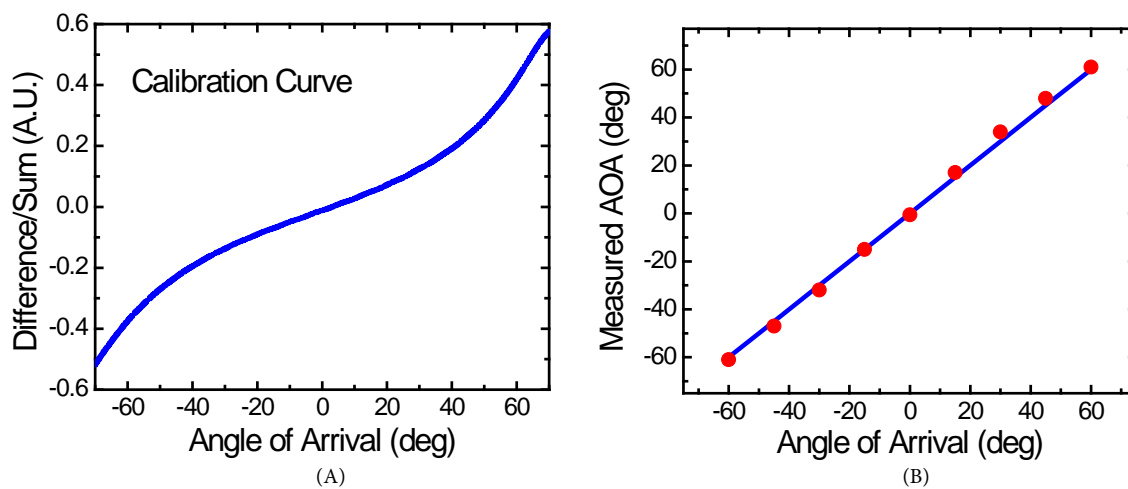
For unambiguous determination of direction of sound, a dual sensor assembly was designed [4] to mount the sensors at a canted angle ($\theta_{off} = 30^\circ$) as shown in Fig. 3A. The canted angle does not necessarily need to be 30° and the smaller the canted angle, the larger the “field of view” is. The directional response of each sensor of the assembly was probed by exciting them at the bending resonance frequency (1.5 kHz). Figure 3B shows the responses of the two sensors as a function of the incident angle of sound from -180° to +180°. As expected, the responses are shifted from one another by 60° (i.e., twice the canted angle).



(A) (B)
FIGURE 3. (A) DUAL SENSOR ASSEMBLY AND (B) MEASURED OUTPUTS OF THE TWO SENSORS AS A FUNCTION OF INCIDENCE ANGLE.

In order to remove the unknown sound pressure at the sensor assembly, the difference over sum ratio was calculated using the data in Fig. 3B for the range from -60° to $+60^\circ$. Figure 4A shows the calculated ratio, which has a tangent dependence with incident angle, and serves as the calibration curve for the two-sensor assembly.

In order to test the feasibility of the two sensor assembly, a field experimentation was carried out at Camp Roberts in California. The signals from both sensors were recorded and processed to determine the direction of sound as described earlier. Measurements were taken at 15° intervals over the range of $\pm 60^\circ$ using a sound source located at about 165 meters from the sensor. The peak responses of the two sensors was computed by the data acquisition system and the difference over the sum at each of the angles was calculated to determine the measured angle using the calibration curves in Fig. 4A. Figure 4B shows the plot of measured vs actual angles along with an ideal response line corresponds to a 45° slope. The average deviation between the measured and actual angles was found to be about 2° close to that of the fly's hearing system.



(A) (B)
FIGURE 4. (A) PLOT OF DIFFERENCE OVER SUM BASED ON THE DATA IN FIG. 3 (B) WHICH ACTS AS THE CALIBRATION CURVE FOR THE SENSOR ASSEMBLY. (B) COMPARISON OF MEASURED AND ACTUAL ANGLES WHEN THE SOUND SOURCE IS AT ABOUT 165 METERS AWAY FROM THE SENSOR ASSEMBLY.

Feasibility study of miniature acoustic directional sensors operating in air with high accuracy directly address the requirements specified by the sponsor. The compact size and low power requirements could be helpful for applications in battlefield environments. Participating student incorporated the results of research in the thesis.

Recommendations for Further Research

Further research is needed to develop a compact data acquisition system will be designed to integrate the dual sensor assembly that operates in air for carrying out field testing. This includes waveform recoding electronics, software to record and analyze the data to extract the bearing information of the incident sound. Initial characterization will be done using an anechoic chamber available to us at NPS which will help us to generate a calibration curve for the sensor assembly. The field testing needs to be focused on determining the maximum range of detection as well as the possibility of identifying sound sources using their acoustic signatures. In addition, the possibility of extending the sensor technology for detection of underwater objects is of considerable interest to the Navy and needs be explored.

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NPS-17-N221-A: Afloat Network Defense Cyber Operations with CDOSS and MAST

Researcher(s): Dr. Gurminder Singh and Mr. John D Fulp

Student Participation: LT Marsha Rowell USN, LT Daniel Parobek USN, SCPO Eric Sebring USN, PO1 Shaun Campbell USN, SCPO Robert Labrenz USN, and CPO Brian Hodgerson USN

Project Summary:

This research is intended to advance shipboard cyber incident response (IR) capability aboard Consolidated Afloat Networks and Enterprise Services (CANES)-enabled vessels by modeling such a capability using already established shipboard response systems (e.g. the Engineering Operational Sequencing System (EOSS) and the Combat Systems Operational Sequencing System (CSOSS)). The current state of shipboard cyber IR is limited, relying predominantly upon the Tier 2 Computer Network Defense Service Provider (CNDSP) Navy Cyber Defense Operations Command (NCDOP) for both detection and remediation services. CANES includes a Security Information and Event Management (SIEM) capability that is not being utilized to its maximum potential. We will advance shipboard cyber IR capability in three principal areas. 1) Improve the current CANES SIEM tool configuration so as to enhance its incident detection and investigation capabilities. 2) Drafting "if-then", indicator-to-action,

sequencing TTP that would aid in the containment and eradication of malicious logic artifacts. 3) Development of IR operator SIEM training to enable informed interaction with SIEM consoles dedicated to incident detection, investigation, reporting, and case tracking. For all three of these, the IR focus/priority is on any malicious actions/artifacts associated with each of the four *incident* categories identified in CJCSM 6510.01B: root-level intrusion, user-level intrusion, denial of service, and malicious logic. Advances in these three areas will present a nascent cyber defense operational sequencing system (CDOSS) capability to CANES-enabled naval vessels

Keywords: *cyber security, incident response (IR), SIEM*

Background:

Like any modern IT system, CANES is vulnerable to both malicious and non-malicious (e.g., erroneous configuration or accidental virus infection) threats. Given the critical shipboard functions performed by the CANES composite system, it is paramount that the Navy invest in the appropriate security controls to support prevention, detection, and recovery from the full spectrum of cyber-related threats.

The current CANES Information Assurance Manager (IAM), CDR James Hammond, contacted NPS researchers in 2015 to discuss possible research that would facilitate a cyber incident response (IR) capability for CANES. This informal discussion led to an NPS capstone project titled "Advancing CANES Shipboard Incident Response Capability Via SIEM" that was completed in March of 2016. This early research on the topic then led to a formal request for more research in the form of a Broad Area Study titled "Afloat Network Defensive Cyber Operations", submitted to the NPS NRP in March of 2016. Currently, shipboard IR capability is predominantly "outsourced" to the Navy's Tier 2 CNDSP, NCDOC. By "outsourced" here, we mean that NCDOC monitors shipboard system activity, detects anomalies, collects related artifacts, conducts targeted analyses, and directs the recovery actions to be taken by shipboard personnel. In this arrangement, shipboard IR is largely relegated to merely taking "reactive" measures as directed by NCDOC.

This research is aimed at introducing "proactive" IR capability to the shipboard operators, and doing so in a manner that would augment/complement the work done by NCDOC. Being sensitive to both training costs, and an already over-worked shipboard IT staff, we believe the best path forward is a more optimally "tuned" and utilized CANES SIEM, currently NetIQ's Sentinel or Security Manager suite. Such a SIEM would greatly expedite the detection and investigation of incidents and other reportable cyber events; thus enabling faster shipboard detection and reaction. Given such cueing from the SIEM, we would then like to have pre-established procedures (i.e., a sequencing system) to guide shipboard responders regarding appropriate containment and recovery actions. This latter guidance is being referred to as a cyber defense operational sequencing system (CDOSS).

Findings and Conclusions

This study provides an ontology of indicators of compromise (IOCs). An ontology, in the information science context, "is a formal naming and definition of the types, properties, and interrelationships of the entities that really, or fundamentally, exist for a particular domain of discourse". In this research, the domain of discourse is cyber IOCs. In Jason Luttgens, et al., book, titled "Incident Response & Computer Forensics", 3rd edition, IOCs creation is defined as "the process of documenting the characteristics and artifacts of an incident in a structured manner." The text goes on to state that "the goal of IOCs is to help

you effectively describe, communicate, and find artifacts related to an incident.” It is noteworthy that IOCs are only definitions. To actually affect detection of an incident, these definitions must ultimately be actualized via technology. The current state of the practice regarding this technology, is the security control (tool) typically referred to as Security Information and Event Management (SIEM). In order for the SIEM to be effective, these definitions must be turned into a high-quality ruleset and supplied to the SIEM. They play a vital role in the detection, as well as the investigation phases, of the incident life cycle.

The purpose of this study is to explore the existing space of the IOCs domain of study (i.e., its current ontology), to summarize it, and to—if efficacious—suggest “extensions” or alterations that would best benefit the incorporation of well-defined cyber IOCs into a target SIEM solution. The current U.S. Navy SIEM solution for the CANES environment is NetIQ.

There is currently no preferred or accepted standard for representing IOCs. The three nascent IOCs standards examined in this thesis are CyBOX, OpenIOC, and YARA. The definition, structure, and examples of each standard were examined and then compared in Chapter III. Each standard has its own pluses and minuses. CyBOX and OpenIOC offer their users the ability to create signatures in XML whereas YARA offers this ability in plain text. YARA and CyBOX can be used on any platform but OpenIOC is specific to Microsoft Windows only. No one standard is better than the other. It depends on the organization and their security needs. The Navy currently uses Snort and Microsoft scripting languages built into NetIQ to write their rules. When compared to the three nascent standards in this thesis, OpenIOC seems to be the closest match.

A research objective for this study has been to help enhance the overall quality of the cyber incident response capability, by informing would be SIEM operators and developers of the structure and semantics of the IOCs that lie at the heart of a SIEM's functionality.

Recommendations for Further Research

Follow on work to this thesis would be identifying the IOCs specific to the shipboard environment and using these to generate rules specific to NetIQ onboard U.S. Navy ships. This can be done through the creation of new rules along with the modification of the existing 1066 rules currently built into the SIEM. This would allow the SIEM's ruleset to be fine-tuned producing fewer false positives and more accurate results. Examining the IOCs used in creating the current NetIQ ruleset will provide a better understanding of the current rules, along with their purpose, and allow them to be adjusted or deleted as necessary.

Another focus for future research is the training and education of Sailors/analysts that are part of the incident response process. This training would be NetIQ-specific and provide a quick reference guide to what IOCs are, what good IOCs looks like, and an example format. It would also provide examples of strong rules and the IOCs used in building them. This would provide the analyst creating or modifying these rules with a quick reference guide as to what the best and most fruitful IOCs are. This could also benefit the intelligence analyst who is providing these IOCs to be used in rule creation. It would give them a better understanding of what data to look for in their daily intel searches. It would allow them to act quicker and with greater confidence on any piece of information they believe is IOCs worthy. A combination of these suggestions will provide the best overall enhancement to the SIEM onboard Navy ships, resulting in a hardening of naval networks. It will provide a more fine-tuned system and better trained personnel. It will provide the skillsets necessary for the incident “first responders” to quickly and

more accurately identify possible security-related incidents or events. This will help identify and stop future system compromise.

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NPS-17-N222-A: Development and Testing of Small, Sea-based, Unmanned Aerial Vehicle (sUAV) in Support of Electromagnetic Maneuver Warfare (EMW)

Researcher(s): Dr. Qing Wang and Mr. Ryan Yamaguchi

Student Participation: LT Lee Suring USN

Project Summary

Naval systems, such as radar, communications, and high-energy laser, emit in the electromagnetic (EM) or electro-optical (EO) wavelengths that propagate through the free atmosphere. Their performances are affected drastically by variations in the atmospheric index of refraction including its mean gradient for EM wavelength and turbulent perturbations for the EO wavelength. Environmental sensing capabilities are crucial for understanding and quantifying these atmospheric effects along an EM/EO propagation path. This project focuses on the integration and testing of environmental sensors aboard a small unmanned aerial system (sUAS), specifically the NPS-modified Finwing Penguin. The sUAS platform can be flown near an EM/EO system to obtain *in-situ* atmospheric measurements to characterize the spatial variability along its propagation path.

A prototype sensor system has been developed and integrated on the NPS Penguin airframe. The system combines several commercial-off-the-shelf meteorological sensors and a data acquisition system. Measured atmospheric variables include mean thermodynamic quantities (temperature, water vapor, and pressure), temperature perturbations at high sampling rate, and horizontal wind speed and direction. The sensors for temperature, humidity, and pressure are mounted to the airframe exterior so that they are fully exposed to the environment while minimally disturbed by the airframe or propeller. Sensor data are acquired locally on a microcontroller and stored on flash memory for post-processing. A major component of the sensor package is the addition of high-rate sampled temperature perturbations using thermocouples that allows direct calculation of the structure parameter of refractive index (C_n^2) in order to quantify the atmospheric scintillation effects on high energy laser systems. Initial test flights were flown with the prototype sensor system at McMillian Airfield – Camp Roberts and ground tests for sensor package evaluation were performed in Marina, CA.

Keywords: *environmental effects, EM/EO propagation, optical turbulence, ducting*

Background

Electromagnetic (EM) and electro-optical (EO) propagation in the atmosphere are affected by variation of the refractive index, which is a function of atmospheric state quantities such as pressure, temperature, and water vapor content (i.e. air density). However, the atmospheric effects on EM and EO propagations are different. EM propagation is primarily affected by the vertical gradient of modified refractive index. While EO propagation is affected mainly by small-scale turbulence.

For naval applications, many EM/EO systems emit within the atmospheric boundary layer, usually at ground or sea level. The marine atmospheric surface layer, which is the lowest ~100 m of the atmosphere, experiences the largest vertical gradients in temperature and humidity, which result in gradient in the modified refractive index (MRI). The MRI gradient structure can lead to the bending of the EM waves toward or away from the earth surface. Refraction toward the earth tends to trap EM emissions and propagate within this layer beyond line-of-sight, a phenomenon called ducting. The electromagnetic duct type, depth, and strength depend on the vertical mean structure of MRI.

Likewise, strong atmospheric effects on EO systems also occur in the surface layer where there is wind shear, thermal, and surface heating/cooling contributing to turbulent mixing and ultimately, fluctuations in the atmospheric refractive index. Those fluctuations can cause the EO beam emissions to change intensity focused upon a target, this phenomenon is called scintillation (quantified by C_n^2). The scintillation effects degrade EO system performances, leading to aiming errors, longer required dwell times, etc.

Small UAS (sUAS) are a cost-effective and easy to use solution to fill the niche between surface-based measurement platforms (e.g. buoys, WaveRider, etc.) and measurements with manned aircraft, providing a three-dimensional view of the lower atmosphere. Due to their small size, sUAS can also be used in difficult to reach areas such as within a wind farm at altitudes that are difficult for tower based measurements. Because of these reasons, there have been many developments and applications of sUAS in the past decades for meteorological applications. Our research is unique because we focus on sampling of the atmosphere variables that affect EM/EO propagations, a subject of crucial military application.

Findings and Conclusions

Spatial characterization of the atmospheric boundary layer becomes problematic in data sparse areas, especially over open water. One solution is to characterize the environment with a sUAS flown with atmospheric sensors that can be easily launched from ship or ground. This project focused on identifying and integrating sensors and data acquisition system onto the NPS Penguin, flight tests, and initial data analysis. The airframe used is adapted from the Finwing Penguin built for the first-person view (FPV) hobby market. The airframe includes a raised pusher propeller scheme that places the propulsion downstream of the meteorological sensors and shields the operator from the propeller during hand-launches.

Mean Meteorological Measurements (EM applications) - As previously mentioned, the EM propagation depends on the gradient of modified index of refraction, which is calculated from measured pressure, temperature and water vapor. The time response and fidelity of these instruments become crucial as the sUAS must fly through these fine gradient structures at various air speeds.

For initial testing, a modified InterMet iMET-1-RSB radiosonde and self-recording iMET-XQ were integrated into the Penguin. For standard meteorological applications, radiosondes are launched with a free-flying weather balloon and retrieves atmospheric quantities such as pressure, temperature, water vapor and wind speed and direction. The iMET-1-RSB and iMET-XQ both measure these quantities except for the wind. Wind speed and direction data are obtained from autopilot navigation and pitot tube systems of the sUAS. The iMET-1-RSB was installed in the NPS Penguin canopy and its temperature and relative humidity sensors boom protruded outside the canopy. The radiosonde outputs data over a UART serial data stream to a microcontroller where they are saved on flash memory. The iMET-XQ was mounted under one of the wings and logged to its internal memory. The data for both iMET-1-RSB and iMET-XQ were sampled at 1 Hz. With those thermodynamic state variables, EM ducts can be identified from the vertical profiles on the modified index of refraction derived from the measured quantities.

Temperature Perturbations (EO applications) - Although water vapor is also one of the variables determining the index of refraction in the optical wavelength, a large component of C_n^2 is the temperature structure parameter (CT_2) and can be calculated with high-rate temperature perturbation measurements.

The temperature perturbation measurement was achieved with a fine-wire thermocouple (0.001 inch diameter) and small diameter (0.02 in) platinum (Pt100) resistive temperature device (RTD). These sensors were mounted to the starboard side of the NPS Penguin body and extended past the nose to reduce thermal effects or density field distortions from the airframe. The thermocouple does not provide highly accurate mean measurements due to its non-linear response and hence there is the need for a second temperature measurement at the cold-junction (electrical connection at the analog-to-digital converter). Albeit slower responding, the more accurate and stable Pt100 temperature sensor is deployed to measure the mean air temperature and is used to adjust the thermocouple's mean temperature component.

The MAX31855 thermocouple 14-bit analog-to-digital converter (ADC) is used to measure the air temperature perturbations and corrects for the cold-junction offset temperature. The small diameter (0.02 in) Pt100 probe is measured with the MAX31865 14-bit ADC and outputs the temperature. The Pt100 and thermocouple ADC data are digitally logged at 20 Hz sampling rate with a Teensy 3.2 microcontroller and stored on a microSD card. The iMET-1-RSB and GPS are logged at 1-Hz on the same microcontroller.

Flight Testing - The sensor package was bench tested initially with the main focus of high-rate data sampling of the thermocouple data with the Teensy 3.2 microcontroller. The Teensy microcontrollers are small in size, light weight, and consume little power, making it possible to integrate onto the Penguin for high-rate sampling. Upon the success of initial bench testing, the package was integrated on the Penguin, and the latest Penguin test flights took place at McMillan Air Field, Camp Roberts, CA in November 2017. Five flights were conducted, each lasting approximately 20 minutes. Several flight patterns were flown at approximately 15 m/s airspeed during this test, which included level and porpoising legs at various altitudes. Nearby the air field, a tower instrumented with mean meteorological measurements provided overall atmospheric condition data during the test flights. Perturbations and mean sensor data are used to calculate CT_2 .

A ground test was performed to thoroughly evaluate the temperature measurements from the Penguin thermocouple against those from a sonic anemometer and a second thermocouple logged on a separate datalogger. The Penguin and sonic anemometer were mounted side-by-side on a truck and drove (backward) at various speeds to mimic the Penguin flight speeds. The purpose of the ground test is to verify that the thermocouple amplifier provides sufficient time-resolution to resolve thermal plumes. The perturbation data from both sonic anemometer and Penguin data will be used to evaluate the capability of obtaining CT2 from a sUAS.

Recommendations for Further Research

High-rate temperature perturbation measurements were achieved in this project for the purpose of deriving CT2 as an estimate of Cn2. The ongoing thesis work by Lt Suring will evaluate the Cn2 measurements against those from the 3-D sonic anemometer. More flight testing is needed, which is planned for the next month in order to thoroughly understand the system performance. While the system can be used as a research tool, it is apparent that the fragile-nature of the fine-wire thermocouple may not meet the requirements for ruggedness for operational use. Housings and sensor supports can be designed to enhance the durability of the sensors, while maintaining its response time.

A next step would be to integrate data system into the autopilot and telemetry data over the navigational data stream. This capability can be achieved by completing data calculation and reduction onboard the NPS Penguin sUAS, which will reduce data flow for minimal bandwidth telemetries. This capability will allow mapping the EM/EO environment in real-time.

NPS-17-N353-A: Fostering Innovation in the Naval Research and Development Establishment

Researcher(s): CDR Sue Higgins USN Ret. and Ms. Ann Gallenson

Student Participation: No students participated in this research project.

Project Summary

This project began a multi-year exploration to consider how developing a culture of learning and innovation can contribute to modernizing NRDE operations required for general research, development, test and evaluation.

In FY17 we laid the foundation for the development of vignette type case studies of successful naval innovations to assist in proliferating best practices across the Naval Research and Development (R&D) Establishment (NRDE).

We started by looking at how large, “traditional” private sector organizations are coping with accelerating rates change. We explored innovation trends and practices that have created lasting results and cultural shifts for comparable public and private sector large organizations to help guide our investigations and help us scope our research and frame our interview questions.

We provided a brief background on the drivers that forced large corporations to seek and eventually create innovation capabilities within their organizations. Second, we identify corporate exemplars, large corporations that have successfully internalized innovation capabilities and practices. Third, we discuss methods of success: a few key practices that fuel the innovations within these companies. Fourth we

briefly discuss the innovation ecosystem of clustering. And finally, we relate how these findings are informing the next stages of our research.

Keywords: *innovation, learning, culture change*

Background

The challenge of maintaining maritime superiority in a globally contested, rapidly changing, asymmetric environment requires the creation and maintenance of a culture that is successfully innovative and appropriately responsive and conducive to learning.

Changing to a culture of learning and innovation is a challenging and lengthy effort. Jay Galbraith'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 orchestrate a culture of learning and innovation in NRDE organizations.

Findings and Conclusions

1. Successful, large corporation-based intrapreneur programs take a systems approach to innovation and tailor their practice to fit their organization and the markets they wish to impact.
2. Leaders can build organizational capacity to transform to and sustain a culture of learning and innovation. They 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.
3. Leaders can develop personal capacity in their people to navigate uncertainty and to thrive in an emergent culture of learning and innovation.
4. Leaders can: lead with questions that empower; engage in conversations for possibility and action; make time for reflection, as in Boyd's original OODA Loop; build trust through sincerity, competence, reliability, engagement; build capacity to work effectively in team; and orchestrate moods conducive to learning.
5. Lessons from large private sector, "traditional" organizations seeking to create cultures of innovation: Leaders are trained and rewarded to take risks, learn constantly, and ask questions; Annual reviews replaced by continuous daily check-ins/updates - entire organizational change; They encouraged experimentation to create external startup agility within traditional corporate cultures; they created internal venture markets and startups.
6. 70-90% of corporate efforts to stimulate intrapreneurship fail.
7. 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 impede learning. Moods of trust, resolution, ambition and confidence are conducive to learning. (Flores 2016)
8. 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.

Recommendations for Further Research

Future work is encouraged about the relationship between culture, organizational change, innovation, learning, moods and leadership.

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NPS-17-N382-A: Investigation into the True Systemic Benefits of Full Ship Shock Trials

Researcher(s): Dr. Young Kwon and Mr. Jarema Didoszak, and Dr. Daniel A. Nussbaum

Student Participation: No students participated in this research project.

Project Summary

This report is provided in response to the suggestion by the present Chief of Naval Operation, ADM Richardson, to assess available ship shock hardness validation procedures. There are currently three options outlined in the U.S. Navy guidance. Those are: 1) Full Ship Shock Trial (FSST), 2) Ship Shock Test Supplemented with Modeling and Simulation (Alternative Shock), and 3) Enhanced Shock Qualification, Surrogate Testing and Modeling and Simulation (referred to herein as ET-M&S).

Of these three options, Alternative Shock Testing has not matured to a level to be a viable option. As a result, the remaining two options, FSST and ET-M&S were of primary focus for this study. These options were investigated, compared using cost, schedule and performance criteria and assessed for overall suitability in future ship shock hardness validation.

Even though full ship shock trials have been very beneficial to date in understanding the potential failure of “as-built” surface ships, they may not be the best option going forward. The use of ET-M&S (Option 3) is concluded to be the better option going forward of those presented for the validation of ship shock hardening.

Keywords: *Full Ship Shock Trials (FSST), shipboard equipment, shock hardening, fluid structure interaction (FSI), underwater explosion (UNDEX), shock response*

Background

A persistent emphasis in the shock hardening of U.S. Navy ships has prevailed since unanticipated mission kills resulted from near miss underwater explosions to surface combatants and submarines during World War II [1-3]. In order to test critical systems and equipment in newly designed ship classes, the at sea live fire ship shock trial has been used as the de facto tool in validation of ship shock hardening for decades. However as early as the turn of the 21st century, the question has been posed “what is the true benefit of these live fire events” and furthermore “is there an alternative method of shock validation that better meets the stringent technical, fiscal and schedule requirements”. Recently the Chief of Naval Operations (CNO) requested that the Naval Postgraduate School (NPS) work with Naval Sea Systems Command (NAVSEA) in investigating the true systemic benefit of Full Ship Shock Trials (FSST) as currently used for surface ship shock hardness validation. A review of test data, engineering analyses and supporting shock trial and equipment shock hardness validation reports [4-40] was conducted. The three options in the validation of shock hardening for surface ships were evaluated based upon common business criteria of cost, schedule and performance.

Findings and Conclusions

The main strengths and weaknesses for each of the options are summarized in Table 1. From the summary it is clear that in terms of ship structural shock hardness validation, the first option, FSST, directly tests the vessel as built, though not to the full design level. Option 2 fails to produce the correct UNDEX loading while Option 3 can provide data up to and beyond the full design level, though requires additional validation of the model by alternative means. With respect to ship systems and equipment, Options 1 and 2 are able to test the entire vessel at once yet again, to only a reduced loading condition, making the result somewhat undesirable due to the associated uncertainty. It is impractical for all systems and equipment to be directly assessed via Option 3, though through selective design of the analysis, based on prior equipment level shock validation, more focused and meaningful testing and investigations can lead to crucial discoveries at the prescribed design level. Once again in the case of crewmember shock assessment, there is some benefit from the reduced level of shock sustained by the crew present aboard during the live fire test series, though the number of Sailors subjected to and “trained” is insignificant. Option 2 is again plagued by an inability to fully match the UNDEX loading. Though not directly “tested” via Option 3, ET-M&S does provide the ability to collect data regarding crewmember response.

		1. FSST	2. Alternative Shock	3. ET-M&S
Ship Structure Shock Hardness	Pros	Obtains physical data under UNDEX	Obtains physical data via testing	Considers design level conditions
	Cons	Performed at reduced shock level	Not representative of UNDEX loading	Requires validation by other means
Equipment & Systems Shock Hardness	Pros	Validates all systems & equipment	Checks all systems & equipment	Checks equipment at desired design level
	Cons	Validation at a reduced threat level	Reduced UNDEX loading	Checks only pre-selected equipment. Requires validation
Crew Shock Hardness	Pros	Provides limited information	Provides limited information	Could be modeled via supplemental testing
	Cons	Performed at reduced shock level	Not representative of UNDEX loading	Not directly addressed in M&S

TABLE 1. SUMMARY OF OPTIONS STRENGTHS AND WEAKNESSES

The following key findings are made based on the investigation of the shock hardening validation options.

- FSST has been very beneficial to date in understanding potential failures affecting the ship mission.
- FSST has provided sound data and experience in order to validate evolving M&S techniques.
- Future use of FSST would provide only limited benefit considering the cost, schedule, environmental impact, and hence results in a diminishing return on investment at this point.
- ET-M&S uses M&S and targeted testing to mitigate shock risk.
- As technology improves, ET-M&S will continue to advance and provide enhanced capabilities in mitigation of ship shock risk while no major changes are expected in future FSST.

Recommendations for Further Research

The following are suggested areas of further refinement and additional study that would benefit the pursuit of validation of ship shock hardness in surface ships.

- [1] For ship designs that are similar to previous ships/classes (e.g. DDG-51 Flt I, IIA, III), the previously validated M&S models can be updated and used without any major physical validation.
- [2] If a ship design is quite different from past ships, then the M&S ship models should be validated against physical test data. For this purpose, a simple and cost effective dynamic loading technique would be beneficial to measure the ship's structural response. This does not need to involve UNDEX and can be done without water, if possible.
- [3] In the case of equipment shock hardening, component level test procedures should be further developed to directly relate the test results to potential failure for the UNDEX loading conditions.
- [4] Future Sink Exercises (SINKEX) and other opportunistic exercises can be used to leverage further advancement of ship equipment validation through ad hoc and expendable instrumentation measurements and data acquisition to better inform future equipment and systems development.

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FLEET FORCES COMMAND

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

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Student Participation: LT Megan Jamison USN

Project Summary

In this project, we examined the available data to see if we could discover insights into the causes of budget and schedule overruns during surface ship maintenance availabilities. The goal was to perform regression analysis that could create models that would be able to predict the likelihood that a given availability was going to go over time/budget. Such models, in theory, would allow the type commander to better plan availabilities and, perhaps, take actions to reduce the likelihood that high risk availabilities would exceed the planned resources.

Unfortunately, the data we examined was in such as state that precluded examination and analysis. There were myriad sources of data for most availabilities, and in most cases, the sources were incomplete and/or did not agree. For example, the start and end dates (both planned and actual) of availabilities were either missing, or if present, rarely agreed between the different data sources. In cases where there were three sources of data, it was more likely the third source listed a third different value for each date than it eliminated the confusion.

Unfortunately, despite significant efforts to break through the confusion on the data, we were unable to conduct any significant statistical analysis due to the poor quality of the data. Despite that, this research points out a major problem with the current method of documenting availabilities. We recommend that the existing data sources be significantly scrubbed by subject matter experts who were involved in the process at the time and can correct the existing databases as much as possible. Additionally, we recommend that collection of data during and after availabilities be prioritized, with the results carefully scrubbed to insure accuracy, and that these results be placed in locations where analysts can easily collect them for analysis. This will need to be corrected prior to being able to glean significant insights from the large amount of data which should be available.

Keywords: *surface maintenance*

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 in the most effective manner, we intended 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

Process

We began with a literature review while we determined which databases we needed access to in order to conduct the analysis. Additionally, we spoke to several people involved in the maintenance process to get insight into the data and its locations. After that, we collected data and attempted to analyze it. As we realized that the data was not fit to be analyzed, we continued to collect data hoping to reach a point where we could conduct a thorough analysis. We also contacted people to get information on where additional (better) data could be located. In the end, we were unable to collect data which we could analyze to produce significant findings.

This study covered United States Navy (USN) surface ships that have undergone one or more CNO availabilities that ended in the years 2002 to 2014. We utilized several databases in this study: the Maintenance Resource System (MRS), the Naval Maintenance Database (NMD), and the Maintenance and Material Management (3M) database. Data collected by public shipyards, largely concerning nuclear aircraft carrier (CVN) class ships, is proprietary to the private yard and not included unless pulled from one of the aforementioned databases.

The majority of the data we collected for analysis resides in the 3M system repository, accessed via the Open Architecture Retrieval System (OARS), managed by Naval Sea Logistics Center in Mechanicsburg, PA. Other databases included here are the Navy Maintenance Database (NMD) and the Maintenance Record System (MRS), both managed by the Surface Maintenance Engineering Planning Program (SURFMEPP). Both the MRS and the NMD focus on costs of maintenance actions, while OARS stores information associated with each job written in the 3M system. Multiple organizations and sources of information contribute to the 3M data system, as well as the NMD.

The focus of this analysis was to be on completion time of availabilities, and therefore the planned and actual completion dates are important data points required for a supervised analysis. The OARS database organization centers on a 'job sequence', which is a unique identifier for each work item. The data downloaded from the "Availability Tracking" table include 21,433 records, each in reference to a single work item. Dates of actual availability completion, though required to be tracked (Commander U. , Joint Fleet Maintenance Manual, Volume II, 2015), are only present in approximately 35% of those work items. The type of availability is also absent from all but a few of these records, as is any reference to an availability number.

Literature Review

Analytical examinations of CNO availabilities tend to focus on cost, rather than issues with time. While increased time in an availability is certainly associated with increases in cost of the availability, the driving factors are not necessarily identical. Below, we discuss studies that investigate aspects of surface ship availabilities linked to increasing the time a ship spends in a major availability, and consideration of each

led to development of the problem statement, approach, and potential areas for data exploration in this study. All of the reviewed literature indicates the issue of identification of drivers toward availability lateness is a complicated process.

Maintenance Requirements Study

The Navy asked the Rand Corporation to determine the effect of reduced maintenance budget and extended service life on the operational availability of the fleet. The cost of ship maintenance will likely rise with the aging fleet, and there is expectation that future O&M allocations will be reduced. With pressure to increase the size of the fleet, retiring older platforms to keep maintenance costs down becomes a less tenable option. This study, in part, utilized the differences between CONUS and OCONUS ship repair facilities and associated maintenance practices to predict the effect of reduced maintenance fleet wide. The authors recommend prioritizing work items and balancing work items between CNO availabilities and intermediate CMAVs in order to improve maintenance efficiency, rather than dispensing with or delaying maintenance (Button, 2015).

2011 SHIPMAIN Report

In 2011, Commander, Navy Regional Maintenance Centers (CNRMC) established the SHIPMAIN Review Team (SMRT) to conduct study of surface ship maintenance and modernization practices, with specific focus on policy and compliance, as delineated by the 2003 Ship Maintenance (SHIPMAIN) program. While the report is not discussed here because it is “For Official Use Only,” some of its findings on data mirrored our own. (Commander NRMC, 2011)

Public Shipyard Study

As a part of their Naval Postgraduate School (NPS) thesis, Caprio and Leszczynski (2012) examined 108 SSN, SSBN, SSGN, CVN, and LHD class ship availabilities that take place in the four public shipyards between the years 2003 to 2011. They break down events at each shipyard in order to identify potential process improvements based on the apparent success of any particular shipyard in an aspect of availability performance. They focus on man-day totals, work stoppage information, and number of work items to generate estimators of the quality and quantity of work ongoing in each shipyard. They do not include data on new work added.

Caprio and Leszczynski acknowledge the limitations on finding results of statistical significance with a sample size of 108 availabilities, but find that shorter availabilities tended to have a larger amount of time overrun as a percentage of total availability time. They also identify a trend of decreasing lateness in availabilities performed at Pearl Harbor Naval Shipyard (PHNS), though there is no investigation into potential influencing factors. There is no association identified between the number of late availabilities and the number of total availabilities underway at any of the shipyards.

Availability Performance Metric Study

As a part of his NPS thesis, White (2013) examines two data sets. The first set with 85 availabilities that occur from the implementation of the Naval Sea Systems Command (NAVSEA) LEAN Release maintenance program in 2006 to 2013, utilizing a data set very similar to Caprio and Leszczynski’s (2012). With the second data set, he compares a few late and timely maintenance availabilities directly, generally with metrics collected on a weekly timescale.

In the larger data set, White finds both increasing and decreasing trends within the LEAN Release-specific metrics, but does not identify potential predictors for availability lateness. Like Caprio and Leszczynski (2012), White finds that the planned length of an availability has an effect on the percentage of lateness likely to occur, though when normalized for availability length there is no trend visible by shipyard or propensity toward lateness observed.

Contract Process Study

As a part of his NPS thesis, Northrup (2015) reviews the contracting process for seven CNO availabilities. His work is also For Official Use Only (FOUO), and therefore not discussed here, but this collection of independent data is consistent with the findings discussed in the 2011 Ship Maintenance Review Team (SMRT) investigation (Commander NRMC, 2011).

Recommendations for Further Research

It was unfortunate that we could not find the data required to perform the analysis we intended to, but this does lead to our recommendations for future work. We recommend that the existing data sources be significantly scrubbed by subject matter experts who were involved in the process at the time and can correct the existing databases as much as possible. Additionally, we recommend that collection of data during and after availabilities be prioritized, with the results carefully scrubbed to insure accuracy, and that these results be placed in locations where analysts can easily collect them for analysis. This will need to be corrected prior to being able to glean significant insights from the large amount of data which should be available.

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NPS-17-N013-A: Documenting U.S. Navy Shipboard Requirements Creep

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Student Participation: LCDR Christine Fletcher USN

Project Summary

U.S. Navy shipboard workload requirements have continued to grow without the addition of more crewmembers to address the additional workload imposed by those requirements. In studies during underway deployments on multiple United States Navy (USN) surface combatants, we have observed that the majority of crew members work far longer than specified in the Navy Availability Factor (NAF) model. However, much of their time may be spent outside "productive work" time. For instance, we have observed that the category of Service Diversion (e.g., meetings, sick call, quarters, inspections, and miscellaneous categories of non-productive time) can account for much of the time a crewmember is not standing watch. Training requirements have also burgeoned with compressed timelines for qualifications. Each additional shipboard requirement may, in itself, be small, but when combined in its entirety, the workload of the ship and crew is no longer sustainable. When faced with too much work, individual Sailors are forced to shed tasks, posing additional risks to the ship and her mission. "Requirements creep" results in reduced operational effectiveness, higher levels of occupational stress, with fewer and shorter opportunities for rest and recuperation for Sailors.

This research was conducted by a team of researchers from the Naval Postgraduate School (NPS), the Navy Manpower Analysis Center (NAVMAC), and the office of Commander, Naval Surface Force, U.S. Pacific Fleet (CNSP). The project sought to determine why U.S. Navy Sailors' working hours exceed the Navy's models. Much of the team's effort is described in detail in a master's thesis by LCDR Christine Fletcher (Fletcher, 2018). The study focused on at-sea tasks for enlisted Sailors serving aboard U.S. Navy Guided Missile Destroyers and sought to meticulously examine the sources of that workload. The project was initially proposed by VADM Thomas Rowden while he served as the Commander, Naval Surface Forces, U.S. Pacific Fleet. It was funded by the Naval Research Program in October 2016 and finalized in March 2018.

The project entailed multiple stages. First, the Navy Manpower Analysis Center (NAVMAC)'s model for USN Destroyer task requirements was systematically reviewed. Then Destroyer leadership with knowledge about enlisted Sailor tasking were interviewed. A questionnaire was administered to deployed officers and enlisted Sailors to gauge their perceived workload. An enlisted at-sea task model was developed and compared to Navy-modeled tasks. An inclusive review of U.S. Navy policies over the past 25 years revealed changes to Navy policy that resulted in decreased Destroyer manning, revised training methodologies, and insufficient maintenance.

Decisions were made to reduce manning levels, relying on claims that technological advances would reduce human workload. These manning shortfalls were accompanied by higher operational tempos, resulting in the further misalignment of manning models with enlisted at-sea tasks. The category of "training" showed the largest misalignment and extra work compared to the manning models. The excess workload seen in training was attributed to added time spent in on-the-job training and qualifications,

warfare training, and underway drills. Navy-wide policy changes have not been vetted through OPNAV N1 to determine their effect on at-sea Sailor workload. We recommended instituting centralized policy analysis for all new initiatives that could potentially affect Sailor workload as well as the periodic reassessment of the Navy Availability Factor. This reassessment should use validated and reliable methods to measure human workload to ensure that estimates are accurate.

Keywords: *Navy manpower, fleet manning, Navy training, Navy maintenance, operational tempo, OPTEMPO, Navy Availability Factor, Navy Standard Workweek, working hours, friction, readiness gap, command and control, sea/shore imbalance, maritime regulations, optimal manning, fatigue, stress*

Background

In 2016, VADM Rowden, Commander, Naval Surface Forces. U. S. Pacific Fleet, requested the Naval Postgraduate School conduct a study to determine fleet requirements creep due to the knowledge that Sailors were working longer hours than planned for in Navy manpower models. No specific event provided the impetus for this research. However, over the course of this study in 2017, the Navy had three surface ship collisions and one grounding within the span of eight months. Findings from the investigations implicated fatigue training and maintenance issues, and excessive workload as factors in the mishaps.

United States Navy shipboard requirements have continued to grow without more crewmembers assigned to the ship to address the additional workload. From inspections to training to administration, requirements placed on Sailors by organizations outside an individual ship's chain of command continue to grow without regard to crew resources. In studies during underway deployments on multiple USN surface combatants, we have observed that the majority of Sailors work far longer than specified in the Navy Standard Work Week (NSWW) (Haynes, 2007; Mason 2009; Shattuck, Matsangas, and Brown 2015; Shattuck, Matsangas, and Powley 2015; OPNAV 2007). In some extreme cases, crewmembers work as much as 15 hours in a 24-hour period. However, much of crewmembers' time may be spent outside "productive work". For instance, we have observed that the category of Service Diversion (consisting of meetings, sick call, quarters, inspections, and miscellaneous categories of non-productive time) can account for much of a crewmember's off-watch duty time. Constraints on shipboard computer terminals and bandwidth also add to the effective workload by forcing crewmembers to wait for available computer terminals and bandwidth in order to complete mandated recordkeeping and training functions which have been moved to computer-based systems. Training requirements have also mushroomed with compressed timelines for qualifications. The time spent studying for personnel qualifications is not explicitly accounted for in the Navy Availability Factor model (OPNAV 2015), the successor of the Navy Standard Work Week. Time that is needed to study for qualifications represents yet another drain on crewmembers' workload. Each additional shipboard requirement may, in itself, be small, but when they are all added together, the overall workload of the ship becomes unmanageable.

The goal of this research was to determine what workload is placed upon U.S. Navy Sailors at sea that may not be included in Navy requirements documentation and manning models. This study focused on U.S. Navy Arleigh Burke Class Destroyers (DDG 51) while on deployment. Five recent studies of USN crews conducted at the Naval Postgraduate School determined that Sailors work an average of 88.3 hours per week while underway -- more than the average of 81 hours of work per week planned by the Navy for enlisted Sailors. By determining the levels and sources of the workload placed on enlisted Sailors, this study identified the reasons for such long working hours to potentially ascertain ways to remediate the

excessive burden. This study seeks to answer the following question. Why are Sailors working longer hours than planned for in Navy manpower models?

Findings and Conclusions

This study began by extensively reviewing Navy manpower history and previous manning studies. Then, a gap analysis was conducted to examine the disparity between the expected working hours planned for by the Navy Availability Factor (Navy Standard Work Week) and actual Sailor working hours. Despite multiple reports examining why accidents occurred within the Navy surface force, no entity has yet looked at and assessed the excessive workload of Sailors to determine why they are working more hours than planned within Navy manpower models. To find the gap between planned and actual workload, we used a behavioral approach for Sailor job analysis, reviewing the actual tasks performed at sea by U.S. Navy Sailors.

We created a baseline model of Sailor shipboard workload, the Mark I model, based upon discussions with Surface Warfare Officers at Naval Postgraduate School. We then flew out to five different commands (four in port and one on deployment) to refine the Mark I model, including at-sea and in-port tasks Sailors must accomplish. This effort focused on those tasks considered to take a "disproportionate amount of time," i.e., greater than average, defined as the Navy Availability Factor (Navy Standard Work Week) by the Navy. From these interviews, we created the Mark II model. We then administered questionnaires to Sailors at sea on deployed Guided Missile Destroyers (DDGs) to assess individual crew member perceptions of workload.

Using this information, we updated to the Mark III model prior to meeting with the Navy Manpower Analysis Center (NAVMAC), the entity responsible for determining minimum manpower requirements. The Mark III model was an attempt to determine which at-sea tasks were specified in Navy manpower models. We provided the Mark III model to the NAVMAC Afloat departmental personnel and NAVMAC leadership for review and comment. From those comments, we made changes and created the Mark IV, representing which tasks are included, partially included, or not included in Navy manpower models.

Interviews and questionnaires about sources of workload provided insight into areas of greater concern. We followed up on these areas of concern, to include the increased Sailor workload resulting from decreased manning from the minimal requirements listed in the Ship Manpower Document, inadequate Food Service Attendant manning, excessive Maintenance and Material Management spot checks, and annual / semi-annual maintenance requirements that are not included in Navy manpower models. We obtained data and reviewed instructions for these areas of concern and confirmed issues for further Navy assessment and review.

In itself, reduced manning degrades readiness and increases risk. These issues are exacerbated as more and more tasks, both warfare and non-warfare, are increasingly levied upon at-sea Sailors. Required tasks that are not related to warfare must still be completed, even though they are not included in the NAVMAC models. Because of this discrepancy, a disparity will always exist between Navy manpower models and actual DDG workload until the models include all Sailor-required tasks.

Recommendations for Further Research

We recommend the U.S. Navy change certain policies and procedures to improve at-sea safety and Sailor quality of life. These recommendations include implementing analysis to determine impact of all Navy-wide policy changes on Sailor workload, instituting a periodic assessment of the Navy Availability Factor (Navy Standard Work Week) including departmental and divisional differences, conducting a fleet-by-fleet review of Operations Orders in order to improve efficiencies as Navy ships transit from fleet to fleet, improving and streamlining training for Sailors, and providing Surface Warfare Officers with in-depth training on shipboard manpower and manning processes.

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NPS-17-N020-A: Distributed Lethality Wargaming

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Project Summary

Distributed lethality (DL) is the overarching end state gained by increasing the lethality (offensive and defensive) of individual units and geographically dispersing these forces. The DL Task Force focused on ways to better understand the strengths and vulnerabilities of the DL concept through an Analytic Agenda informed through wargaming at NPS. Two wargames were created and conducted by NPS students through the OA4604 Wargaming Applications course to assist with the maturation of the DL concept to

include the investigation of the impact of new and emerging technologies as well as the incorporation of joint and international assets as potential DL concept enablers. Leveraging NPS Defense Analysis and Operations Research department faculty and students, two analytic wargames were executed in FY 17 to explore the DL concept to include concepts for employment, capabilities, and responsibilities in given scenarios. These scenarios utilized the unique attributes of our NPS students by leveraging personnel from all services, curricula, and nationalities.

Keywords: *distributed lethality, fleet design, wargaming*

Distributed Lethality -South China Sea Wargame

Background

The objective of the wargame was to study the impact of distributed lethality (DL) on a potential adversary's decision-making during Phase 0 (shaping) and Phase 1 (deterrence) operations compared to more traditional, concentrated forces. Analysis was conducted to support surface warfare (SUW) and (OPNAV N96) in determining which elements within an adaptive force package (AFP) add the most operational flexibility and capability. Other concepts such as near-future technologies, Joint Force capabilities, and the impact of DL logistics were explored. This memorandum provides the background, study methodology, key findings, and recommendations that were derived from the wargame.

DL is an operational employment concept that combines increased surface warfare striking power with increased targeting capabilities by a geographically dispersed force. The goal of this concept is to achieve sea control by increasing networking capabilities with a distributed and potent offensive force. These technologically advanced assets will "hold the adversary at risk—at range." A single scenario based in the South China Sea was used to compare the effectiveness of various DL AFP compositions. This study consisted of three wargame plays: a tutorial game using a CSG, and two games with different AFP compositions. Each game had two movement phases that enabled the teams to receive information regarding the operational picture. This information allowed the teams to develop counteraction plans and provided data points for analysis.

Process - Players were divided into two teams: Red and Blue. Red team played the role of the adversary, and had a constant force structure throughout all games. Blue team's force structure used a predetermined AFP that was selected at the beginning of each game. Blue team had a player designated to represent a regional partner nation (Green team). Green team played with a constant force structure. Schedule conflicts prevented an international officer playing the role of a regional partner, and Green was played by a retired United States Navy Captain. The Data Collection and Management Plan (DCMP) focused data collection during three phases of the wargame. The scenario remained constant throughout the game to allow players to focus on DL and AFP considerations.

1. **Movement Phase.** The movement phase allows players to plan the employment of their forces on a map graphic. This phase was composed of two sub-phases completed in order. The planning sub-phase utilized a scorecard and map graphic to document player actions. After the planning, the white cell adjudicated all player movements. This adjudication sub-phase methodically determined which objectives were accomplished, which units were discovered, and which units were held at risk by each team. Each game had two movement phases: an initial movement and final movement. The total number of movement phases was restricted by the time available to conduct the wargame.
2. **Seminar wargame.** The bulk of the data collection was completed during the seminar wargame. Each individual team member had the opportunity to discuss the advantages and disadvantages of their

plan, and identified how DL helped or hindered their planning process and assessment of adversary moves. The seminar was a dialogue centered on the research interests of the sponsor. Conversation was directed by the analysis team's seminar facilitator to implement the DCMP.

3. Post-game Assessment. The post-game assessment was conducted to capture player inputs into questions not answered during the seminar. This survey completed the wargame data collection requirements.

Findings - DL concepts changed the behavior of the adversary during Phase 0 and Phase 1 operations. Red behavior varied depending on the Blue AFP force selection. Blue utilized near-future technologies, particularly in weapons and unmanned systems, to fill perceived gaps in their force capabilities.

- DL provides more uncertainty in adversary decision making compared to a conventional, concentrated force.
- Deterrence to Red forces relied on Blue force's strategic positioning, numerical strength, and capabilities.
- Across all of the AFPs, the Guided Missile Destroyer (DDG) component with an extended weapon strike range (Maritime Strike Tomahawk (MST)) was perceived by Blue and Red teams to be the most threatening unit.
- Effectiveness of the DDG/MST combination was dependent upon the use of other assets for scouting and targeting (Medium Displacement Unmanned Surface Vessel (MDUSV), Tactically Exploited Reconnaissance Node (TERN, F-35B), littoral combat ship (LCS), Mark VI patrol boat (Mark VI PB), etc) so that the heavy "shooters" could remain at the periphery of the battlespace where they were less likely to be detected and targeted.
- Each AFP had unique advantages and shortfalls identified by the Blue team. Near-future unmanned technologies were identified as a possible solution to shortfalls.
- Red movement and behavior was overt when facing a Blue AFP equipped with advanced air units.
- DL fuel logistics challenge conventional replenishment of naval forces.

Recommendations - This was the fourth wargame conducted on Phase 0 and Phase 1 DL concepts. Many of the lessons learned from previous wargames were incorporated to refine the mechanics of the game. Further wargames that improve upon the body of this work are required for a more complete understanding of DL in theater shaping and deterring activities. The following are recommendations learned from this study:

Table 1. An adequately sized and capable force is required by Blue to effectively deter Red. Red forces outnumbered Blue's and had perfect knowledge of Blue AFP composition. During gameplay Red was able to calculate which ships were unlocated and often were undeterred by these possible threats. Removing this knowledge via refined game play which accounts for TACSIT and IPB would introduce more uncertainty into Red's decision making and potentially lead to different behavior in Phase 0 and Phase 1 operations.

Table 2. This wargame was the first to utilize the Combat Logistics Force planning tool to explore implications of fuel logistics on Phase 0 and Phase 1 DL wargames. The feasibility of Blue force employment plans was explored after completion of the seminar game. Under favorable model assumptions, the distance between forces set by Blue players provided a logistics challenge. New resupply concepts may be needed to overcome these challenges. Future wargames should specifically address these challenges.

Table 3. The native sea traffic to the South China Sea was not included in the wargame. Players did not have to consider the challenges to planning and associated complications to targeting solutions added by this clutter. Furthermore, potential for each force to receive intelligence about their opponents from non-military sources, such as commercial traffic, was not specifically addressed. These factors could be significant to DL concepts and should be explored.

Table 4. Multiple movement phases (turns) were utilized within one wargame scenario. Time and study goals limited the number of turns to two. More turns could provide more information and insight into player decision making and logic. Smaller time increments between turns and more adjudications are recommended to further these findings.

Conclusions - The distributed lethality concept is a complex and capable employment technique. During shaping and deterring phases, players must balance exposure levels to their adversary to accomplish desired end states. Adversary's level of deterrence depends on their ability to recognize unfavorable conditions to their forces. DL messaging must convey these threats and build a public understanding of this new capability. Adaptive force packages must be comprised of sufficient number of units with each providing legitimate threats to a potential adversary to be most effective.

Fleet Design Wargame

Background

The United States Navy is no longer assured of maritime supremacy. Since the end of the Cold War, the Navy has focused primarily on force projection, allowing sea control capabilities to atrophy. Meanwhile, other emerging powers have radically transformed from coastal defense forces to formidable, peer-level adversaries. Therefore, the U.S. Navy must adapt its Fleet Design to win the sea control fight. In the scenario, RED was attempting to land an amphibious force on an island belonging to GREEN, and ally of BLUE. The mission of US forces was to deter the amphibious landing and to defeat it by force if necessary. The Fleet Design Wargame is played at the operational level, and it is a closed game, so that the "fog of war" is simulated. It is hybrid of a system and a seminar game, meaning that the opposing teams play according to fixed rules, followed by open discussion afterwards.

Process - The Fleet Design Wargame consisted of three separate gameplay sessions. During each session, the BLUE Team received a different order of battle. During gameplay, the study team observed the players' decisions to organize and maneuver their forces, as well as the rationale behind those decisions. After two to three turns of gameplay, a member of the study team facilitated a seminar in which all players discussed the game results. Each team, BLUE and RED, had a leader playing as the "Task Force Commander," and a supporting staff. The Blue Team consisted of three SWOs, a Navy pilot, an Air Force pilot, a Navy cryptologic warfare officer, two human resources officers, and a supply officer. The RED team consisted of three SWOs, one Marine naval flight officer (NFO), one Navy cryptologic warfare officer, two naval intelligence officers, and two supply officers. Search was adjudicated using probability tables and dice. Combat actions are being analyzed using combat models, such as a stochastic implementation of the salvo model.

Findings and Conclusions

The game demonstrated the combat potential that networked platforms, sensors, and weapons provide. Long endurance systems, such as the MQ-4C Triton and the Medium Displacement Unmanned Surface Vessel (MDUSV) can be the eyes and ears of missile platforms like destroyers. The game also showed that

with its range alone, an ASUW-capable Maritime Strike Tomahawk provides BLUE forces with greater flexibility when stationing units. On the other hand, unmanned systems also provide RED with a wider range of options to escalate and test U.S. resolve during phase 1, making these systems perhaps better suited for Phase 2. The study team also found that expeditionary warfare can have a double effect on the sea control fight. The presence of an LHA is a “double threat” to the enemy, acting as both an F-35B platform, and as a means of landing Marines.

Recommendations for Further Research

Additional wargames need to be designed, conducted, and analyzed in order to further develop concepts, integrate joint and combined assets, and examine new technologies for future integration.

NPS-17-N047-A: Convoy Defense Operations

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Project Summary

This project explores the modern application of at-sea convoy defense in light of modern anti-ship cruise missile-firing nuclear and diesel submarines, long range anti-ship missiles cruise missiles (ASCM) from surface ships and aircraft, and advanced ocean surveillance systems. Originally started as an extension to a Center for Naval Analyses study at the request of Commander, Naval Surface Forces (CNSF), this project expanded to two theses studies, the subject of three Joint Campaign Analysis course capstone projects, and the expansion of Naval Surface Warfare Center, Dahlgren Division (NSWCDD)’s agent-based modeling capability to include convoy tactical analysis. Although some specific findings are classified and already delivered to CNSF and OPNAV N96, a general overview includes:

- Addition of an LHA and its F-35 air wing to a convoy defense adds significant early warning and defense against ASCM attack on the convoy;
- If sufficient defense platforms are available, an outer screen along the convoy’s intended path can be effective addition in decreasing convoy loss, particularly against ASCM firing submarines;
- The Medium Displacement Unmanned Surface Vessels with direct path sonar are an effective addition to screen search capabilities, particularly for its long on-station times;
- Layered, close in screening of the convoy is superior to a “zone defense” where anti-submarine warfare (ASW) platforms search well ahead of the convoy’s intended path;
- When acoustic conditions favor submarines, attacking the convoy first with torpedoes then opening for missile attack can be an effective Red tactic.

Keywords: *convoy defense, air defense*

Background

At-sea convoy screening by surface ships and aircraft was well studied and employed in World War II and most recently in Operation Earnest Will (24 July 1987 – 26 September 1988) when Kuwaiti-owned tankers were protected in the Iran-Iraq War. Today, potential adversaries’ advanced offensive capabilities to

interdict the United States sea lines of communications inspire visiting merchant shipping protection in times of increased tensions and conflict. This classified and unclassified research uses warfare analysis, modeling and simulation, and intelligent experiment design to gain insight into the best way to defend a convoy in contested environments. Tactical situations are taken from the latest defense planning guidance scenarios.

The Operations Research Department at the Naval Postgraduate School has extensive experience in integrating warfare analysis with officer graduate education in the Operations Analysis, Joint Operational Logistics, Defense Analysis, Systems Analysis, and Systems Engineering Analysis programs. Specifically, Operations Research students and faculty have extensive experience in using simulation and intelligence experiment design to explore a large span of performance parameters and decision variables within a tactical situation to gain insight on how best to advance tactical employment or develop concepts of operations.

This project uses these methods to explore tactics associated with sea convoy defense against a technologically advanced blue water adversary. It augments information gain from a recent classified study sponsored by Commander, Naval Surface Forces and OPNAV N96, Surface Warfare Sponsor. This effort included building agent-based models to reflect convoy defense operations, assessing those models by exploring the question of escort force composition, and addressing specific sponsor concerns with those and other campaign analysis models.

Findings and Conclusions

This project was conducted in three parallel and dependent paths: development of two agent-based models to reflect convoy operations, challenging students in three Joint Campaign Analysis classes to integrate convoy defense analysis in their course capstone study, and conducting two theses (one classified and one unclassified) to specifically address questions originally raised by the sponsor and additional issues raised from on-going efforts.

The LITMUS agenda-based model, a Navy owned model developed by NSWCCD, was modified to reflect convoy defense tactics against various Red threats. MANA, an open-source agent based model was used to create another simulation to generate and assess various convoy tactics. These simulation models were then used in the two theses efforts.

Independent sections of the NPS Joint Campaign Analysis class were given a major war at sea scenario against near peer competitors where convoy and resupply protection is necessary. Specific escort and defense tactics requirements were analyzed for convoy routes from Guam to Tokyo, Subic, and Singapore as well as trans-Atlantic routes. Simulation, queueing theory and circulation probabilistic models were used to provide the following key insights:

- In both theaters (Atlantic and Pacific) significant effort to prevent Red submarine breakout of ports or confined areas using SSNs, offensive mines, underwater sensors, and Medium Displacement Unmanned Surface Vessel may limit the undersea threat to convoys to about 60% of the original Red force across a campaign.
- Due to large ocean areas for Red submarines to transit, area anti-submarine warfare (ASW) assets like P-8s and nuclear submarines (SSNs) are not well employed in open-ocean “zone” support of convoys. Instead, these assets are best employed in choke points, within enemy’s missile engagement zone of the convoy, or in set barriers ahead of the convoy’s path.

- Red's heavy weight torpedoes present a greater threat (sinking) to individual convoy ships than ASCMs.
- Augmenting a close in escort screen with an ASW Surface Action group stationed from 30 – 100 nautical miles ahead of the convoy group is effective in defense. No additional defense is provided with using a SSN in this outer screen, freeing these assets for higher campaign priorities.
- If convoy defense resources are limited, a close in screen should be given first priority.

From these modeling and capstone project initiatives, two theses were conducted--one classified and the other unclassified depending on the data used and nature of the research question. Both used the same analytical methodology. Tactical analysis was conducted of specific tactical situations to identify important performance parameters and variables within the scenarios. Ranges of possible tactical employment methods with weapon and sensor performances are identified to create an intelligent experimental design with the purpose of identifying those conditions which produce the most favorable outcomes for Blue. Simulations of specific tactical engagements are then constructed and run hundreds of thousands of times to form an extensive data base for analysis. Advanced statistical techniques are then applied to find those tactical employment methods, sensor and weapon performances for Blue which produce desired outcomes.

LT Jon Edwards conducted a classified thesis focused on adding an amphibious assault ship (LHA) with F-35 aircraft to a convoy defense (Edwards, 2017). His work's insights were provided to CNSF in both classified briefings and reports, however, it can be reported in this summary that the F-35 capability to work in coordination with Guided Missile Destroyers (DDGs) added a significant defense capability against ASCMs due to increased warning time of attack, enabling over-the-horizon missile defense, and the F-35 organic capability against some ASCM. LT Edwards worked directly with the NPS SEED center and NSWCCD build the LITMUS agent-based model used in his thesis.

Akhtar Zaman Khan, Lieutenant Commander, Pakistan Navy, conducted another, unclassified thesis using the open source MANA simulation (Zaman, 2017). His explorations are focused on the benefits of close-in layered screens compared to a longer range zone defense, use of Medium Displacement Unmanned Surface Vessels equipped with direct path sonar in the screens, and varying Red submarine tactics (firing missiles first or torpedoes first). His findings show that given sufficient resources, an outer screen along the convoy's path within the expected submarine missile danger zone can be effective tactic. However, assigning area ASW assets in a "Zone" defense further forward the convoy has little effect. This is in line with the Joint Campaign Analysis findings. An intermediate screen (from 25-30 NM ahead of the convoy) provides a defense in depth for a submarine approaching for torpedo engagement or close in missile attack, and against missile-firing fast patrol boats. Zaman also shows that a Red submarine benefiting from advantageous acoustic conditions may consider approaching for a torpedo attack to ensure ship kills before opening for a follow-on missile attack.

Recommendations for Further Research

As new capabilities in unmanned systems, sensors, and weapons are introduced, additional analysis is desired to understand how they may be employed in defense of a convoy throughout a campaign, particularly if any may free expensive manned platforms for other campaign missions. A better understanding of Red convoy attack tactics through research and analysis is also desired to test against blue tactics.

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NPS-17-N061-A: Surface Ship Safety Predictive Analysis

Researcher(s): Dr. Douglas MacKinnon and Dr. Shelley Gallup

Student Participation: LCDR Alejandro Musquiz USN and LT Mark Roach USN

Project Summary

This research seeks to find root causes of Class A or B mishaps in Navy surface ships in order to identify ships at risk for future mishaps. Additionally, by looking at data from ships that experienced mishaps between 2012 and 2017, and by searching beyond the root cause of specific causal factors for these incidents, we may be able to determine if indicator variables could have predicted the ships were at risk. We explored the landing helicopter dock (LHD), landing platform/dock (LPD) (San Antonio Class), and Guided Missile Cruiser (CG) ship classes, as these classes experienced the most mishaps from 2012–2017. We used linear regression, descriptive statistics, time-series analysis, and data optimization as the primary methods to examine our collected data. We implemented a reverse-forecasting, or “backcasting,” approach to correlate variables to LHD, LPD, and CG class ships that have experienced a Class A or B mishap in the studied years. We were unable to identify a correlation in the numerous data sets. Small amounts of correlation were found in the data models, but nothing statistically significant that would help predict future mishaps.

Keywords: *mishaps, safety, linear regression, prediction model, Class A mishap, Class B mishap*

Background

In an era of reduced available assets, the Navy is consistently asked to search for ways to reduce its costs and to more efficiently use the granted resources. In the area of safety, we seek to learn how and why Class A and B mishaps occur. We note that there likely exist numerous highly correlated and predictive variables that may show causation into the likelihood of occurrence of these mishaps and that there may be discovered new insight into the identification of other avenues to explore to minimize these incidents. This research sought to identify the root cause and perform data regression analysis across multiple ship classes, with the continuing goal of developing a predictive tool for identifying ships at risk before mishaps occur and to help identify appropriate command interventions.

Findings and Conclusions (to include Process)

The linear regression analysis portion of our research yielded no statistically significant correlations between the dependent variable of the occurrence of a shipboard mishap and the independent variables listed here:

- Number of departures from specifications (DFS's)
- CAT 2 Casualty Report (CASREP) Count
- CAT 2 CASREP Duration
- CAT 3 CASREP Count

- CAT 3 CASREP Duration
- CAT 4 CASREP Count
- CAT 4 CASREP Duration
- Steaming Hours Underway
- Steaming Hours Not Underway
- Total Steaming Hours

This conclusion is based on the results of the linear regression technique used, which did not yield a coefficient of determination higher than 44% for any one variable. The coefficient of determination is a mathematical value which measures the correlation between the dependent and independent variables. Most of the coefficients of determination for the independent variables were significantly lower than 44%, but the ones of note were discussed in Chapter IV.

For the time series analysis portion of our research, we attempted to represent a significant finding by graphing prior to each mishap, each independent variable for a three-, six-, and twelve-month timeframe prior to each individual mishap. This time series and trend analysis did not yield any obvious trends with all of the variables showing a random distribution for each of the time frames we graphed. Without any clear trend, we were unable to build a foundation for a predictive tool using this methodology.

Our research used other methods besides linear regression and time series analysis. Using the mean in data analysis was another approach for facets of our data. From the mean analysis comparing the commanding officer's (CO)'s length of time in command individually and with all units that experienced mishap, it was evident that most COs were in the first half of their command tour when a mishap occurred. The other pieces of data that used mean analysis such as the Safety inspection reports and Board of Inspection and Survey (INSURV) reports did not show areas that were evidently above or below the mean leading us to a conclusion that the data was non-causative.

Recommendations for Further Research

The gathering of such large amounts of historical data posed a significant challenge due to the numerous organizations that we had to contact to obtain it. Determining which organizations would have the data necessary was another challenge. There were data recommended for this study that might have an impact on our models and the conclusions drawn. As we contacted Afloat Training Group (ATG) in the data collection phase, it was found that data kept in these commands for the Atlantic and Pacific Areas of Responsibility didn't go back far enough to support this research. We learned previous training cycle inspection reports were not kept in a database or hard copy for numerous commands. As future research is conducted, we recommend ATG keep an up to date database for Ship training cycle reports and individual warfare certifications and inspection results. Early on in this research, we identified ATG data as a top factor in ship readiness evaluations, but were unable to utilize this area of focus in our data collection and analysis, as the data were unavailable to review.

Other areas were identified as potential data collection items for this research, but mainly due to poor data records kept at numerous individual commands, we were unable to attain records for Crew Certification, Maintenance and Material Management (3M), Fit/Fill Ship manning and Navy Enlisted Classification (NEC) shortfalls, Navigation Checkride reports, and additional Crew Intangibles such as a Crew Swap or homeport shift. As other research is conducted, from our experience, these records would aid in an analysis, but historical data are not kept for these areas of focus.

Future research would greatly benefit if shipboard data are consolidated to a small number of data archives, aiding in the data collection and filtering to specific events. As previously discussed, mishap events differ drastically, and building a model tailored to identify factors when combining all the mishaps together is a huge challenge. Future models and research would benefit from our research data, but with other internal behavior analyses of individual ships, factors leading or contributing to mishaps might be discovered.

NPS-17-N086-A: Mapping Dark Maritime Networks

Researcher(s): Dr. Wayne Porter, Dr. Camber Warren, Mr. Albert Barreto, and Mr. Rob Schroeder

Student Participation: LT Andrew Sollish USN

Project Summary

This research applied community *detection and database algorithms* in order to identify subgroups of vessels of interest, owners, operators, ports, cargoes, and specific activities associated with *artificial reef enhancement* and construction in the South China Sea. Historical automatic identification system (AIS) tracks and current maritime databases were used to develop visual *topologic/sociogram depictions* of the *dark/grey maritime network* that connects these nodes (ships, events, organizations, ports, activities) so that metrics of centrality, density, cohesiveness/structural holes, and clustering could be longitudinally measured and integrated into standard *Maritime Domain Awareness* systems (e.g. SEAVISION, AIS) to improve tracking capability. These social network matrices were dynamically updated by open source databases to provide insights into *real-time awareness and tracking* for operational purposes. Further analytic tools were developed specifically to assist operators in understanding transit connections between ships in the network, ports, and operating areas (OPAREAS) commonly visited.

The focus of this research was on the identification and tracking of agents-members (vessels, owners/operators, port facilities, cargoes) of the *reef enhancement dark/grey maritime network*. *Social (maritime) network analysis* matrices resulted in graphical depiction and analysis of network topologies and sociograms of the dark maritime network that supports reef enhancement activities in the *South China Sea*. The data in the dark network matrix was populated by, and dynamically updated through, the integration of unclassified data base information using algorithms developed as part of the research.

Keywords: *detection and database algorithms, topologic/sociogram depictions, Maritime Domain Awareness, real-time awareness and tracking, dark maritime network, artificial reef enhancement, South China Sea, social (maritime) network analysis*

Background

The Naval Postgraduate School (NPS) Common Operational Research Environment (CORE) Lab has successfully employed social network analysis (SNA) - not to be confused with social media exploitation, which may, or may not be a subset of SNA - in a number of terrestrial domains to disrupt terrorist and insurgency networks, improvised explosive device (IED) networks, cyber networks, and narcotics networks. It is, however, only recently being applied to the unique dark networks (social networks that do not operate with transparency) or grey networks (social networks that operate partially in the open) in the vast maritime domain.

The advent of hybrid warfare and activities in the so-called grey zone have highlighted the need to focus more attention on identifying and geo-locating key stakeholders/agents in social networks that operate in the maritime domain. Such network members might represent identified ships/platforms (e.g. arms carriers, surveillance platforms, dredges, petroleum tankers, mother ships, etc), individuals (e.g. ships' crews, provocateurs, traffickers, military personnel, terrorists, etc), organizations (e.g. state-owned enterprises (SOEs), insurance companies, navies, militias, cartels, money launderers, commercial enterprises), agencies (e.g. state-sponsored intelligence, economic, cyber, political, transportation), home ports and ports of call, and events (e.g. terrorism, ship boardings, maritime confrontations, terra forma activity, incursions, arms deliveries). The application of social network analysis and open source database integration for the identification, mapping and tracking of vessels, owners/operators, facilities, activities and cargoes associated with artificial reef construction and enhancement in the South China Sea could significantly increase situational awareness and enhance operational capability to monitor and/or disrupt this highly sensitive activity.

Traditionally, Maritime Domain Awareness has focused on intelligence, surveillance, and reconnaissance of activities at sea with limited cross domain link analysis of events, carriers, and sponsors (Wallace and Mesko, 2013). The distinction between link analysis and social network analysis is that while the former might link the ties between different objects (individuals, articles being trafficked, events), social network analysis only maps the ties between similar objects. For example, while link analysis might connect ten individuals with various objects, the objects to which they are connected may differ from one another, with individuals only linked via dissimilar object associations (apples to oranges) making it difficult to compare the number of common ties among individuals. Social network analysis, on the other hand, only studies similar objects, comparing like ties among individual agents (apples to apples). This social network may be connected through either one mode or two mode matrices: one mode analysis ties ships to other ships for example, and two mode analysis might tie ships to holding companies, specific activities/events, and ports they have in common. While data is routinely collected on the attributes (characteristics) of agents and stakeholders which might be helpful in link analysis, less attention has been paid to the collection of relational data. This can be achieved through algorithmic searches designed to sort large data sets from dynamic, open source (maritime, news, and other) databases (Hays, et al, 2010; Franzese, et al, 2012; Robbins, et al, 2007). The use of social network analysis that integrates attribute data with relational data provides metrics for network analytics (e.g. eigenvector centrality, density, clustering, cohesiveness/structural holes) not possible with link analysis (Kadushin, 2012; Watts, 2004; Borgatti, Everett, Johnson, 2013; Freeman, 2013, Granovetter, 1973; Prell, 2012). [See Appendix A for Social (Maritime) Network Analysis Terminology]

Social network analysis, social media exploitation, and big data integration from existing databases may be applied to any nefarious (grey or dark) maritime network, providing the ability to geo-locate and track stakeholders and nodes in these networks in physical and virtual space. This would significantly improve our ability to disrupt these networks either through direct (e.g. kinetic action) or indirect (e.g. financial sanctions and or diplomatic influence) means. Further, the statistical basis for social (maritime) network analysis provides the means to assess our effectiveness by dynamically measuring changes in the network over time. The outcomes from this analysis should enable not only the potential to predict future terra forma activity in the South China Sea but to leverage the information gathered on licit and illicit commercial shipping companies to facilitate enhanced money-tracking and better inform sanction regimes.

Findings and Conclusions

This case study looks at 314 ships that were identified as either travelling to one of the Spratly or Paracel Islands claimed by the People's Republic of China, or had a co-location with those ships in the South China Sea during the time period November 2014 – Nov 2015 (Ships whose trajectories, port of origin, and flag/company information made it likely that a co-occurrence was random, and that they were not involved in reef enhancement activities, were filtered out). The majority of these ships, 164, were cargo types (bulk carrier, cargo, refrigerated cargo); 42 of these ships were related to the Chinese Coast Guard or other Chinese law enforcement ships; 24 were tug or pilot ships; 22 were offshore supply or research vessels; 18 were dredgers, salvage vessels, or other specialized ships; nine were tankers or fuel carriers, five were fishing vessels; and the remaining 30 were either classified as “other” or are of unknown type.

Not all of the 314 ships provided the same amount of publicly available information. Of the 314 ships, only 83 ships broadcasted a valid International Maritime Organization (IMO) number, which is a unique reference number for ships that was created as part of the International Convention for the Safety of Life at Sea. These 83 ships have registered information that gives details about their owners. For the remaining 231 ships, additional information on 103 of the ships was found through various internet websites, with ownership information often automatically translated from Chinese using Google Translate (Google, 2017).

Port and Island Analysis: The transit routes of these ships were analyzed in order to identify which ports or islands they visited during this time period. A ship was considered to be arriving at a port or island if it broadcast an AIS location within a certain distance threshold (five nautical miles) from the Chinese ports or islands. If a ship's location was determined to be within the threshold for multiple ports, the closest port was considered its destination. Connections, based on their travel routes, were created between the different destinations. For example, the bulk carrier Wu Chang Hai travelled from the port of Basuo to Subi Reef, from Subi Reef to Fiery Cross Reef, and then from Fiery Cross Reef to the port of Tianjin Xin Gang. This resulted in the following directed connections: Basuo -> Subi Reef -> Fiery Cross Reef -> Tianjin Xin Gang.

Additionally, this same information was depicted as a network. Both show the importance that Mischief Reef and Fiery Cross Reef play in terms of brokerage between other nodes, with connections not just from Chinese Ports, but also a large number of connections between the Spratly Islands. Mischief Reef, for example, had 74 trips coming from Chinese ports and 64 trips departing Mischief Reef to a Chinese port.

Mischief Reef had a significant amount of traffic between it and the Spratly and Paracel Islands, with 145 trips leaving Mischief Reef to one or more of the Spratly and Paracel Islands, and 182 trips coming to Mischief Reef from one of the Spratly and Paracel Islands. Fiery Cross Reef had: 34 trips coming from one of the Chinese ports and 37 trips going back towards the Chinese ports; 190 trips coming from the Spratly and Paracel Islands to Fiery Cross Reef; and 170 trips leaving Fiery Cross Reef to another one of the Spratly and Paracel Islands. The connection between Fiery Cross Reef and Mischief Reef was, also, very strong, and had 37 trips leaving Mischief Reef to Fiery Cross Reef and 48 trips from Fiery Cross reef to Mischief Reef.

Ship to Ship Network: For each month, a ship-to-ship network was created by determining whether the ships were co-located, within 3km of each other at the same time based on route trajectories. The first month, November 2014, is depicted in Figure 1. With the tracks of the ships on the left and the resulting network based on the tracks on the right.

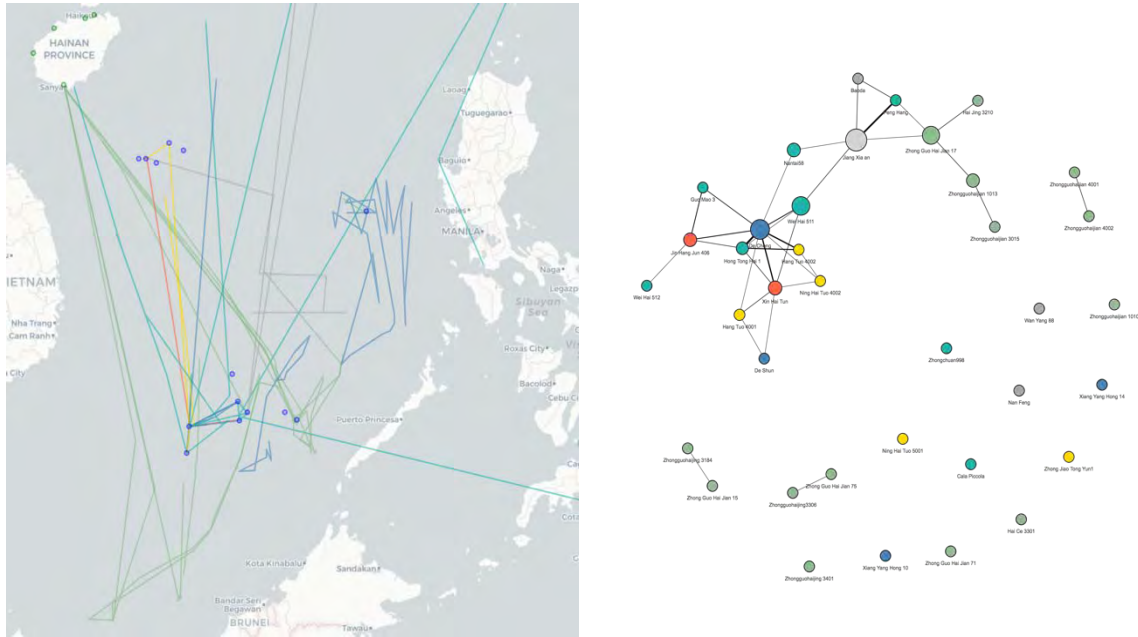


FIGURE 1: NOVEMBER 2014 WITH TRACKS (LEFT), AND NETWORK (RIGHT) COLORED BY SHIP TYPE. NODES SIZED BY BETWEENNESS.

The ships are sized by betweenness and a measure for brokerage potential, and thicker connections indicates that the two ships had co-occurrences on multiple days. Clusters tend to be formed around locations, such as the different islands/reefs. Nodes that are not connected to other nodes represent ships travelling in the South China Sea area with no co-occurrences detected. The network changes over time, with more ships lingering at the reefs/islands, causing the clusters to grow larger.

The Company Network: Initial research that identified links between reef enhancement vessels and their holding companies was already discussed and illustrated (Figure 2). Connections between companies that own identified ships of interest were further examined in more detail using information and records gathered from the Tokyo Memorandum of Understanding Port State Control (PSC) database and through co-location algorithms (ships conducting operations in the same proximity at the same time). Figure 2 illustrates connections between companies based on their ships routinely being co-located within a specific South China Sea area of interest (e.g. Mischief Reef, Fiery Cross Reef, Spratly or Paracel Islands) between November 2014 and March 2016. Some companies owned multiple ships within the network, such as China Yantai Salvage, while other companies owned only a single ship within the network, such as Fujian Shipping Company.

Specific companies of interest were then evaluated by examining two different structural characteristics of the network: core affiliations and brokerage potential. The first feature was to identify which companies were a part of the network's core. This was accomplished by using k-core analysis which extracted out the subgroup where the nodes (companies) were connected to at least 13 other nodes (companies) within the subgroup. In Figure 2, nodes that are part of the core of the network are a shade of blue, with nodes on the periphery colored a shade of green.

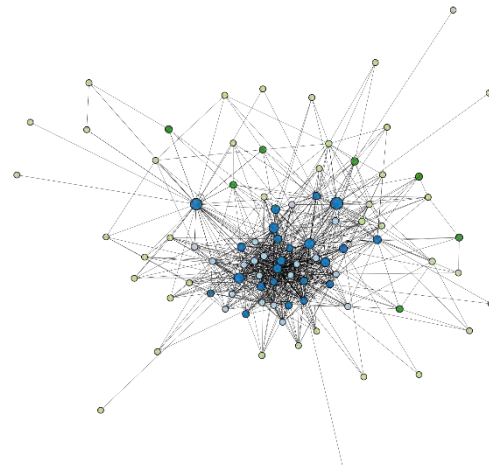


FIGURE 2: COMPANY NETWORK BASED ON SHIP'S CO-LOCATION. NODES SIZED BY BETWEENNESS. BLUE NODES ARE PART OF THE CORE AND GREEN NODES THE PERIPHERY. DARKER NODES HAVE BETWEENNESS CENTRALITY OVER 0.0202.

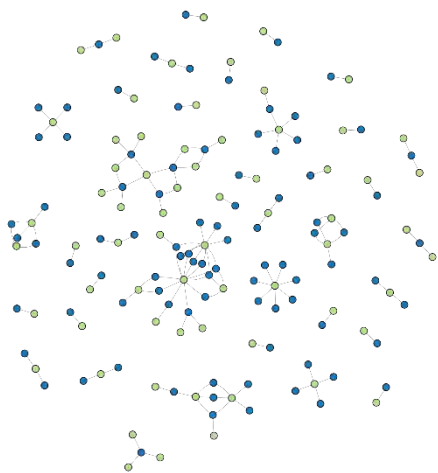


FIGURE 3: TWO-MODE NETWORKS OF SHIPS (BLUE) CONNECTED TO COMPANIES (GREEN).

Additionally, companies that might play a brokerage role (by connecting nodes within the network) are also of interest. In order to identify these companies, betweenness centrality for the network was calculated. The company with the highest betweenness centrality in this network is CNPC Offshore Engineering Company and is the largest node located in the upper right of Figure 2. The nodes that had a betweenness centrality higher than the mean betweenness centrality for the network (0.0202) are colored dark blue or dark green in Figure 2.

Companies, and the ships they own, that were either part of the core or had high betweenness centrality in the company to company network were identified as such. Further research was then conducted to identify other companies affiliated with the operation of these ships (e.g. the technical manager of the ship, the registered owner of the ship, or the group beneficiary for the ship). Figure 3 provides a two-mode network of ships that are connected to these various companies, excluding those

with connections directly to the Government of China. The largest component, near the center of the network, contains a number of Chinese dredging companies and the associated (support) ships.

Companies that share a connection to the same ship are then linked to each other in order to make a one-mode network (a network consisting only of companies), with additional links that may tie one company to another (such as the tie between the parent and subsidiary company). The resulting network (Figure 4) contains four large components (with more than two nodes).

The largest component of this company to company network, in green, has 13 companies in its subgroup. The largest node in this subgroup is China Huaneng Group, which is a state-owned electric utility that also is highly involved in investment and construction. Of note, the companies in this subgroup that are directly linked to ships in the shipping network are all connected to cargo ships.

The second largest component of the company to company network, in red, has 11 companies in its subgroup. The China Communications Construction Co., Ltd. (CCCC) is the most central node. The CCCC conglomerate contains companies that own a large number of the dredgers, as well as tugs and offshore supply vessels, that are part of the shipping network.

The third largest component of the company to company network, in blue, has 10 companies in its subgroup. The largest and most central node of this subgroup is China Ocean Shipping (Group) Company. This is a giant shipping conglomerate that is often abbreviated as COSCO.

The fourth largest component of the company to company network, in purple, consists of four companies that are part of the China National Petroleum Corporation. These companies were connected to a number of offshore supply vessels in the shipping network.

Analyzing direct connections between companies could be expanded through further research and investigation. Additionally, being able to identify individual board members of these companies would provide insight into how these board members might use ties to other industries of conglomerates or PRC governmental offices that support reef enhancement activities.

Use of Historic AIS Data and the Development of a Maritime / Port Analysis Tool

Students in the NPS Operations Research Department performed significant data analysis work to filter and analyze the historic AIS tracks for geographic areas of interest. As a result, they used R code and RShiny user interface to develop a graphic analytics tool capable of sorting and focusing on specific ships, ports, and reefs of interest within selected timeframes. They concluded that AIS can provide additional

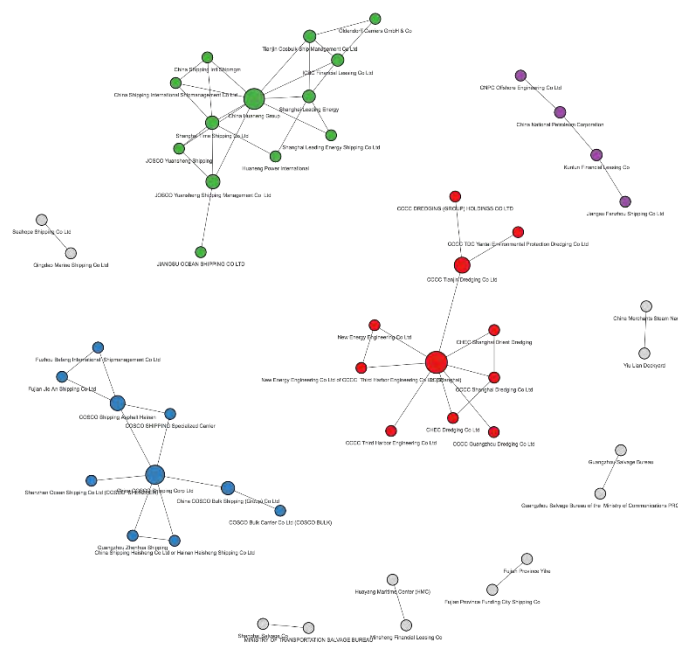


FIGURE 4: COMPANIES CONNECTED TO OTHER COMPANIES BASED ON BUSINESS RELATIONSHIPS. NODES SIZED BY BETWEENNESS AND COLORED BY COMPONENT.

open source information about the construction of the Chinese Terraform islands. The data analytic tool allows users to:

- periodically update the list of known vessels associated with the construction of the islands upon the receipt of new AIS data
- periodically update the list of ports that are associated with the construction of the island based upon the vessels that are related to the construction of the islands.
- geographically visualize the vessel trajectories of the vessels related to the construction of the islands on an interactive map
- visualize the relative importance of each port and island based on the volume of vessel traffic between each using an interactive chord diagram
- retrieve a new list of MMSI and IMO combinations that were not previously known to the user

Leaflet Plot of Filtered Vessels (Red), Ports (Green), and Islands (Blue)

Maritime Relations Analysis Tool

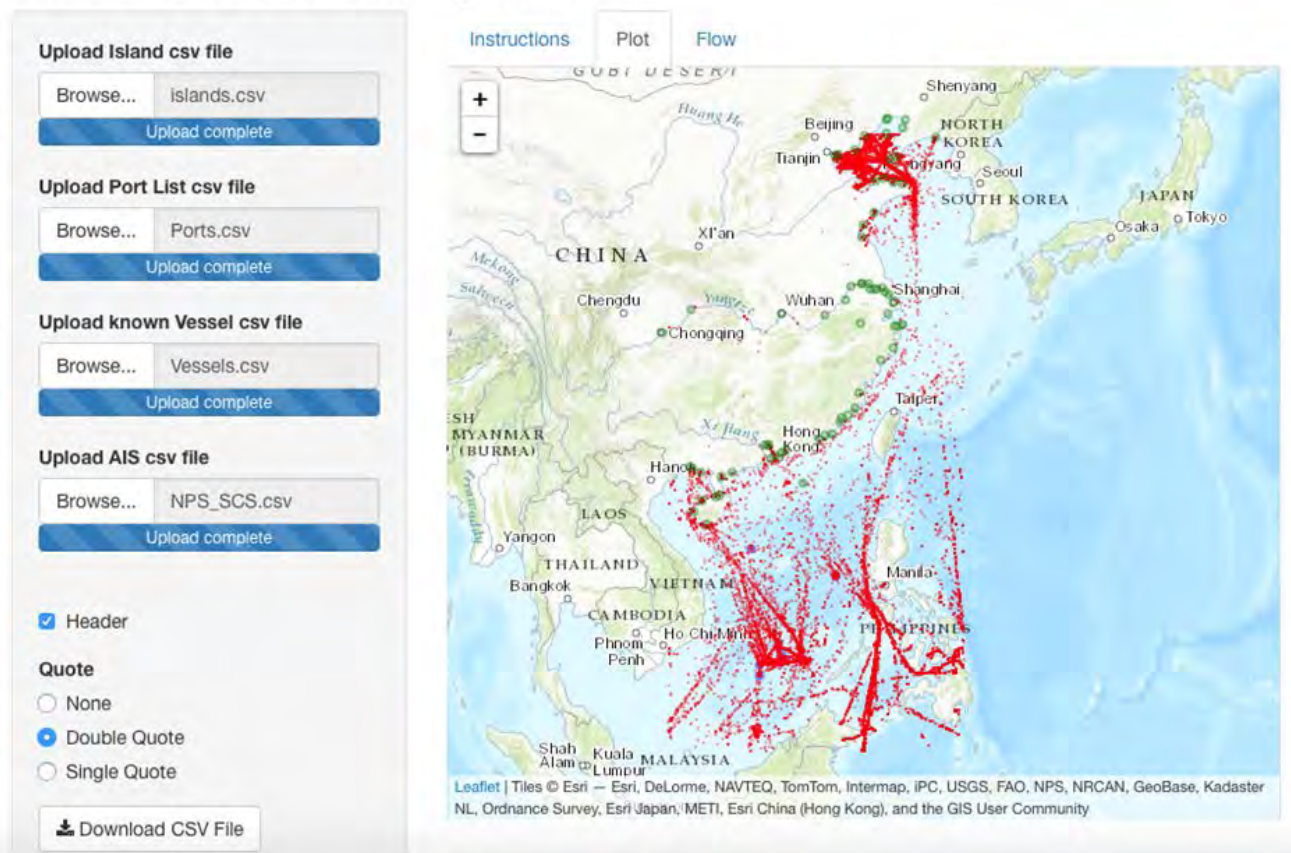


FIGURE 5: USER-FILTERED SHIPS, PORTS, AND ISLANDS

One of the visualization methods used to show the resulting data after filtering the original AIS file is a leaflet plot (Figure 5). This shows the user where the new vessels are located in the familiar view of a world map, specifically the South China Sea area. This helps clarify which Chinese ports and routes are most heavily trafficked by the vessels of interest.

Based on the research discussed above, the following findings are provided in response to the research questions:

A - Can social network analysis enhance maritime domain awareness and interdiction operations?

The outcomes from this analysis should offer not only the potential to predict future terra forma activity in the South China Sea but to leverage the information gathered on licit and illicit commercial shipping companies to facilitate enhanced money-tracking and better inform sanction regimes against the large, publicly-traded holding/operating companies whose assets are contributing to potential United Nations (UN) Convention on Law of the Seas violations. Using commercially available geospatial and temporal data, researchers were also able to develop a network of homeports for dredging and support vessels. This data enables more robust analysis within the maritime network.

B - What role do maritime dark/grey networks play in supporting artificial reef construction in the South China Sea?

NPS researchers have identified 314 Chinese vessels that are assessed to have engaged in dredging, terra forma, or reef enhancement operations in the South China Sea. Principally, these vessels are involved in the construction of artificial land formations in the Spratly and Paracel Islands, Mischief, Subi, and Fiery Cross Reefs. The vessels are collectively owned by as many as 88 different companies, some of which are parents or subsidiaries of one another. Initial research that identified links between reef enhancement vessels and their holding companies was conducted and illustrated. Connections between companies that own identified ships of interest were further examined in more detail using information and records gathered from the Tokyo Memorandum of Understanding Port State Control (PSC) database and through co-location algorithms (ships conducting operations in the same proximity at the same time). Specific companies of interest were then evaluated by examining two different structural characteristics of the network: core affiliations and brokerage potential. Companies that might play a brokerage role (by connecting nodes within company to company sub-networks) were identified by measuring their betweenness centrality.

The largest and most active of the companies is the China Communications Construction Company (CCCC), a publicly-traded, state-owned entity (SOE) with numerous subsidiaries including the CCCC Dredging Group Ltd. The CCCC conglomerate contains companies that own a large number of the dredgers, as well as tugs and offshore supply vessels, that are part of the shipping network. It owns regional dredging companies headquartered from north to south in Tianjin, Shanghai, and Guangzhou, respectively. The CNPC Offshore Engineering Company and the China Huaneng Group, which is a state-owned electric utility that also is highly involved in investment and construction, were also key nodes with high brokerage potential (by connecting nodes within the company to company sub-networks).

C - Can existing analytic tools (e.g. ORA, UCINET for social network analysis; AIS and SeaVISION for geo-locating/tracking) be integrated for improved identification, geo-location, and tracking of maritime dark network platforms (military and commercial), associated owners/operators/state-owned enterprises, commonly used ports, activities, and cargoes?

We have concluded from the research we conducted and the tools we developed, that depictions of the maritime networks and chord diagrams of OPAREAS and ports visited associated with specific ships of interest could, with relative ease, be integrated into existing platforms such as SEAVISION. This would significantly contribute to an awareness of specific ship affiliations and activities. Additionally, this

information could contribute to predictive analysis to determine where impending reef enhancement activity may begin.

During the course of this research, Dr. Porter demonstrated the tools and research being developed for the Commander of the 7th Fleet (COMSEVENTHFLT) for attendees of the annual Maritime Domain Awareness (MDA) conference and the Five Eyes (FVEYS) Pacific Threat and Targeting Workshop at NPS, as well as for ADM Davidson, Commander, Fleet Forces Command. A good deal of interest was generated with US Coast Guard personnel, FVEYS MDA partners, representatives from the National Maritime Intelligence-Integration Office (NMIO), including RADM Sharp (Commander, NMIO), and with representatives from NRL and the Office of Naval Intelligence (ONI). Additionally, Dr. Porter briefed a visiting Congressional Delegation from the House Finance and Armed Services Committees on the potential value this research could provide in seeking sanctions through the UN or unilaterally.

D - Can technologies currently being pursued by SPAWAR, NRL, and ONI (e.g. ship recognition algorithms and sensors) be integrated as unstructured data into the social network matrices to enhance identification and tracking?

During the course of this research, Dr. Porter had the opportunity to exchange information and ideas with SPAWAR representatives working with ship recognition algorithms and software as well as with a variety of air- and space-borne sensors. It was acknowledged that the application of these capabilities could enhance both cueing and the identification of vessels operating in areas of interest, to broaden the membership of the identified maritime network supporting reef enhancement activity.

E - Can this research be used to enhance maritime domain awareness in other areas of maritime dark network activities such as illicit trafficking, piracy, hybrid warfare and IUU?

NPS researchers and attendees of the annual Maritime Domain Awareness (MDA) conference and FVEYS Pacific Threat and Targeting Workshop have concluded that there is the potential to use maritime network analysis and tools to enhance MDA in areas of illicit trafficking, piracy, and illegal, unregulated, and unreported fishing (IUU).

Recommendations for Further Research

Follow-on work is already underway for Commander, Logistics Group Western Pacific (COMLOG WESTPAC), applying maritime network analysis to enhance logistics effectiveness, and maritime network analysis training opportunities have been discussed with members of ADM Davidson's staff, using tools developed at NPS. Further, there has been a great deal of interest generated by the Swedish Chief of Joint Operations and Chief of the Navy, as well as with the Norwegian military and their research institutions in applying maritime network analysis to Russian hybrid warfare and maritime operations in the Baltic.

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NPS-17-N090-C: Distributed Command and Control in Navy Integrated Fire Control - Counter Air (NIFC-CA)

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Project Summary

This research was accomplished in response to a topic submitted by U.S. Naval Surface Forces titled “Distributed Lethality: Decentralized C2 in a Centralized World.” Multiple challenges exist in how to take distributed lethality (DL) from an aspirational concept to an at sea capability. To address this, the Navy is conducting a small number of expensive and highly constrained at sea and large-scale wargaming experiments to better understand the impacts of capabilities and tactics associated with DL. The goal of this effort was to advance the Navy’s ability to use closed-form constructive simulation to allow us to examine thousands of simulated DL battles varying scores of factors (e.g., combatants, formations, tactics, threats, environments, and more). The modeling environment used is the agent-based orchestrated simulation through modeling (OSM), currently under development at Naval Surface Warfare Center, Dahlgren Division (NSWCDD). As a step towards being able to better simulate and analyze broader Navy DL issues, this research focused on the potential value of and associated Concepts of Operation (CONOPS) for an area related to distributed lethality—Navy Integrated Fire Control - Counter Air (NIFC-CA). We found that OSM is currently inadequate for modeling the full features of NIFC-CA, but advances are being made and additional requirements have been identified. In addition, preliminary classified tactical insights were gleaned.

Keywords: *Navy Integrated Fire Control – Counter Air (NIFC-CA), distributed lethality, orchestrated simulation through modeling (OSM), agent-based modeling, data farming*

Background

The distributed lethality (DL) concept envisions transforming surface combatants into a more distributed, offensive-minded force. A fully-integrated distributed force will be extremely lethal and put enormous stress on potential advisories throughout an area of operations. However, many challenges exist in how to transition DL to an at sea capability—not the least of which is determining the appropriate distributed command and control procedures. In a distributed force, who decides to shoot, at what targets, and using what assets (e.g., another ship’s missile)? The best way to explore various options is through experimentation. Unfortunately, physical experiments involving large force-on-force battles are prohibitively expensive and thus extremely limited. Multi-player wargames are another valuable option, but these too are relatively limited in the options the Navy can investigate.

This research complements the Navy’s at-sea experiments and wargaming exercises by advancing our ability to model DL using the Navy Surface Warfare Center (NSWC)’s orchestrated simulation through modeling (OSM) environment. OSM is an agent-based modeling framework being developed by the Navy to study several emerging naval concepts, such as DL. The Naval Postgraduate School (NPS) and NSWCDD have previously partnered to use OSM to develop tactics for Navy ships defending against swarm attacks from the air and sea. To focus this effort, NIFC-CA CONOPS are explored using a scenario developed for a recent Navy wargame in OSM and explored over a wide range of conditions. While NIFC-

CA does not fall under all DL definitions, from a modeling perspective they are similar in that distributed units need to share situational awareness and resources. Consequently, this research improved OSM by adding new model objects and capabilities in new and extended scenarios and provided tools to help with OSM's verification, validation, and accreditation.

Findings and Conclusions

The study had three phases. Phase I advanced the suitability of OSM as a modeling and analysis framework for the study of DL, with NIFC-CA as a focus area. Phase II used the resulting model and tens of thousands of simulated missions to identify tentative insights relating to NIFC-CA (see Souba 2017). Finally, in phase III, advances to OSM and data farming were made to explore manned and unmanned teaming in combat between surface action groups (see Tanalega 2018) and the teaming of a P-8 with a Medium Displacement Unmanned Surface Vessel (MDUSV) in ASW operations (see Tilus 2018).

A scenario based on the Navy's 2014 Naval Integrated Fire Control – Counter Air (NIFC-CA) wargame was implemented in OSM. It is worth noting that only four experiments were made in the detailed human-in-the-loop wargame. To complement those four data points, tens of thousands of simulated NIFC-CA missions were made using OSM. Moreover, those experiments utilized an advanced design of experiments and were run in parallel using a computing cluster. In its current state, OSM is not ready to model a full NIFC-CA scenario. NSWC has been made aware of OSM's limitations and needed improvements, and they are addressing them. With further development, OSM has the potential to be an invaluable tool to the NIFC-CA program and in studying many other DL technologies and tactics. The experiments provided some tentative tactical insights regarding saturation levels, the efficient allocation of missiles, and identifying bottlenecks in the kill chain (see Souba 2017).

Advances to OSM and data farming were also made to explore warfare between surface action groups (see Tanalega 2018) and the teaming of a P-8 with a Medium Displacement Unmanned Surface Vessel (MDUSV) in ASW operations (see Tilus 2018). In the former study, an analysis of almost 30,000 simulated surface battles found that passive sensor range is the most influential factor improving a force's probability of being first-to-fire. The addition of MDUSVs with a tethered parasail enables this capability. In the latter study, nearly 100,000 simulated tactical ASW engagements showed that teaming an MDUSV with a P-8 significantly reduces the time it takes to find and prosecute a submarine trying to cross a barrier.

Recommendations for Further Research

Extensive experimentation is required to determine the military worth of new capabilities and the tactics that realizes their full potential. Closed-form computer experimentation complements what can be learned through physical experimentation. Thus, the Navy should continue to improve OSM and our ability to use it to explore a breadth of distributed maritime warfighting issues.

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NPS-17-N091-A: Underwater Masked Carrier Acoustic Communication

Researcher(s): Dr. Justin P. Rohrer and Mr. Charles Prince

Student Participation: LT Andrew N. Mauldin USN and LT Ryan Ferrao USN

Project Summary

The Underwater Masked Carrier Acoustic Communications project has proceeded to the validation phase via modeling, showing that masked underwater acoustics is a reasonable form of communication that the adversary will not easily detect via aural and visual inspection. We simulated use of a stealthy algorithm and have proceeded to automate ingestion of a carrier signal and embedding of the steganographic symbols. We have also proceeded to improving throughput via QPSK adaptation of Passerieux’s Method, however this work is not yet complete. Both the automated method of repeating a carrier signal with the embedded signal and the QPSK are new works not previously discussed in literature.

Keywords: *masked underwater acoustic communication, underwater glider, ocean sensor network, underwater acoustic communication*

Background

Underwater acoustic sound contains losses and distortions due to many boundaries and transitions affecting the speed of sound in water due to many causes. The multiple items affecting sound in water are speed of sound in water, which is affected by pressure, temperature, salinity, and multiple interface layers. There are many interface layers in the ocean due to the same items as above, but additionally due to ocean surface, seafloor. An additional problem with ocean acoustic sounds is that ocean affects sound differently according to frequency, with high frequencies affected more than lower frequencies, this causes time delays as the wave travels through the media and from the interface transition type, both acute transitions and gradual transitions caused by changes from point to point in temperature, pressure, and salinity. If there is motion involved in the sounds transmission, or reception, then there is a Doppler effect, that is sound waves extending or compressing due to velocity of the sender, receiver, or both. The speed of sound in water is critical in modeling acoustic communication (Etter, 2013). We have found many models that are in use, but none of them model underwater acoustic communication (UAC) well given the use of a time and frequency spectrum.

Steganography of underwater acoustics must contend with properties specific to underwater acoustics and therefore, what research that has been performed for acoustics in air is of little use. The vast majority of research for acoustic steganography is acoustics in air. A problem with naval forms of UAC steganography is that a trained sonar operator must not be able to tell the difference between a naturally

occurring underwater sound, and one which is modified to include steganographic symbols, which would allow our capable adversaries the ability to know where the sender is once the communication is detected and the noise triangulated. For our use case of underwater sensors, such as gliders and underwater vehicles (UVs), their detection may lead to their destruction, or modified negative behavior of our adversaries to counter act our measures.

One set of noises that seem to be promising is the area of biologic mimicry. The problem with using background noise is that there must be background noise for the transmission to not be distinguished, and yet this may cause the signal to be difficult to be received, low signal-to-noise ratio (SNR). Biologic mimicry has the feature that the noise can stand out among the background noises, that is it provides superior SNR. Biologic noises can be used themselves without steganography using a large set of noises that represent symbols (F. Djebbar, 2012). Some of the best-known biologic noises are whale noises that can travel hundreds of miles in the deep-sea acoustic channel. The problem is that eventually these sets must be reused and therefore the likelihood of being detected is raised, or a set of new noises must be constantly reloaded by the network, which also leads to its own problems. An additional problem is that whales are very large and possibly detectable and tend to travel only in certain areas at certain times of the year, so another problem of biologic use is that the noise must be appropriate to the area, and we would prefer smaller (less easily tracked) biologics.

Biologic noise with steganography raises the bar as far as a noise not being detected as communication. The idea is a naturally occurring biologic sound is recorded from the nearby area for one-time use, and then embedded with symbols, and then transmitted. While on the receiving end there is a steganographic key to unlock the symbols that would otherwise look like random noise as compared to the original signal. This is found in Passerieux's method where a signal is broken up into sub parts with breaks in between which act to mitigate propagation distortions. Symbols are then embedded in a transform of the sub parts. The result cannot be distinguished from the whole using sonar. This method was used by Passerieux using Binary Phase-Shift Keying (BPSK), additionally Passerieux stated that the method should be able to handle Quadrature Phase-Shift Keying (QPSK), which should allow two times the rate of transmitted symbols as BPSK. Passerieux's works state that further work in optimal detection of possible carrier signals as well as optimization of the method's choice of coefficients, and the method of breaking up the carrier signal for transformation, and transmission still needs to be performed (Passerieux, 2010) (Passerieux J. M., 25May2017).

The Passerieux transform as well as the knowledge bases of the different disciplines have caused us to reach out to the math, physics, electrical engineering, and oceanography departments for collaboration.

Findings and Conclusions

This work is truly multidisciplinary work involving computer science, oceanography, mathematics, physics, and electrical engineering. Research performed has included many specialized disciplines such as; detectability of possible forms of acoustic communication, modeling acoustic communication, recreation of Passerieux's BPSK, designing QPSK for Passerieux's method, and creating an optimized automated way to perform the Passerieux method. We plan to evaluate the resultant signal based on ability to detect and decode the signal and have yet to validate results using actual UAC methods, either in a tank or at sea (out of scope for this project). The completed work involves MATLAB modeling.

We have evaluated different methods of steganography and modelled the effective sonar reading of each method and also evaluated how well the signal would propagate through the underwater medium. Our findings indicate that transmissions using Passerieux's method have the best chance of going undetected by a skilled underwater operator.

We were able to recreate Passerieux's BPSK method of transmitting symbols steganographically. This was a significant effort due to the fact that no artifacts are provided by Passerieux to recreate his method either from his papers or from his patent application (the patent has not yet been granted). There are quite a few variables that go into composing the Passerieux transform and the resultant output wave, depending on variables used, can be impossible to discern, or easy to discern. In addition, the signal has variable guard bands so that the underwater acoustic affects do not distort the signal enough to make it unrecoverable. Based on initial analysis, it appears that some signals could travel well over 5km without problem and while still detecting ~100% of the symbols, at a data rate of two symbols per second, BPSK. QPSK would double that rate, and further improvements are likely feasible, pending future research.

We are also determining how to automatically ingest a signal of opportunity, add the guard bands, transform the signal with the stego signal in order to not be detectable, such that the new signal is ready for transmission. Part of this work is modeling the underwater channel for optimization. We have found that there are quite a few models, but none of the models do justice to the process that must be performed for optimization. An improvement to the models that were being used must be performed first. Modeling the UAC channel may become an iterative process, which Dr. Kevin Smith of the physics department is helping us with, and making good progress currently. Automatically taking a signal and adding the stego signal in an optimal way is new work.

Another area currently under investigation and nearing completion is developing the QPSK model. Passerieux, in his papers and patent, mentions that QPSK should be possible using his method. QPSK should double the rate of transmission of the BPSK method. Creating the QPSK transform, based on Passerieux method will be new work.

The student hopes to be able to validate how effective Passerieux's method is using entropy as a key determinant to analyzing the final transmitted signal output using Passerieux's method. Not much work has been performed in this area yet, but validation of the results in this way should be performed. Additionally, the student would like to validate the system using a tank test, and perhaps a live underwater test, perhaps off the pier in Monterey. Assessing and rating steganography for UAC will be new work.

Use cases: This work should help underwater gliders, or underwater vehicles (UVs) in general to communicate without giving away their position, or existence, allowing the UVs to go unnoticed while they collect data on adversaries, or complete their missions. When the UVs need to dump a lot of data they could do so via light at close proximity, perhaps via another glider that then transmits to buoys, undersea receptors, or a secondary UV can transmit radio frequency (RF) from the ocean's surface, keeping the primary UV hidden.

Recommendations for Further Research

There are many follow-on research areas to address. The modeling of the UAC channel could be improved. A glider test at sea should be made once the students work is completed. A look into underwater sensors should be made using this method of transmission. Improvements in the automated

method of creating the Passerieux signal can be made, both once the modeling is improved and a closer look at each of the variables that makes the transform, as well as how to optimally break up the carrier signal into the carrier segments. A look at how best to use this technology should be made, that is how can we improve our detection of underwater areas using this technology? Can we modulate existing sonar to transmit a Passerieux signal? Passerieux stated that he was able to perform this task and read the symbols at 5km, but can we recreate this with U.S. naval equipment? Finally, can we detect this method's use by an adversary, and therefore pinpoint the transmitting device?

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NPS-17-N091-C: LPI Signaling in Anti-Access Environments using QR Streaming and Digital Flashing Light (DFL)

Researcher(s): Dr. Don Brutzman and Dr. Mike Bailey

Student Participation: No students participated in this research project.

Project Summary

Optical signaling is a commonly used technique for message passing at sea that has been used for hundreds of years. In modern times several methods remain in common use: Morse code via flashing light and specially designed maritime signal flags, with semaphore flags are also possible. However training is difficult and time consuming, making the achievement of competence in such signaling skills impractical for sailors afloat. This project has built a prototype training tool for Morse, signal flag and semaphore message designed as a training tool and tactical decision aid (TDA) suitable for use in maritime and shipboard environments. Recent work has shown that QR Codes provide a similar capability for optical signaling suitable for humans with machine support. Integrating each together and preparing for potential training use offers an excellent path for future work.

Keywords: *Low-Probability-of- Intercept (LPI), optical signaling, Morse code, semaphore flags, QR codes, training tool, Network Optional Warfare (NOW)*

Background

Naval forces do not have to be engaged in constant centralized communication. Deployed Navy vessels have demonstrated independence of action in stealthy coordinated operations for hundreds of years. Littoral operations, unmanned systems, and a refactored force mix for surface ships pose a growing set of

naval challenges and opportunities. Network Optional Warfare (NOW) precepts include Efficient Messaging, Optical Signaling, Semantic Coherence and Ethical Human Supervision of Autonomy for deliberate, stealthy, minimalist, tactical communications.

In future naval conflicts, there is strong potential for enemy denial or exploitation of legacy C2 paths. The Network Optional Warfare (NOW) operational concept has shown that the Navy needs optical communications paths for conveying tactical orders and other vital communications which are jam-resistant and low-probability-of-intercept (LPI). In several projected warfighting scenarios, either an opponent can be able to deny use of legacy communications paths, or else their use will compromise the location of our forces. Either way, we must develop auxiliary means of transmitting tactical information, including engagement orders and targeting information, without being jammed or counter-detected.

Historic techniques include flashing light, flag hoist, and semaphore, but these methods are manpower-intensive, low-bandwidth, and short-ranged. Better alternatives include quick response (QR) code streaming, digital flashing light (DFL) and light fidelity (LiFi) optical transmission paths. This project contributes to restoration of classic fleet competencies in optical signaling by focusing on a software-assist tool.

Findings and Conclusions

Within the last 1-2 decades, naval ships have endured limited capabilities in flashing light or signal flags due to the long training periods needed to achieve sailor proficiency in these difficult skills. Automated systems might someday show the ability to automatically read and send such messages. However such progress will require adaptation of visual recognition artificial-intelligence (AI) tools in comprehensive systems. Building such an AI system is possible with current technology but would require significant development. Difficulty is compounded first by challenges of pointing video systems at the right source location, and second by the great variety of visual clarity that might be encountered in heavy seas or limited visibility.

This project instead focuses on supporting sailors in operating existing equipment. Machine-assisted techniques can provide visual feedback when learning, composing, sending and receiving messages. This puts the best intelligence available – qualified sailors – squarely in the middle of the process. Under current ship configurations, sailors need to ensure that the correct messages are sent. Similarly, sailors have the best visual recognition skills under varied environmental conditions to understand and decode difficult-to-read flashing light streams or signal hoists.

We have focused on producing an initial-prototype training tool that might also be used during afloat operations. We have implemented this program using open-source Java software that can be operated on simple low-cost standalone computer tablets. Once installed, the low-cost tablet might then have any network connections disabled to have zero network connection (and thus minimal security vulnerabilities). We chose this design for minimal cost, easy portability, and deployability ashore/afloat. This work received design inputs and feedback from a small number of fleet-experienced officers regarding usability, though no thesis student participated in the project.

Example use cases:

- Sailors taking optical-signaling instruction can use tablets to learn in class or independently.
- Ship's bridge composes a message, types it into the tablet, and the message is approved by watch team and commanding officer/officer of the deck (CO/OOD). The sailor then brings the tablet topside to either select the right signal flags for hoisting, or for operation of the flashing light.
- Sailor in the ship's Combat Information Center (CIC) uses topside optics to record photo/video imagery of another ship's optical communications. Comparing captured images to the software tool allows them to repeatedly refine their decoding until confident the received message is correct. This approach can work well regardless of visibility conditions.

This codebase is published using a nonrestrictive open-source license that permits further modification by industry or educational institutions without relinquishing any government rights.

A video demonstrating the current tool is provided with the software archive, available at <https://gitlab.nps.edu/Savage/OpticalSignaling/tree/master/OpticalSignalingCommsToolbox>

Recommendations for Further Research

This project is well suited for follow-on work. Cooperative development of an improved tool with schoolhouse feedback can achieve best possible student learning and instructor effectiveness. Motivations for such training can include production of procedures and precautions for shipboard use. Publicizing availability of the software together with a community of interest can establish a positive feedback loop for end-user suggestions and software updates. Engagement of instructors, trainees and end-users afloat can keep track of emerging fleet capabilities in optical signaling.

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NPS-17-N186-A: Leveraging Low-cost Sensors to Form Self-organizing Sensor Networks

Researcher(s): Dr. Gurminder Singh and Mr. John H Gibson

Student Participation: LCDR Andrew R Belding USN and LT Chris Henson USN

Project Summary

There is a significant gap between emerging state-of-the-art commercial-off-the-shelf (COTS) remote sensor networks, and those currently employed by the U.S. Navy. Through recent advances in sensor, processor and network technologies, the idea of an unattended, expendable, and deploy-for-purpose sensor network is neither cost prohibitive nor science fiction. With expendable sensor nodes the operations and maintenance costs (O&M) are drastically reduced, and the end user is provided with a wider range of deployment locations where persistent presence may not be a requirement. This research intends to identify the essential characteristics and capabilities of current unattended maritime intelligence, surveillance, and reconnaissance (ISR) systems and compare those to the capabilities of emerging low-cost devices. Further, it intends to provide a proof-of-concept architecture and concept of

implementation utilizing these emerging devices to address the operational requirements of Seventh Fleet forces. Key items of analysis will include overall system cost, ease of deployment, sensor networking/device-to-device communication, bandwidth requirements and limitations, network robustness and security, means of data exfiltration and aggregation, sensor life and power limitations/requirements, and classification concerns.

Keywords: *wireless sensor networks, surveillance, internet of things (IoT).*

Background

As commercial technology and telecom industries have rallied around the “Internet of Things” in recent years, the adoption of literal “clouds” of miniaturized sensors have permeated all walks of life. The cost of creating and deploying these sensors has reached an all-time low, and the capability provided by tiny embedded computers is comparable to those of desktop machines only a few years ago.

Currently, the U.S. Navy’s operational employment of large scale, unattended maritime sensor networks is very limited. This is a result of significant fiscal and logistical hurdles that constrain effective use. High sensor cost and complexity, resource intensive deployment and retrieval mechanisms, intricate data exfiltration methods, and limited availability have made unattended maritime sensor networks a relative scarcity. Recent studies have identified the criticality of maritime sensor networks [Johnson, Cale: 2015] and explored various persistent deployment options [Kent, 2015]. One current methodology includes laying down a field of sonobuoys, at a cost of more than a million dollars per deployment. This study will focus on employing inexpensive, single-use sensors in mass to achieve tactical awareness.

Self-forming sensor networks, composed of emerging, low-cost, small form-factor sensors offer opportunities to revolutionize the means of surveilling remote lines of communication critical to counter anti-access and area denial (A2/AD) and ISR operations. Further, emerging low-cost, small form-factor processing devices, such as the Raspberry Pi, offer improved capabilities and increased area coverage at extremely reduced costs. The most recent version of these devices includes several radios capable of establishing self-organizing networks. Further, a variety of low-cost sensors have been developed to interface with them. The combination of low cost sensors, low-power networking radios, and low cost processing devices results in a commodity-like opportunity for the development of expendable sensor networks.

Findings and Conclusions

The goal of this study was fourfold. First, explore Navy policy and ISR requirements and determine the general breadth of maritime wireless sensor network use. Second, research and compile the necessary hardware and software components needed to create a low-cost wireless sensor node able to collect and process 802.11 wireless signals and GPS data. Third, provide a technology demonstrator able to collect and process wireless and GPS signals collected by a scalable sensor network. Last and most importantly, leverage in-network processing capabilities to enable the processing of network data without the use of a central database while isolating and reporting relevant events to the end user. Through exploring current policy, it is clear that the capabilities a maritime ISR sensor network could provide are in high demand. The explosion of IoT technology growth provides a wealth of technologies and hardware which can support these capability requirements.

As a technology demonstrator, we built TLCSN– a network of nine collection nodes comprising three geographically separate zones. For the cost of less than \$120, we were able to build and program an individual wireless sensor node. Each node consisted of power, collection, networking and processing capabilities. These capabilities leveraged in-network processing to remove any reliance on formal infrastructure or data back-haul for analysis.

The first construct of TLCSN consisted of a single zone with a network of three nodes. This configuration was tested and able to correctly identify, track, and categorize transmitters within the collection area of the zone. The architecture was subsequently expanded to include three separate zones, accomplishing the same fundamental tasks in a scalable fashion across a larger geographic area. These three zonal networks communicated and collaborated with each other to help identify and track objects of interest.

The hardware components used to build each node were widely available pieces of commodity electronics. The software libraries used were all open source and available at no cost to a developer. Message Queuing Telemetry Transport (MQTT) protocol was used at the application layer to create the network, and the MOSQUITTO broker and client software were used to control the connections. Simple MySQL databases were used on each of the nodes with the overall control software being written using Python 2.7.

During the implementation and testing phases, the functionality of the individual sensor node, followed by its performance in a networked environment, were documented. The sensor node performed well in both the simple collection of data as well as the critical analysis and transmission of data across the network. The actual range of each collection node was not explicitly tested in every environment; however, access points were seen up to 100 meters away in suburban settings. The ability of the sensor nodes to collaborate, each maintaining detailed records of its own collection, enables the in-network processing capabilities desired. As a result, the sensor network no longer relies upon a central repository for the consolidation of data, but rather distributes the responsibility across the network itself and leverages each node for the reporting of relevant events. TLCSN's use of in-network processing provides an example of how a sensor network can directly support the ISR collection requirements of a commander, without relying on an expensive, bandwidth-intensive link back to a central database. This provides the potential to increase collection footprints in both the tactical maritime and ground operating environments where these high bandwidth links may be unavailable.

TLCSN does not provide an immediate solution to existing ISR gaps at the tactical edge; nor could it immediately replace existing ISR collection systems. For either of these to happen, significantly more work would need to be done from testing, development and productization standpoints. What it does provide is how emerging IoT technologies can drive the development of future sensor nodes and sensor networks.

The construction of TLCSN widens the scope of visibility for future sensor network development based on the IoT technology. It also provides a platform for the integration of additional sensors and physical network technologies on a mission-dependent basis. The choice of components is an example of how to mitigate many of the past, cost-prohibitive limitations, of wireless sensor network employment. TLCSN provides a framework upon which future sensor networks can be developed and deployed, catering to a low cost of acquisition, and a broad scope of tactical usage. With the overall architecture in place, each component of the system can be modified or refined to provide increased versatility and operational effectiveness. For the maritime environment, various buoy systems exist and the existing sensor node

hardware is easily adapted to fit various forms. For traditional ground based operations, the existing network and node constructs provide simple and expendable capability that can be used to increase ISR collection by tactical forces.

Recommendations for Further Research

Additional proposals for follow on work are divided into four main categories addressing: the network itself, the storage and manipulation of collected data, the sensors and technologies targeted, and the actual physical employment of TLCSN.

1. Physical Network

The physical and transport layers of TLCSN were abstracted out of most of the tests conducted in this study, as the emphasis was placed on the sharing and analysis of data within the network. Future testing should address implementing TLCSN across various ad-hoc network technologies demonstrating true infrastructure-less capabilities. There are various “mesh” networking technologies that provide support for TCP/IP connectivity at a low cost. In this study sensor nodes were also assumed to be static. The additional issue of having mobile nodes could also be explored and expanded upon to provide a wider range of network uses.

2. Data Storage

In this study, the storage and recovery of data was conducted using simple MySQL databases and basic queries. More research should be conducted into optimizing how data is managed both within each sensor and across the network. Finding ways to generate faster efficient queries to extend battery life and minimize processing power could provide valuable improvements to the system. Additional optimization of data transmission to take into account the possibility of overlapping collection areas will also increase the scope of use for the system as well as its efficiency.

3. Target Medium

The 802.11 wireless technology was used because it provides a large amount of data with significant potential for intelligence gain. However, depending on the area of operation, there may be many other wireless technologies that are more relevant for collection. The Raspberry Pi possesses the processing power to support many more sensors as well as conduct additional tasks such as image processing and facial recognition. Expanding TLCSN to provide a wider range of data could increase the operation impact of the system. Thus, it may be useful to expand the collection scope to look at various supervisory control and data acquisition (SCADA) protocols that might be more relevant to mission taskings.

4. Testing Environment

TLCSN has significant potential in both the maritime and shore-based environments. Additional testing and deployments should be conducted in both environments, as well as hybrid combinations of the two. A system of multiintelligence sensors that is able to provide data across the littorals, both from the sea and the shore in concert, will greatly enable commanders of maritime and amphibious forces.

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NPS-17-N186-B: Employing Distributed Low-Cost Sensors ISO C7F Operations

Researcher(s): Dr. Dan Boger, CAPT Scot Miller USN Ret., CDR Sue Higgins USN Ret., and Ms. Ann Gallenson

Student Participation: No students participated in this research project.

Project Summary

The U.S. Navy's 7th Fleet requested using a Design Thinking methodology to explore the efficacy of disposable sensors in their 48 million square mile area of responsibility (AOR) to improve situational awareness. Through interviews with military experts, sensor designers, and researchers, we collected the background information to create the context scenarios for design sprints for teams of international military officers from the U.S., Sweden, Malaysia, Singapore, and the Naval Postgraduate School faculty. The design sprints, conducted by teams of two to six individuals, lasted five hours and concluded with out-briefs and cross-team discussions.

Military and sensor designers cautioned that the entire life cycle of sensors and their encasing technologies be well matched to both surveillance needs and environmental conditions. The sensor data requires similar considerations regarding timely accessibility, security, reliability, interoperability, and analyses. The sprints' results focused on exploring existing sensors, data management, analytic integration, military limitations and socio-political institutions for gathering and acting on surveillance information. From brainstorming through design, the teams favored new uses for the data from existing and emerging sensors and sensor systems. The four core insights were: 1) the value of any sensor depreciates once deployed; 2) sensors have a half-life, but the data accumulate informational value over time through aggregation, analyses, and simulation; 3) 7th fleet and other security entities in the region function as "sensors" for the political and commercial stakeholders in the region; and 4) the Navy should first focus on leveraging the value of the data they currently collect.

Keywords: *low cost sensors, distributed sensors, sensor networks, big data, disposable sensors, Design Thinking, geospatial analysis, South China Sea (SCS)*

Background

The U.S. Navy's 7th Fleet Area of Responsibility (AOR) encompasses more than 48 million square miles from the Kuril Islands in the north to the Antarctic in the south, and from the International Date Line to the 68th meridian east. The AOR includes 36 maritime countries and the world's five largest foreign armed forces. Developing a distributed and disposable air, land, and sea sensor strategy is a key to operating in denied environments. The Topic Sponsors requested that we use a Design Thinking methodology to explore the use of disposable sensors in their AOR to improve situational awareness.

The Design Thinking method we use is a team-based, five-phase approach developed at the Stanford d. School (Kelly and Kelly, 2013) and modified to incorporate scenario framing aspects of war gaming (Curry and Perla, 2012). The phases of Design Thinking are: 1) *Discovery* of the problem space through archival research and interviews with experts and users; 2) *Definition* of the design challenge or problem statement; 3) *Ideation* – brainstorming for design concepts converging into design direction; 4) *Prototyping* of low resolution concept maps to test assumptions and refine approach after testing; and 5)

Testing of the prototypes by presenting them to other design teams, experts and sponsors. During the discovery phase we interviewed sensor research sponsors from the U.S. Army, Special Operation Forces, Coast Guard, U.S. Navy, and researchers from the Navy and academic institutions gathered at the Joint Interagency Field Experimentation (JIFX) Laboratory in California. We then interviewed oceanic sensor designers and researchers at the Moss Landing Marine Laboratories in California. Interview notes were combined with information on sensor types, the South China Sea, and 7th Fleet to create “futures scenarios” focusing on North Korea, fishing disputes, and shoal-based oil and gas excavation. The latter scenario was presented to twenty-two students from the Swedish Defence University (SEDU) in a five-hour sprint as part of a Technologies for Information Operations (TIO) course. The other scenarios were addressed by six individuals in two student and faculty teams during a five-hour sprint. As a proof of concept, geospatial analysis on AIS data in the South China Sea was focused on Chinese Coast Guard ship movements. The analysis revealed maritime law infractions that predated reports by at least 30 days.

Findings and Conclusions

- Combine existing sensor and non-sensor data to address regional concerns.
- Consider expanding existing technologies like SOSUS, augmenting it with automatic identification system (AIS) data.
- Sensors physically degrade but their data have a cumulative value.
- Only introduce new sensors if the return on investment is high.
- Cultivate regional partnerships for data collection, sharing, analyses, and interpretation.
- Seventh Fleet and other entities should serve as “sensors” for regional governments.

Recommendations for Further Research

- Combine AIS data and other data sources to analytically model and explore movements in the South China Sea (SCS).
- Design a data plan, aligned with the Navy’s Data Strategy, before new sensors are introduced.
- Identify open source, crowd-sourced platforms for data sharing and display.

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NPS-17-N297-A: Creating Unclassified SE Asia Maritime Domain Awareness

Researcher(s): Dr. Dan Boger and CAPT Scot Miller USN Ret.

Student Participation: CDR Erik Lavoie USN and LCDR Erin Wreski USN, LT Stevie Greenway USN, LT Coey Sipes USN, LT Daniel Miner USN, and LT Kris Sousa USN

Project Summary

The goal of this research is to build upon the concepts of operations (CONOPS) developed in year one in order to create an exercise plan that will then be used in Southeast Asia Cooperation and Training (SEACAT) exercise 2018. The overall goal of the multi-year thesis project focuses on designing, implementing and analyzing an experiment at (SEACAT) that can be applied to real-world scenarios. This research is the result of comprehensive research into socio-economic issues plaguing the South China Sea (SCS), programs that can assist with Maritime Domain Awareness (MDA) operations in the SCS and the applicability of these programs to SEACAT 2018.

Process Improvements

This experiment is still at a planning stage but will be tested at SEACAT 2018. The next steps will be critical in moving from the theoretical into the practical. This research will produce an experiment, but it must be cultivated with the input of Commander, Task Force (CTF) 73 and our partner nations at CTF 73 to maximize its effectiveness. Some of the difficulties and restrictions that were encountered in developing our exercise plan were eventually mitigated and should be used in the future in confirming the experiment. We recommend that points of contact at CTF 73 be identified early, as determining the right person to speak to, for the right product we were addressing, took a significant amount of time. Again, a common information sharing portal would elevate this issue.

A key recommendation would be to obtain a list of personnel, their nationalities, and their languages that will be present at the pre-planning conference for SEACAT 2018 to be held in April 2018. Once this is acquired, determination of their account access to SeaVision or All Partners Access Network (APAN) is revealed, and they can go through the setup process if needed. If their respective country does not currently have an agreement with SeaVision, then participants can be shown the benefits and the usefulness of SeaVision. If the attendees of the pre-planning SEACAT 2018 conference speak a language that is not already loaded into APAN, then requests to the support team of APAN can be made.

One more update to the process involves the procurement of the specific areas of operations that the vessel(s) of interest (VOI) will use during SEACAT 2018. Having this information will be crucial to utilize SeaVision to its full potential. As Wreski and Lavoie noted in their thesis, having additional imagery of the VOI will improve "SPOTR's classification and identification processes" (Wreski & Lavoie, 2017, p.90). Without a sufficient number of images of the VOI, SPOTR's ability to detect, identify and categorize the VOI is dramatically reduced. Currently, the VOI selection process involves contracts and contract bidding, so that the VOI are not released until right before the exercise. We suggest that the bidding process occurs earlier in the planning stages so that the VOI are identified at least two months before the exercise to allow for proper software updates through SPOTR and SeaVision.

Findings and Conclusions

Our research has shown the growing importance of the SCS to the region, our country and the world. Without a stable SCS where countries abide by international law, illicit activities including overfishing, piracy, and energy extraction will continue to accelerate with far-reaching consequences.

We have developed a detailed proposal on how to gain acceptance of our methodology, as well as proven the utility of our proposal. It is our intention this exercise plan be used during SEACAT 2018. Once implemented, this will be valuable to the U.S. Navy by transferring some of the policing responsibility to our allies in the region, who will be able to allocate law enforcement (LE) personnel to these critical areas. The tools such as SeaVision, and APAN, along with the eventual merger of SPOTR into these awareness tools, will continue to improve their functionality and users will become comfortable using them. The dark vessels will therefore become more easily identifiable, and it will become easier to thwart illicit activities.

Recommendations for Further Research

Import Imagery Data into SeaVision

We have learned through personal communication with SeaVision developers that SeaVision's ability to assist its users is dependent on the number of data sources that are fed into the program. Currently, SeaVision obtains imagery from the MarineTraffic website. Registered users on MarineTraffic are able to upload photos, and are "included in the MarineTraffic Photo Directory" (MarineTraffic, 2018). Similar to the MDA service Equasis, the validity of the imagery is questionable due to MarineTraffic not validating its authenticity before displaying it on the website. Therefore, it is pertinent that SeaVision ensure that the source of its imagery and other supporting data can be verified and trusted.

Transition to Future Capabilities

With the growing advances in technology, one can only ascertain that the capabilities for MDA will also continue to grow. Two areas of interest include grey MDA networks and big data databases. In grey networks, atypical features are focused on, such as crew size, crewmember names, and port visits. Grey MDA information can be gathered through a variety of sources, including social networking sites, government and non-government entities. The information can assist law enforcement (LE) by providing them with known criminal names in order to arrest or confiscate ships involved in illegal activity. Big data databases are constantly updated, and users can run queries based on their specific needs. The information gathered from big data databases can be immensely useful, providing LE officials another tool to help navigate their AOR. This alone would save money and reduce unnecessary patrols.

Secondly, we believe that unmanned vehicles (UxVs) and artificial intelligence (AI) will help in MDA. UxVs and AI can collectively work together to patrol vast maritime regions and gather a litany of data that can be gathered and processed in near real-time. Maintaining a proper schedule of UxVs and AI operations will reduce the risk to personnel patrolling the sea and will enable them to redirect their focus to other critical issues.

UNITED STATES MARINE CORPS

HQMC AVIATION (HQMC AVN)

NPS-17-M014-A: The Effects of Crew Rest on Performance in Marine Corps Aviation

Researcher(s): Dr. Nita L. Shattuck, Professor, Dr. Samuel E. Buttrey, LtCol Mark Raffetto, and Dr. Panagiotis Matsangas

Student Participation: Maj Rachel A. Gonzales USMC and Capt Alex W. Ryan USMC

Project Summary

This project sought to determine how sleep affects cognitive performance in Marine aviators in a highly-regimented training environment. Expanding upon prior studies in military educational environments, the study assessed the relationship between sleep and performance of students and instructors attending the Weapons and Tactics Instructor (WTI) course at Marine Aviation Weapons and Tactics Squadron-1 (MAWTS-1) in Yuma, Arizona. Results showed that sleep duration and sleep efficiency (i.e., sleep quality) remained high throughout the course; however, study participation waned significantly around the midpoint of the course. Both instructors and students appeared to receive adequate amounts of good quality sleep (overall average of seven hours and 24 minutes per night). There was little variability in the sleep patterns, meaning that all WTI participants were abiding by the crew rest regulations. Many of the volunteer participants opted to drop out of the study about halfway through the course, coinciding with the start of the in-flight portion of the syllabus. Consequently, non-compliance posed a significant challenge that limited our ability to correlate sleep to final course performance. We also measured self-reported fatigue and mood using standardized questionnaires. Results from subjective assessments showed a significant increase in self-reported fatigue as the course progressed.

Keywords: *Marine Aviation Weapons and Tactics Squadron, MAWTS-1, sleep, performance, crew rest period, fatigue*

Background

An ever-growing body of scientific evidence supports the positive relationship between sleep and learning, especially with respect to memory consolidation. When adolescents and young adults are subjected to the rigorous academic demands of military training regimes, their sleep patterns are continually disrupted with foreshortened sleep periods and inflexibility in opportunities for recuperative sleep (Miller et al. 2008; Baldus 2002; Miller and Shattuck 2005; Miller, Shattuck, and Matsangas 2010; Miller et al. 2010).

This study expanded upon prior research in the training environment of MAWTS-1 (Maynard 2008). Data collected in 2005-2006 suggested that the students in WTI were not sleep-deprived and for this population of well-rested aviators, sleep was not a significant factor in predicting exam and flight scores. The 2008 findings suggest that Naval aviators during WTI complied with crew rest, a requirement spelled out in OPNAVINST 3710. The instruction states that an eight-hour opportunity for uninterrupted sleep must be provided for every 24-hour period. However, this requirement does not guarantee that the

crewmember will receive eight hours of sleep nor does it stipulate when that sleep should occur. It should be noted, however, that the results of the 2005 and 2006 data collection efforts were limited in scope since they studied a small number of individual students (less than 10% of the student population).

Findings and Conclusions

The focus of the current field study was to determine, outside of a structured laboratory environment, if the performance of an individual participating in WTI 2-16 course was impacted by either the quality or quantity of sleep received (Gonzales 2017). This question was addressed using various objective and subjective measures of performance and fatigue. Sleep quantity and quality were evaluated using wrist-worn actigraphy data from 11 staff members and six (6) students. Subjective data included three sets of questionnaires collected throughout the course.

In general, results from the objective sleep data showed that throughout the course, there was good sleep quantity and quality. Based on the individual mean sleep durations of 17 participants with actigraphic recordings for the entire course, mean participant sleep duration for WTI 2-16 was 7.40 hours (seven hours and 24 minutes) with a standard deviation of 29 minutes. Mean participant sleep efficiency for the course was 95.06% with a standard deviation of 2.52%. Furthermore, nights in the course that appeared to have a lower average amount of sleep were followed by nights with greater than average sleep. These findings confirmed that students and instructors were using crew rest periods effectively.

An additional research question considered was whether there was any portion of the curriculum where either students or the staff were sleep deprived. Based on the objective actigraphic data collected, insufficient sleep did not appear to be an issue. However, results from the questionnaires, specifically an increase in the Profile of Mood State (POMS) Fatigue sub-score and an increase in the number of participants reporting Epworth Sleepiness Scale (ESS) scores >10, indicate that self-reported fatigue increased over the course. In particular, the POMS Fatigue sub-scores for all participants worsened over the course of the study. The changes for the student group were reflected in the p-values = 0.01 between the second and third administration and the first and third administration. For the staff, the changes in POMS Fatigue sub-scores were more severe and were reflected in p-values < 0.001 between the second and third administration and the first and third administration.

Objective performance data, collected in the form of psychomotor vigilance tests (PVT) scores, showed consistent performance throughout the course with respect to speed and accuracy for PVTs. However, the staff members had consistently faster reaction times and fewer errors than the students. The objective data showed overall good sleep habits for study participants and consistent PVT performance. Additionally, the collection of this data outside of a structured laboratory environment helped identify several of the challenges in cleaning and processing the information and led to the development of a repeatable process that could be refined or automated as part of future work.

This study also compared the current results to the WTI 2-05 course results. For WTI 2-05, there were 20 students and staff that volunteered as participants. The nightly sleep averaged seven hours and three minutes with a standard deviation of 29 minutes. As previously mentioned, the 17 WTI 2-16 participants' mean sleep duration was seven hours and 24 minutes with a standard deviation of 29 minutes. This comparison suggests that average sleep duration has risen slightly but overall, has remained relatively consistent for the WTI staff and students over the past 10 years.

Recommendations for Further Research

Participation, compliance, and data processing efficiency were three major challenges that resulted in difficulty correlating sleep to performance. However, valuable insight was gained from various metrics including self-reported POMS and ESS scores. This study outlines a detailed methodology, lessons learned, recommendations for follow-on analysis, and improvements for future studies.

Due to the length of the WTI curriculum, collecting data for the entire period posed a significant challenge, evidenced by a large number of participants who dropped out of the study. In the future, the length of the overall study should be kept as short as possible to gather the data needed, especially when actigraphy is being utilized. Utilizing electronic questionnaires may improve compliance with the research protocol and increase response rate.

Based on interviews conducted at the conclusion of the study, we recommend that future efforts focus on aircraft maintainers. Even though not directly involved with the implementation of the course, aircraft maintainers work long hours during the WTI and have never been studied.

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NPS-17-M087-A: Air Base Ground Defense (ABGD) ISO Expeditionary Force-21 (EF-21)

Researcher(s): Dr. Gurminder Singh

Student Participation: CPT Dingyao Hoon SAF, Mr. Yueng Hao Kenneth Foo SG DSTA, and Capt Caleb Wu USMC

Project Summary

Enhanced Marine Air Ground Task Force Operations (EMO), as described in Marine Corps Operating Concepts, 2010, and Distributed Operations concepts, envision tactical elements dispersed over a wide geographic area to shape the battle space. [Commander's Handbook for Joint Support to Distributed Forces, Apr 2011]. The key aspect of this study was investigating extending the sensing capabilities of Forward Arming and Refueling Posts (FARPs), which are forward operating locations intended to reduce the turn-around time for aircraft missions. Moreover, the study examined the potential use of unmanned, smart sensor networks to provide indications and warnings (I&W) of perimeter breaches, enabling defense forces to maintain situational awareness while contributing to better Marine Air Ground Task Force (MAGTF) situational understanding.

Keywords: *wireless sensor networks, facial recognition, short-range radar, passive infrared*

Background

Attacks on air bases are executed to confound the capabilities of air assets to affect the battlespace. The tactics continue to leverage emerging technologies, complicating defensive tactics, techniques, and procedures (TTPs). Conventional and insurgent actors repeatedly exploited gaps in the defense in order to damage aircraft and impair air operations. Forward deployed maneuver sustainment operations, such as Forward Arming and Refueling Points (FARPs) are critical centers of gravity that adversaries seek to disrupt or destroy to adversely impact maneuver operations. Perimeter defense assets are essential for disrupting such adversary actions, such as indirect fire and infiltration. Extending the detection range of perimeter breaches improves defense's situational awareness and seeks to identify and respond to threats before they can be brought to bear on friendly assets. A low cost wireless sensor network comprising Raspberry Pi nodes equipped with short range radars, cameras, and motion sensors was built to give force protection personnel early warning of adversary actions. The network of sensor nodes proved capable of not only providing detection of perimeter breaches, but also gave detailed imagery and kinetic information on the intruder.

The value of distributed operations to cover a wide geographic area in order to shape the battle space is widely recognized. Distributed operations concepts enable U.S. and allied forces to efficiently allocate forces for a wide range of tasks, from civil operations to combat, as well as successfully engage with local population and defeat insurgencies. Dispersing forces exposes personnel, equipment, and infrastructures to further risk; and the limited manning of forward elements complicates defensive operations. Often times, the troop-to-task-ratio is less than optimal complicating force protection in the deployed environment. Leveraging technological efficiencies in surveillance and early detection can help alleviate the manpower shortfall and better provide force protection and situational awareness.

Findings and Conclusions

The objective of this effort was to design, develop and validate a low-cost unmanned wireless ground sensor network using commercial-off-the-shelf equipment, with a target aggregate unit cost of approximately \$100 USD per node. We leveraged existing technology to create a reliable and resilient ad-hoc mesh network for surveillance of FARP perimeters to allow any unmanned ground sensor nodes within the operating base to connect to the network automatically. However, consideration for robustness of component housing, such as is required for typical militarization, was not considered. The performance of the sensor network was validated under field conditions at Camp Roberts, CA. The network architecture, network communication interfaces were judged beneficial for future employment and support of new suites of commercial off-the-shelf (COTS) sensors and devices.

However, several limitations were determined during the course of the field experimentation for the Hoon and Foo thesis. Foremost among them were the limited range of the passive infrared (PIR) sensors and the time required to trigger the cameras to affect facial recognition. Capt Wu took up these issues for his thesis research. Specifically, his modification to the system design of CPT Hoon and Mr. Foo includes short range radar in order to provide a first-layer of detection, the detections of which are used to trigger the cameras associated with the PIR nodes, providing sufficient time for them to prepare for image captures. Wu's design was demonstrated during recent lab tours at the Naval Postgraduate School (NPS) and will be further demonstrated under field conditions during the Joint Inter-agency Field Experiment during March 2018.

Recommendations for Further Research

The PIR sensors used by Capt Hoon and Mr. Foo, and subsequently by Capt Wu, are susceptible to false detections due to variations in cloud cover and background lighting. More capable sensors should be investigated to determine if these false positives can be reduced. Capt Wu explored the inclusion of low-cost short-range radar as a means of extending the range of the sensor detection field of view. Other sensor types may be considered, such as light detection and ranging (LiDAR), or acoustic sensors. Such sensors could provide further layering of detection capabilities.

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HQMC MANPOWER & RESERVE AFFAIRS (HQMC M&RA)

NPS-17-M001-A: Issues in Marine Corps Talent Management

Researcher(s): Maj Chad W. Seagren USMC

Student Participation: Capt Richard Larger USMC and Capt Ryan Aukerman USMC

Project Summary

In this study, we apply quantitative analysis techniques to examine the extent to which the Marine Corp's Junior Enlisted Performance Evaluation System (hereafter "Proficiency and Conduct System") effectively identifies high-quality Marines and flags them for various career milestones such as promotion and retention. We assess the Proficiency and Conduct System with respect to a number of credible attributes identified in the scholarly literature, to include consistency, reliability, and accuracy. We find that the current system appears to provide sufficient information regarding the relative performance of Marines within their military occupational specialties (MOS) to identify high performers. The current system has significant room for improvement however, so we examine several margins along improvements could be made and weigh them against the additional bureaucratic burden they may create.

Keywords: *performance evaluation, Marine Corps, enlisted, talent management*

Background

Marines of ranks corporal and below make up approximately 60% of the Marine Corps' total end-strength. This bottom-heavy force structure tends to require that the Marine Corps expend a relatively large proportion of its resources to recruit, train, and develop junior Marines. This force structure also creates an opportunity for the First Term Alignment Plan (FTAP) to offer re-enlistment to only those Marines who have proven themselves to be of the highest quality during their initial term. In order to exploit the force shaping opportunity provided by the FTAP, the Marine Corps must reliably identify high-quality Marines. The primary tools the institution employs to measure the performance of corporals and below are the duty Proficiency and Conduct marks. Each Marine in this category receives such marks approximately twice per year. The marks are a primary element in both the composite score and the computed tier score which determine promotions and reenlistment opportunity. Aside from a Marine's commanding officer's recommendation, the duty Proficiency and Conduct marks are the only element of these scores that depend on the input of the Marine's leaders. In other words, the other aspects of a Marine's composite score are nearly entirely under the Marine's control (i.e. rifle score, physical fitness test, combat fitness test), while the Proficiency and Conduct marks are intended to reflect how well the Marine performed his day-to-day job, as judged subjectively by his or her chain of command.

Findings and Conclusions

Larger (2017) provides the bulk of the quantitative analysis for this project in his thesis, while Aukerman (2018) provides most of the qualitative analysis. Seagren (2018) conducts a literature review, extends certain parts of Larger's quantitative work, and provides a summary of the overall findings of the project.

We examine the Proficiency and Conduct system with respect to reliability, validity, accuracy, and practicality. Our data is comprised of semi-annual observations of all active-duty E4s and below from February 2006 to August 2016. This generates over 2.5 million observations of 418,369 unique Marines. In addition, from 2010 to 2013, a total of 26,358 of these Marines are promoted to sergeant and we have the first two years of their fitness reports.

A performance evaluation system is reliable “the extent to which a set of measurements is free from variance due to random error or the extent to which the variance in a set of measurements is due to systematic sources” (Landy and Far, 1983: p. 9). While we are unable to examine a more customary notion of inter-rater reliability, we can examine the extent to which the institution as a whole appears to measure similar Marines equitably. Namely, we investigate whether the scores of Marines in a particular military occupational specialty (MOS) are biased with respect to the type of unit to which they are assigned. In particular, we are interested in whether, say, Administrative Specialists (0111) assigned to ground combat units receive different scores on average than those Administrative Specialists assigned to headquarters units. Since Marines are essentially randomly assigned to their first unit out of bootcamp, one would think that the Marines randomly assigned to ground combat units would have the same mean Proficiency and Conduct scores as those assigned anywhere else. To the extent that they differ, it might be an indication that different parts of the Marine Corps use the evaluation tool differently.

We examine the twenty-five largest MOSs (they account for over 60% of the Marines in our sample) with linear regression models and find that only three MOSs seem to have average Proficiency marks that vary substantially according to units and only two MOSs have average Conduct marks that vary substantially (Seagren, 2018: pp. 16-21). Further examination reveals that these differences account for a difference of at most, about one to two months expected Time in Grade when it comes to promotions. That is, while a Marine in a particular MOS might receive an unlucky assignment to a type of unit that appears to systematically assign lower scores to Marines with that MOS, the worst case appears to be that Marine’s promotion is slowed by approximately two months (Seagren 2018: pp. 24-29).

A valid performance measure is one that measures what it is intended to measure and is relevant to the organization’s goals. We examine the extent to which Proficiency and Conduct marks contribute significantly to Composite Scores and the extent to which such marks might predict future performance as recorded in subsequent fitness reports. One way that the performance evaluation system could fail is that it does not provide sufficient variation in scores to differentiate between Marines for promotion purposes. Factor analysis reveals that Proficiency and Conduct scores are the most important contributions to Composite Scores. Thus, the system translates variance in Proficiency and Conduct scores into meaningfully higher or lower composite scores.

In addition, the latent variables from the factor analysis are the most important factors in a regression where the response variable is sergeant Fitness Report scores. This suggests that Marines with relatively high Proficiency and Conduct scores also tend to receive high fitness reports. The fitness report is a substantially more detailed and elaborate artifact and generally believed to be a more effective measurement of performance. This result is strong evidence towards the validity of the Proficiency and Conduct system.

Accuracy is the extent to a measurement within a rating system matches the true level of performance. One of the aspects we consider is the extent to which Proficiency and Conduct marks are distinct measures. We find convincing evidence that they are not. For example, a linear regression with Conduct

grade as the response and Proficiency grade as the explanatory variable provides an estimate of the slope of 0.95 (p.value < 0.001, $R^2 = 0.71$). Thus, much of the information contained in the pair of Proficiency and Conduct scores together actually resides in one of them.

We also examine the practicality of the Proficiency and Conduct System. We take practicality to mean that performance measures are observable, interpretable, usable, and acceptable to those who need to make personnel management decisions. Ultimately, we find that while there is room for improvement, for the most part raters appear to be generally identifying the behaviors associated with future success in the Marine Corps.

Improvements to consider

The quantitative analysis reveals that the Proficiency and Conduct system performs adequately, but there is room for improvement. It is important to note one of the most important qualities of the current system is its efficiency and moderate level of administrative burden, especially relative to the process of writing and submitting fitness reports. Here we pose two recommendations that provide substantial benefits regardless of other potential modifications the Marine Corps might consider.

R1) Reassign responsibility for performance evaluation from Director, Manpower Information Systems Division (M)I to Manpower Management Records & Performance (MMRP). Transferring responsibility to MMRP would enable the Marine Corps to exploit that branch's comparative advantage in performance evaluation and system management.

R2) Expand the training provided at both officer and enlisted Professional Military Education courses to include information on cognitive biases. The crucial take-away from the academic literature is that training raters to avoid biases and effectively apply the rating framework is an effective way to improve rating accuracy (Pursell, et al, 1980). The progression from Marine reported on (ratee) to rater is important for enlisted Marines to master as they ascend the ranks since staff non-commissioned officers are the expected to be subject matter experts for this evaluation process and very often provide crucial input to officers on this matter.

Thus, we find that resources invested in R1 and R2 would likely demonstrably improve the system's effectiveness. In light of the conclusions drawn from the quantitative analysis, we recommend the Marine Corps consider five courses of action: (S1) Drop all subjective measures of performance; (S2) Consolidate into a single rating scale; (S3) Keep the current system, but improve the interpretability of the rating format; (S4) Create additional measurement scales; (S5) Create a performance development scheme.

The most ambitious of these is S5, which is the primary focus of Aukerman's thesis. He performs a benchmark analysis with a performance development tool employed by the firm Adobe. While a performance development tool might be more time consuming than the status quo, the concomitant improvement in the identification and development of high quality junior Marines might make it worthwhile, especially given that the importance of talent management is expected to grow in the future.

Course of Actions (COAs) S2 and S3 are only small departures from the status quo, but hold promise for relatively large benefits. One of the most definitive conclusions of our analysis is that Proficiency and Conduct marks do not appear to be distinct measures. Thus, S2 calls for eliminating one of the scales. The modified system would likely perform nearly as well but with a substantial reduction in administrative burden. See Aukerman (2017: p. 48) for more information.

As for S3, the Marine Corps Individual Records Administrative Manual (IRAM) mentions certain attributes to consider when assigning Proficiency and Conduct marks (USMC, 2000). Larger (2017: pp. 37-39) notes the likelihood of logical error given that approximately half of the attributes for Proficiency could conceivably be considered part of Conduct, and vice-versa. For example, personal appearance is listed under proficiency, but could easily fall under conduct. Similarly, the IRAM guides raters to employ the "whole Marine" concept, which many raters take to mean that Marines should be given high Proficiency scores *because* they have high Physical Fitness Test scores or high rifle qualification scores. But those objective scores are already contained in the composite score, so using them as an input to the subjective measure of performance reduces the effectiveness of the measure. Since the current system already has two measures, it seems reasonable that devoting resources to improving its effectiveness along these lines would improve the system without substantially adding to the extant administrative burden. See Larger (2017: pp. 77-78) for more information.

Recommendations for Further Research

The most pressing future work is an analysis of the extent to which the administrative process of managing Proficiency and Conduct marks for the entire population of junior enlisted Marines holds their leadership accountable for proper and timely execution. Junior Marines are substantially more numerous than Marines who receive fitness reports, and they are less able to ensure their chain of command performs administrative tasks on time. The way that Total Force Data Warehouse (TFDW) stores Proficiency and Conduct marks prevented a more thorough analysis of the timeliness with which the typical Marine's semi-annual Proficiency and Conduct marks are submitted. If changes are made to the performance evaluation system, consideration should be paid toward ensuring discipline is instilled in the system.

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NPS-17-M360-A: Variable Flow Model (VFM) for USMC Manpower Analysis

Researcher(s): Dr. William R. Gates, Dr. Kenneth Doerr, and Maj Chad W. Seagren USMC

Student Participation: LCDR Ben Grossi RAN

Project Summary

We present an approach to managing the enlisted force structure of the Marine Corps. Our approach examines attrition and retention rates over time, based on evolving (dynamic) targets for the number of Marines at every rank, in order to provide recommendations on promotion and accession rates. There are budgetary limitations on the number of accessions allowed in any year, but as realized accessions are variable (there is random attrition even among new hires) flexible bounds are established around an accession target. Time-in-grade targets must also be maintained for the long-term health of the force-structure, and these targets constrain promotion rates from above and below. As targets are both evolving and uncertain, we establish upper and lower bounds on these targets as well. Our approach produces a policy for promotion and accession that minimizes the weighted expected cost of the force structure falling outside targeted bounds, across a multi-year planning horizon. We provide post-hoc analysis of our results on field data, comparing the risk-adjusted cost of our solution against a solution that merely minimizes the expected deviations from the targeted force structure.

Keywords: *manpower planning, Markov, stochastic, variable flow, force structure*

Background

In today's environment of budgetary uncertainty, sequestration, and constrained resources, the Marine Corps finds itself in need of a tool to improve long-term manpower planning. New policy initiatives such as the blended retirement system and Force of the Future proposals require thorough what-if analysis if their effects are to be anticipated. The Marine Corps possesses decades of empirical data on the continuation behavior of individual Marines, but since it is all under the legacy retirement system it provides limited information with respect to how Marines might behave under the new retirement system. In addition, manpower analysts are commonly asked to quantify the effect proposed structure changes on the "health" of the particular community, but they lack a tool to adequately relate changes in structure to promotion timing at different ranks. Our model fills these gaps in capability. The force structure of a community is simply the amount of inventory at each grade within that community. For example, in one community the force structure for four grades is as follows:

E03	E05	E06	E08
842	382	255	208

In this project, we develop a force structure planning model that seeks to set accession and promotion rates, along with attrition targets (these are the decision variables) so as to minimize the cost of missing force structure targets. We model the 'push-pull' nature of the marine community by allowing exogenously set promotion rates in the lower ranks (push) but only attrition target changes (beyond random attrition) in the upper ranks (pull). Yearly accession is a decision variable, with the accession vector (who goes to which grade) estimated from historical data.

The Marines define two kinds of force structure targets for their enlisted communities: Time-In-Grade, and Inventory Size. For example, the Time-In-grade Targets for the community shown in the previous table is three years, for each of the grades shown (E03-E08). While the Inventory Size targets for these grades in this community are:

E03	E05	E06	E08
811	443	305	234

Similar targets are specified for each grade in each community. But since attrition rates are random and targets change from year-to-year, hitting targets exactly may not be possible, or even desirable. For example, if we ‘make target’ via early or delayed promotion, or terminating highly skilled, and hard to replace Marines, this might produce worse problems in the long term than it solves in the short term. Our model captures these costs across a seven-year planning horizon.

In particular, we define a level of acceptable risk associated with each Inventory Size and Time-In-Grade target. The definition of acceptable risk entails an assumption that there is an upper-and-lower bound on Inventory Size and Time-In-Grade, and that so long as the community stays within those bounds, the actual cost is negligible. For Time-In-Grade targets, the Marines already do this. For example, the bounds on the Time-In-Grade target of three years in our example is stated as 3 years \pm 0.5 years. That is, USMC assumes it will not hurt their chances for later promotion, or affect productivity, so long as Marines in this community and in these grades are promoted within the range of 2.5 to 3.5 years. In our model, so long as at least $(1 / 3.5)^{\text{th}}$ of the Marines at each rank are promoted, and at most $(1 / 2.5)^{\text{th}}$ of the marines are promoted, no Time-In-Grade penalty is incurred. The Marines do not currently state an acceptable risk for their Inventory Size targets, so in our research, we assume a base rate of \pm 1% of the Inventory Target is acceptable. So, for example, the target given for E03s of 811 would have a lower bound of 811-8.1 (rounded down) and an upper bound of 811+8.1 (rounded up), and we assume that a realized inventory size within that range would incur no penalty.

However, since attrition rates are variable, the inventory size realized in any year, at any grade, is also variable. So, outside the acceptable range of each target, we calculate a risk-adjusted penalty: the probability the inventory will be realized at any level outside the range, times the number of Marines that would fall outside of the range. Missed targets in the E08 inventory are weighted more heavily than missed targets in the E03 inventory, proportional to the relative salary of Marines in those grades. We model attrition as a hyper-geometric random variable, based on parameters estimated from historical data. While the binomial distribution is consistent with the standard Markovian approach to manpower planning, the hyper-geometric accounts for the fact that, for each attrition, the remaining pool of a community (in a particular grade) is now smaller. The difference between the binomial and hypergeometric estimates is trivial for any large-sized community grade, but for smaller sized community grades (e.g., E08) the estimates may be practically different. The hypergeometric is conservative (it estimates less attrition), and the assumption is not controversial.

In other words, we calculate two costs in our model – the conditional value at risk (CVAR) associated with the risk that the number of marines promoted each year falls outside the acceptable range, and the CVAR associated with the risk that the inventory size falls outside the acceptable range. We call the sum of these two costs the *community cost* of the plan.

The optimization model seeks to minimize these costs across a seven-year time horizon. This is important because, when inventory targets are dynamic (e.g., increasing or decreasing over time), the model can make intelligent recommendations balancing Time-In-Grade costs associated with changing promotion rates against the need to build (or reduce) inventory levels across grades over time. We can also examine the effect of shocks-to-the-system such as changes to retirement incentives, and how such one-time changes impact force structure over time.

The model is built entirely in Excel, using an Excel Add-In (Crystal Ball) to model stochastic elements. It is intended as a prototype and proof-of-concept. The model is designed in such a way that additional communities can be assessed without additional programming. All the inputs are specified on a single worksheet, and the optimization engine works against whatever data is placed on that input worksheet. As a part of calibrating the stochastic model, we developed a deterministic-equivalent non-linear program using The Solver, which can be run by users who do not have access to the Crystal Ball add-in. This is important because the client does not currently have easy access to the Crystal-Ball add-in on their Navy Marine Corps Intranet (NMCI) computers. However, the two models are not equivalent. For example, if the expected inventory level falls within the acceptable range of a target, the deterministic-equivalent model calculates a zero cost, which the stochastic model calculates as the probability-weighted cost that the inventory will fall outside the acceptable range (even though the expected value is within the acceptable range).

Findings and Conclusions

The outputs to our model are suggested accession goals and promotion targets for a single enlisted community, along with associated risk assessments. The risk assessments are based on Monte Carlo simulation, and include such things as the risk of inventory levels going over / under targeted levels at each rank (Grade Adjusted Recapitulation (GAR)).

We used two datasets to build and test our model. First, single year targets for the USMC 03 Occupational Field (OccFld) along with historical data such as attrition behavior from FY12 through FY16. Since we did not have USMC Inventory Size Targets for multiple years, we used multi-year target and inventory data from the Sea Mechanic subspecialty in the Royal Australian Navy to test the multiple-year version of the model. (We received multiple year target information from USMC in March 2018 and will report the results of the model runs against that data in the final report.)

Here we will outline three important aspects of our results: short term versus long term solutions, expected value results versus risk-weighted results, and the structural incompatibility that may exist between Inventory and Time-In-Grade targets.

The results of our model show that myopic solutions to single-year problems underperform solutions which look ahead to multiple years, even though the single-year solutions may be superior. For example, a myopic solution to the year-one problem in our sample data has a community cost of 97, and using that myopic solution as a (fixed) starting point, the myopic solution to the year-two problem has a community cost of 313: a total two-year community cost of 410. However, when the two years are solved jointly, the solution has a two-year community cost of 399. While this result (that myopic solutions and local optima are inferior to global solutions) is obvious, and perhaps trivial from a research point-of-view, a tool such as the one we have developed has important practical implications. Because of the immediate needs of a community, planners and analysts are always under some pressure to provide the best short term

solutions. A tool which allows the long term cost of short term thinking to be captured facilitates a discussion, and can improve manpower outcomes.

When calibrating our simulation (search) based optimization against our deterministic results, we encountered significant differences in cost associated with the same solutions. The deterministic solution would often underestimate a community cost, or even estimate that it would be zero, merely because the expected value of inventory was within the acceptable range, ignoring the sometimes substantial probability that the inventory would fall outside the acceptable range. This is best captured with the image on the following page (and in the quad chart), but given the request not to embed any graphics in this summary, we will briefly try to explain in words. So, for example, for the E03 grade, the expected size of the inventory in the optimal solution was 796, just below the lower bound of 803. The deterministic model estimates this cost as $803 - 796 = 7$. However, the stochastic model captures the probability that the inventory size varies between 761 and 829 because of random attrition, and assigns the appropriate probability-weighted costs to those outcomes. Again, while this is not unexpected from a research point of view, it has practical implications for Marine manpower planning. In particular, the understanding that hitting a target exactly is a low-probability event, and the recognition that in fact, communities have already built a robust infrastructure to deal with small deviations from planned targets, allows for an informed discussion of what ‘acceptable risk’ should be. The Marines currently have not defined any notion of ‘acceptable risk’ around inventory targets. Establishing such targets might facilitate better long term planning. It could be, for example, that better outcomes can be obtained by broadening the range of acceptable risk from what we have modeled, but increasing the penalties of falling outside that range substantially. The tool we have developed can also support what-if analysis of changes to the acceptable range of time-in-grade targets, or short term violations of those targets.

Finally, it is possible to estimate a force structure from both the current data (the existing transition matrix establishes a steady state structure, if one assumes it is stationary), and the Time In Grade targets (which establish promotion rates that can be used in conjunction with estimates of the other variables in the transition matrix to estimate a steady-state force structure). And of course, the targets each year are themselves a (desired) force structure. What we have noticed in our analysis is that these force structure estimates are not compatible in the data sets we have been given. In conducting our analysis, we noted that the Royal Australian Navy (RAN) targets varied considerably over the seven-year time horizon, and that this involved considerable community cost, because the model had to strike a year-to-year balance, and changes in targets to higher ranks, in particular, involved costs to lower ranks in prior years. For the Marine data we had, too, we noticed substantial differences in desired force structure between the force structure target we had, the Time-In-Grade guidance, and the historical data (transition matrix). We do not think these structural differences are accidental: based on our understanding of the current process, the two sets of targets (Time-In-Grade, and Inventory Size) are set by two different processes, with two different goals. While the two processes communicate, we do not believe they currently have a tool to facilitate an explicit discussion of the differences their targets entail in guidance for force structure. We think the tool we have developed can support a more explicit discussion of those differences, and potentially lead to outcomes that better match multiple sets of expectations.

Recommendations for Further Research

Our research could be extended in a number of ways. For example, it would be beneficial to apply the model to examine the impact of a major policy initiative such as the blended retirement system, using actual data for a wide variety of Occupational Fields. By modeling one or more elements of the accession

vector as a decision variable, bounded by endogenous attrition from previous years, we can model the impact of sabbaticals, and allow what-if analysis on that, or similar proposals. In addition, it could be used to support the initiative that is underway to examine Skill Grade Flow Rates across the Marine Corps. A Skill Grade Flow Rate for a particular Occupational Field is the ratio of the number of structure billets at one paygrade to the number in the paygrade below. Finally, this model could be employed to examine the trade-off between achieving the desired or proposed structure and maintaining appropriate promotion timing.

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HQMC PLANS, POLICIES & OPERATIONS (HQMC PP&O)

NPS-17-M177-A: Multi-Agent Modeling in Support of Non-Lethal Capability Effectiveness Analysis

Researcher(s): Dr. Steven B. Hall

Student Participation: No students participated in this research project.

Project Summary

This project yielded a computational model of the influence of non-lethal weapons on the behavior and attitudes of the crowds upon which they are typically utilized. The resulting model, called 'WRENCH' (Workbench for Refining Rules of Engagement Against Crowd Hostiles) supports doctrine developers and operational planners in developing an understanding of how non-lethal weapons can best be utilized to achieve mission success (without unduly alienating the populace) as well as doctrine, organization, training, materiel, leadership and education, personnel and facilities (DOTMLPF) acquisition specialists in understanding when a new class of non-lethal weapons (NLWs) could productively be added to the arsenal.

WRENCH provides the user with the tools to explore the consequences of employing rules of engagement (ROEs) that either intentionally or unintentionally (e.g., via 'collateral damage') apply more coercive force than necessary (i.e., "excessive force"), to members of the crowds, in order to compel them to comply with the (assumed legitimate) objectives of the Security Forces. While "excessive force" may, at times, be pragmatically directed at individuals, in order to manage overall crowd behavior, a deeper understanding of how "anger" and "fear" are engendered in a crowd and then are consequently either dissipated or amplified as they contagiously spread through the crowd facilitates the development of more effective ROEs governing which weapons to use against which crowd elements; in what locations; and under what circumstances.

Keywords: *non-lethal weapons, rules of engagement, crowd behavior modeling, sustaining legitimacy, stability operations*

Background

A substantial body of scholarly work has been published, in recent years (as reflected in the included Select Bibliography), on the behavior of "crowds" that are "on the move". Much of this recent literature has been particularly focused on crowds that are effectively "in flight" from some collectively perceived dynamic threat (e.g., a "sense-making crisis") and are thus consequently "evacuating" an uncertain and fearful situation in a state that is distinguished by the *diminishing* influence of shared "social identities". The behavior of "fearful crowd" constituents, in these contexts, can be effectively modeled as being largely determined by the drive to *individually* survive amongst a mob of similarly motivated agents.

A *considerably* smaller proportion of recent scholarly work has focused on *angry* (e.g., protesting) crowds; composed of constituents that share *increasingly* influential social identities, born out of a mutual sense of frustration and/or injustice and behavioral focused by shared (and often evolving) intentions. Perhaps not surprisingly the historical pinnacle of such scholarly research into ‘angry crowds’ peaked around the time of the tumultuously rise, in the U.S., of civil unrest during the Vietnam War era and is only now apparently reentering an ascendant phase.

Critically, and perhaps also unsurprisingly, that earlier literature suggested that the behavior of angry crowds is considerably more *complex* than the simple ‘flight’ behaviors of fearful crowds. Angry crowds, amongst other characteristics, manifest: context-sensitive emergent cognitive behaviors (along with irrational biases); multi-scale identity dynamics; adaptive structural (/role) differentiation; and collective “emotional” states (linked only tangentially to individual emotional states). In short; angry crowd behavior is determined by the dynamics of social identities much more so than fearful crowd behavior is.

What has heretofore gone largely unexamined is how to pragmatically understand/model the behavior of crowds that find themselves engaged with a *recalcitrant* “othe” in the process of pursuing their objective(s), i.e., *angry* crowds which induce their own *fearful* situations in conflict.

Prototypically these *angry/fearful crowds* are driven by unmet “needs” that are mutually recognized as being both shared by the crowd constituents and potentially satisfied by an “other”. Pragmatically angry/fearful crowds fall into two natural kinds.

The simpler kind stems from a shared frustration at being unable to satisfy *survival* needs, that an “other” is suspected of being capable of remediating. Ultimately the desperation generated by these unmet survival needs tends to trigger a simple, mob-based, “fight” response that is similar in complexity to the fear-driven mobs in “flight”.

The other, more important, challenging and complex, kind of angry/fearful crowd stems from a shared frustration in being able to satisfy “their” *belonging* needs (i.e., to be a part of something larger) that, once again, the “other” is perceived of as potentially having the capability to remediate. The collective apprehension that “we” may have been “betrayed”, by an “other” (masquerading as part of “us”), has been consistently shown to trigger angry behavior amongst the “we” along with a willingness to sacrifice individual interests for the collective interests of the “we”. The response of the “other” to such challenges can either exacerbate the crowd’s perception of the offending agent as an illegitimate/ uncooperative actor or conversely (and generally preferably) reestablish the “nobility” of the offender’s intentions and reestablish their status as part of “us”.

When an angry/fearful crowd finds itself confronting Security Force “others” (often backed by and representing a supporting “State”) who are willing to apply coercive measures to assert their own will and/or maintain their status, then the resulting crowd behavior is *complexly* determined by an intricate dance on the *edge-of-chaos* between their anger and their fear.

How that process is managed directly impacts the security force’s mission effectiveness but, often more importantly, it often has lingering impacts on the crowd’s perception of the legitimacy of both the Security Forces themselves as well as of the State to which they belong.

Ultimately, when the “other” (i.e., the “Security Forces”) are in possession of a “monopoly on violence”, the key determinant of the crowd’s assessment of their legitimacy/nobility lies in their assessment of whether any use of coercive measures, by the Security Forces, is in the service of their shared interests versus in the service of the restricted interests of the Security Forces and/or an “alien” social identity that they serve.

Two factors are particular instrumental in the crowd’s assessment of the “authentic” intentions of the Security Forces:

Factor 1: Is the use of any coercive force “rule-governed”, i.e., is it unambiguously intended to compel a behavior that is clearly articulable/articulated? E.g., does it stop immediately when the desired behavior is manifested, i.e., is it “disciplined” and absent of “excessive-force”?

Factor 2: Is it responsive to the “narrative values” of those whom it claims to serve? E.g., does the crowd believe that the behavior being compelled at least “could” be in *its* (often long-term) interests? (Note: without feeling “heard” a crowd can conclude it is being “subjugated” even if coercive measures are applied with discipline).

Effectively communicating Factor 1 (disciplinary intent) can be a challenge for Security Forces for at least two reasons: 1) How much coercion is minimally necessary to compel compliance varies from person-to-person as a function of their *susceptibility* to “pain” and their *willingness to endure* “pain” (i.e., their anger-driven willingness to “sacrifice”). Applying *more* coercive force, to any crowd constituent, than is *necessary* to achieve compliance contributes to the crowd’s perception of the Security Force’s illegitimacy, *but* failure to control disruptive *collective* crowd behavior itself will be perceived as incompetence and similarly contribute to a sense of illegitimacy. 2) The targeting precision of our non-lethal weapons is such that in many cases some level of “collateral damage” is all but unavoidable, i.e., *the* weapon that is required to compel compliance from a targeted constituent will unavoidably impact adjacent constituents, where its coercive impact will sometimes be superfluous (and excessive).

Effectively communicating Factor 2 (concern receptivity) can also be a challenge for Security Forces for, again, at least two reasons: 1) The rules being imposed are, in general, often a function of political processes that are simply beyond the immediate influence of engaging Security Forces (SFs) and as such SFs are limited to attempts to explain the legitimacy of these rules. 2) To the extent that SFs have the autonomy to “negotiate” mutually acceptable solutions, with the crowd, it can be difficult to “correctly” identify the desires of the crowd and/or who can effectively give voice to them, especially given what is often their dynamic nature.

The ultimate challenge for Security Forces, who are compelled to engage hostile crowds but constrained to minimize legitimacy loss, is thus is to communicate an intent to assert a disciplined use of coercive measures against just those targets who would negatively impact the collective capacity to respond to existing and anticipatable shared challenges. In short, their goal is to communicate an intent to preserve collective resiliency, in a highly dynamic and uncertain context, which consists of a coherent shared narrative that is derived from an openness to constituent input.

At the heart of our Security Force's capacity to do this effectively is their well-rehearsed compliance with a defined set of rules that define who, what, where, when, and why this particular crowd should be engaged with these particular coercive measures. Heretofore these optimal rules of engagement (ROEs) against hostile crowds have been only imprecisely articulated and largely delegated to field commanders to clarify using their experience and intuitions ... a process, due to the non-linear complexity of fearful/angry crowds, that has had limited pragmatic value.

The intention of this work was to attempt to design and prototype a non-linear (multi-agent) model of angry/fearful crowd behavior such that effective ROEs could be defined for engaging particular crowds that would minimize Security Force and State legitimacy loss due to such engagements.

Findings and Conclusions

The result of this effort was a working prototype of the behavior of angry/fearful crowds that are being engaged by Security Forces using (non-lethal) coercive weapons. The prototype is called *WRENCH* (Workbench for Refining Rules of Engagement Against Crowd Hostiles). *WRENCH* is implemented in the publicly available NetLogo programming language and it is readily and freely available to be downloaded, run, explored, and modified. The *WRENCH* code is both readable and well-documented, and consequently *WRENCH* serves as its own ultimate authoritative source of both *what* algorithms were implemented in *WRENCH* and *how* they were implemented. The following discussion provides a conceptual overview of the *WRENCH* architecture.

WRENCH is a multi-agent (non-linear) complex adaptive system model. Individual people are explicitly modeled as agents; as are families, ethnic groups, crowds, vehicles and security forces. Technically "relations" are also "agents", in NetLogo (as are terrain patches), and these *links* define connections between otherwise autonomous agents and consequently define various kinds of higher-level "social identities," whether they be ethnic, familial, leader/follower, or target/shooter.

Autonomous agents (i.e., *people*) may be dynamically (re)configured to attempt to maintain a specifiable personal space around themselves while at the same time they can also be (re)configured to attempt to remain in proximity to other (defined either generically or preferentially) members of the crowd. They can wander aimlessly around town ("shopping"), or they can establish directed behavioral goals. They can be (re)configured to have a specifiable bias for following roads. They always remain 'outdoors', but they tend to linger a bit at "shop windows". They tend to get out of the way of vehicles ... but they aren't in a particular hurry to do so. With the exception of the "berserks" (the angriest people) they can be thwarted by lethal threats ... but such threats come at a cost to SF legitimacy.

People come in different "kinds", distinguished by their ethnicity, age, and gender. Different kinds of people respond differently to various kinds of stimuli, for example, as the research literature suggests; women's fear dissipates more slowly than does men's fear. The initial composition of the crowd can be specified as can their initial attitude towards the Security Forces. Each person is defined by the anger they harbor towards the Security Forces (in general a reflection of how they feel about the 'State') as well as the fear they have of the Security Forces. In general, crowd members will *hear* any call to protest against the State (if they are in the proximity of the call), but whether they heed that call will be a function of how much animosity (anger) they hold towards the State/Security Forces versus how much fear they have of them. Simply put; people comply with the requests/demands of the Security Forces when their "fear" exceeds their "anger". If a person isn't angry then they'll comply without fear.

People have the capacity to perceive the world immediately around themselves and in particular to notice events that take place between the Security Forces and members of their crowd. They effectively ‘talk’ to people who they care about and are, in turn, empathetically influenced by their anger and fear. Fear, whether generated directly via experienced pain or indirectly via empathy, dissipates over time while anger only responds to events that originate in the external world and are either directed experienced, immediate perceived, or indirectly heard about. Application of excessive coercive force directly and indirectly generates anger while the application of non-compelling coercive force reduces anger. All coercive force generates pain and consequently fear, but the amount of pain and consequently fear is directly proportional to the severity of the weapon.

When a “siege” starts the Security Forces, in the vicinity, do their best to disperse themselves around the siege target (i.e., the “compound”) to protect it. Managing the crowd involves selecting a spatially located crowd target to engage and a type of weapon to engage with. NLWs have a “blast radius”, and any person within that radius is impacted. SFs don’t initially know much about the intentions of individual people but they can infer how angry they (currently) are by what kinds of coercive measure they do and do not respond to with compliance behavior. Rules-of-Engagement (ROEs) determine which location will be engaged with what weapon at any particular time. SFs are limited in terms of how rapidly they can engage. WRENCH is currently delivered with one customized ROEs set along with the capacity for users to specify (limited) alternative ROEs.

The ultimate measure of effectiveness by which competing ROEs are judged is the loss of SF legitimacy relative to mission effectiveness. This defines a Pareto optimal frontier from which an analyst can assign weights to the relative importance of mission success versus legitimacy loss to select the optimal ROEs for the specific scenario. The customizable ROE graphical user interface (GUI) has been designed to facilitate automated ‘design-of-experiments’ (e.g., *nearly orthogonal latin hypercube* - NOLT) based on exploration of the ROE design space to find an optimal solution.

Other available WRENCH measures of performance (MoPs) and measure of effectiveness (MoEs) include: the mission delay as a function of mission time; the number of adversarial “intruders” as a function of mission time; a dynamically updated graphical depiction of the crowd composition; a dynamically updated graphical depiction of the total quantity of each coercive measure type (severity) applied to each crowd demographic; the mean crowd fear as a function of mission time; the mean crowd anger as a function of mission time; and the loss of SF/State legitimacy over the duration of the mission simulation interval. WRENCH has also been designed to interface with higher-level combat simulators, such as Combat XXI, to facilitate analyses of how crowd engagements can impact larger scale tactical and operational objectives.

The final result of this proof-of-concept investigation has been a conclusive demonstration that a theoretically and empirically anchored crowd behavior model can pragmatically be built that provides for a principled method of defining and selecting the rules-of-engagements that should be utilized against a specified crowd type in order to maximize mission effectiveness including legitimacy loss minimization.

This finding addresses a serious restriction on our current utilization of NLWs that stemmed from a concern over their potential to generate and/or trigger negative repercussions, in the aftermath of their utilization, and/or within the larger ‘witnessing’ population. The work also paves the way for NLW

acquisition specialists to define requirements for new and improved NLWs that would fill systematically identified and rigorously defined capability gaps. Finally, the work paves the way for advanced training systems to be built that will more effectively train soldiers to faithfully employ the optimized ROEs defined for the specific scenario.

Recommendations for Further Research

The WRENCH prototype serves well as a foundation for a number of angry/fearful crowd behavior model enhancements. Amongst the next spiral of recommended enhancements are: a complete implementation of the user capability to specify customized ROEs; an implementation of the cognitive consequences of issuing warnings prior to the application of severe coercive measures; integrated support of automated design-of-experiments exploration of the ROE design space; reimplementation for larger-scale crowd management; and advanced ROEs strategies that maximize crowd “voice giving.”

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I MARINE EXPEDITIONARY FORCE (I MEF)

NPS-17-M248-A: Optimized Aerial Communication Layer

Researcher(s): Dr. Gurminder Singh

Student Participation: Capt Adrian Felder USMC, Capt Micah Akin USMC, Mr. Claes Nyberg SMOd

Project Summary

This research continued the exploration and experimentation of alternative courses of action to address the need for beyond-line-of-site communications to support Enhanced MAGTF Operations (EMO). Of particular interest are solutions that support communications on-the-move, as well as continued-operations in satellite-limited or satellite-denied environments. Through a series of faculty-led, student-executed lab and field experiments, we investigated support for low data-rate optical communication to support applications such as small text file transfer and chat. The supported thesis also describes the potential for the designed optical system to support higher data-rates. The research also explored the use of Android devices to host ad hoc, multi-hop, infrastructure-less, wireless (mesh) networks to support voice and data.

Keywords: *free-space optics, QR-code, infrastructure-less networks, ad hoc networking*

Background

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 transit of forces to the objective area. The high mobility of such forces requires flexible communications to maintain effective command and control (C2), particularly in satellite-denied environments. The research conducted to date characterized the aerial assets available as platforms to support communications relay systems, explored potential commercial off-the-shelf radio systems that may provide encrypted tunnel support for tactical IP traffic, and examined the capabilities of high altitude balloon platforms to carry such radios. It included initial exploration of potentially very high bandwidth capabilities from emerging free space optical systems, although such systems are still range limited. The research also explored very low bandwidth communications (less than 16 Kbps), demonstrating an interoperability capability between Harris Falcon III radios and Thales Multiband Inter/Intra Team Radios (MBITR) when configured to communicate over the Space Data Corporation SkySat UHF control link, providing simple internet relay chat (IRC) and limited-sized file transfer.

This research, leveraging several theses, extended the study of free-space optics with particular emphasis on novel data coding schemes. We explored free-space optics as a means to send data encoded by Morse code over light emitting diodes. This capability was then extended using QR-codes to send data over multiple parallel laser beams. This novel implementation of multiple input, multiple output (MIMO) streaming of data allows for significant redundancy, and thus robust data transmission, limited primarily by the capabilities of the processor used to encode/decode the data, as well as the sensitivity of the photo-collector used as the signal receiver. The use of QR-coded data allows for the data source to remain concealed while the data is projected against a viewable surface and detected on that surface by a remote

receiver. This adds a layer of signal-covertness if non-visible light is used, such as infrared or ultraviolet, though this study did not explicitly assess that capability.

The research also investigated the capability of implementing mobile ad hoc networks using Android devices as the principal communications node. Through this research, we determined that commercial-off-the-shelf Android smartphones no longer support ad hoc (infrastructure-less) wireless local area (WiFi) networking. As most workarounds for this change in the Android capability severely limit the functionality and throughput of the system, we considered the utility of “jail-breaking” the device such that “root” user access could be enabled in order to re-enable the ad hoc mode that is inherent in some of the wireless chip-sets comprising original equipment manufacturer (OEM) devices. While such device “rooting” raises security concerns, such concerns should be manageable through organization-level device management schemes. Successful re-enabling of the WiFi ad hoc mode will allow for using commercial off-the-shelf (COTS) Android devices to implement mobile networks to support on-the-move forces where existing tactical radios do not provide sufficient data rates to support timely imagery delivery.

Findings and Conclusions

The objective of this effort was to design, develop, and validate a low-cost data communications capability suitable to satellite-denied environments. The research demonstrated the ability to use low-cost laser diodes to implement a highly robust, reliable means of sending low data-rate data in radio frequency (RF)-constrained environments. This capability may be enhanced by utilizing more capable receivers, such as high-speed photovoltaic receptors or high-definition-capable cameras, to increase achievable data rates.

The research delineates a process to determine whether a given Android smartphone is capable of hosting an ad hoc WiFi relay based on its incorporated chipset. The results also describe the methodology for gaining root access to such smartphones in order enable the dormant ad hoc networking code.

Recommendations for Further Research

Additional field experimentation is needed to explore the use of free space optical systems to utilize QR-codes as a means of delivering data in specific tactical environments. Issues to be considered are the range at which reflected QR-codes may be detected, the means to project the QR-coded data on a reflective surface, and the distance the QR image may be projected from the source without significant signal deterioration.

Additional field experimentation is also needed with Android devices to explore the achievable network capacity of ad hoc networks comprising these devices, in particular the integration of such ad hoc networks with existing tactical radio networks, such as those comprising Falcon III devices utilizing the proprietary Adaptive Networking Wideband Waveform.

II MARINE EXPEDITIONARY FORCE (II MEF)

NPS-17-M021-A: KM/IM/Communication Relationships

Researcher(s): Dr. Randy William Maule

Student Participation: Capt Nicholas Bakewell USMC

Project Summary

Management of information, systems, and networks within II MEF is divided between different units, resulting in incomplete technical and operational analysis. A comprehensive view of the tactical information infrastructure is required to ensure operational integrity. This project advanced an analysis framework and models, implementation methodology, and tooling to monitor and assess communication flows, information processes, and knowledge representation within II MEF tactical command. Analysis was based on industry technologies successfully deployed by the principal investigator (PI) for over a decade with forward deployed units in naval, joint forces, and coalition exercises.

Analysis of data, systems and communications as they impact knowledge and information assets in tactical engagements is a complex challenge due to the exponential number of variables and the extremely large data sets required for analysis. Tactical forces may be significantly impacted by electronic attacks in future engagements and research into processes to understand these attacks and ensure data and information integrity is needed. Models were developed to help II MEF more rapidly understand the impact of systems and communication performance variables, and the impact of cyber and electronic attacks against forward-deployed forces. The intent is to provide a more effective defense through systems and data validation, and a means to automate complex technical monitoring and maintenance to achieve data resiliency.

Keywords: *information technology, information systems, information management, knowledge management, knowledge visualization, communications, data management, data measurement, data analysis, data science*

Background

Assessment of knowledge systems, information management, communications, and cyber infrastructure in naval, joint forces and coalition exercises over the past 15 years have identified warfighter capability gaps in tactical C4ISR systems analysis (Maule, Jensen, & Gallup, 2014, 2013, 2012). Tests have included systematic evaluation of information technologies, communications infrastructure, data flows, and knowledge management. Results and lessons learned from these operational exercises have been integrated into this report to support II MEF command and control in a denied or degraded environment (C2D2E).

Technical analysis included knowledge and information system process assessment (Maule, 2016, 2007; Maule & Lewis, 2011; Maule, Gallup, & Jensen, 2010; Maule & Gallup, 2010, 2007), modeling techniques for information infrastructure and knowledge representation (Maule, 2015b, 2015c, 2014b, 2012b), and

metrics to evaluate electronic engagements and cyberattacks on C4ISR systems (Maule, 2014b; Maule, Goldberg, Baker, McElvain, & Sinopoli, 2015).

Historically, assessment of knowledge, information, and communication relationships in tactical electronic engagements has been inconclusive due to the absence of appropriate models and test methodology, and the necessary instrumentation for real-time analytics. As such, mission systems status and data validity assessment have been incomplete and potentially inaccurate. Research herein advances system/workflow models to help II MEF IMO better monitor knowledge, information and communications relationships and perform data readiness assessment based on analytic methodology, enterprise tooling, and data science applied by the PI in naval, joint forces, and coalition exercises.

Methodology is advanced within the context of complexity science. The approach is interdisciplinary, with characteristics both technical and human to determine mission system readiness and data operational effectiveness. Evidence of the need for complexity analysis is evident in II MEF:

- Multi-layered communication architecture
- Multiple organizational structures to achieve a mission capability
- Organizational boundaries that impact assessment
- Multiple routes for media and data from sources to users
- Adversary capabilities for automated, multi-layered attacks
- Diverse and dynamic technical, operational and environmental contexts

Within each context are core components, each with its own data set which must be assessed—both independently to evaluate the component, and collectively to evaluate the operation of the component within the system of systems (SoS) architecture. Systems readiness and data viability assessment therein requires an evaluation of all variables that impact the validity of data upon which decisions are based. This includes the RF spectrum, satellite and network communications, and systems technical and functional performance—as well as the impact of outside interference and human intervention.

Findings and Conclusions

This report established infrastructure models, software, and processes to optimize knowledge, information and communication relationships. The solutions support the concept methodology advanced in the associated thesis: Modeling Cyber Threats to Gain Indications and Warnings in an Expeditionary, Asymmetrical Environment by Captain Nicholas Bakewell. The thesis provides the conceptual “what” needs to be done; this report provides the “how”.

Included are technologies to monitor and assess tactical information and communications, and systems and data. Data integrity within mission systems was a focus, with tools and processes to provide capability status, analytic visualizations to populate an information management/knowledge management (IM/KM) portal for warfighter dissemination, and detailed reports to support command decisions.

In the suggested workflow, resource monitors correlate system and service data with event information. Data is compared against baselines to assess deviations which may indicate performance problems, signal interference, or electronic attack. Dashboards show the operations of services, with output rendered into readily understood charts and dials. The knowledge tier applies cognitive algorithms to integrate data, system, and network information.

Adaptive complexity was advanced as a method to understand the dynamic interplay between components in tactical operations. Automation was advanced for forward-deployed tactical forces in anti-access/area denial (A2AD) environments where reach-back for technical assistance would not be available. Workflow models help warfighters understand the impact of electronic warfare on mission data. Methods were advanced to ensure systems readiness through data validation and resiliency.

A data vulnerability assessment framework (DVAF) was advanced as a means for readiness assessment. Results within technical, operational, and environmental context derive an overall mission systems and data readiness coefficient. Sensors assess communication flows, agents measure information streams, and data science software produces visualizations for status and readiness assessment. Lifecycle analysis within operational and environmental context, over time, produce a readiness coefficient—and with a sufficient number of tests, a confidence level for that coefficient.

Recommendations for Further Research

Future research may implement one or more of the software sets advanced in this report. Extensions of this research may address organizational variables found to impact tactical mission readiness. New research may advance artificial intelligence (AI)-based machine learning and predictive algorithms for tactical communication, information, and knowledge automation. Cyber aspects of information relationships may be explored, along with cognitive AI techniques to improve real-time analytics. Data science algorithms to derive useful knowledge from compiled mission data may be further evaluated. Integration of technical processes for analysis automation are a logical progression of the research advanced in this report.

Integration of real-time predictive algorithms into II MEF information and knowledge operations would help decision makers in electronically-challenged environments.

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MARINE CORPS COLLEGE OF DISTANCE EDUCATION AND TRAINING (CDET)

NPS-17-M146-A: Ripper Academy Operations & Analytics

Researcher(s): Dr. Frank Barrett

Student Participation: Maj Rebecca Bolz USMC

Project Summary

The Department of Defense (DoD) lacks case studies that investigate and detail change management, system dynamics, and even more specifically, the innovation and adoption of information technology systems. The purpose of this qualitative study is to develop an in-depth case study to explore the factors that contributed to the United States Marine Corps' (USMC) innovation and adoption of Ripper Academy, a video streaming platform that allows a specific subset of Marines to create, share, and view user generated video content. This research addresses the research question: How can the USMC successfully employ the principles of change management and system dynamics to innovate and ensure the adoption of information technology systems?

Using the change formula, Kotter's Eight-Stage process, and the ADKAR change model, an analysis of the Ripper Academy case study will highlight change management factors that contribute to the innovation of information technology systems. Referencing the limits to growth archetype and Bass diffusion model, an examination of the Ripper Academy case study will emphasize how an understanding of system dynamics can help ensure the adoption of information technology systems.

The Ripper Academy case study emphasizes the importance of having internal and external champions, a vision for the future, the support of a guiding coalition, both bottom up and top down support, and actual data when implementing an organizational change. If organizations want to be successful in implementing change, they need to understand change management. Additionally, the Ripper Academy case study exhibited the benefits of leveraging the principles of system dynamics to more accurately comprehend the dynamic behaviors of complex systems. To understand the adoption of new information technology systems, leaders must recognize how both growing actions and slowing actions can influence the adoption of new technology.

Keywords: *information technology, information technology system, IT, innovation, adoption, change management, system dynamics, Ripper Academy*

Background

The United States Marine Corps (USMC) invests a significant amount of time, effort, and resources in the training and education of its most valuable assets, Marines. In 1998, the USMC developed an online learning management system, Marine Corps Distance Learning Network (MarineNet), to host electronic distance learning products to support annual training, entry-level training, military occupational specialty (MOS) training, pre-deployment training, and professional military education (Gavin, 2015; Marine Corps Concepts and Programs, n.d.). MarineNet has been comprised primarily of interactive multimedia instruction, instructional graphics, videos, and audio files to improve the traditional learning paradigms and create a cohesive instructional package in the absence of an instructor (College of Distance Education and Training, n.d.).

In 2014, the Marine Corps University's College of Distance Education and Training (CDET) conducted the MarineNet User Engagement Exercise (MUE2) to identify the expressed needs of MarineNet's end users, Marines. MUE2 was a series of engagements with Marines from the Fleet Marine Forces and Marine Forces Reserve to provide the College of Distance Education and Training with a data-driven decision support methodology to help prioritize the architectural changes necessary to develop the next generation of MarineNet (Gavin, 2015). The findings of the MUE2 indicated that the MarineNet end users believed the system lacked both usefulness and relevance in terms of content, delivery, and dissemination methods (Gavin 2015). In order to address these identified deficiencies, the College of Distance Education and Training began the development of a number of initiatives intended to redesign their suite of services (Gavin, 2015). One of the first major initiatives was the innovation of a video streaming platform that eventually came to be known as Ripper Academy (Gavin, 2015). Ripper Academy is a video streaming platform that provides a specific subset of Marines with a capability to create, share, and view user generated video content through MarineNet.

This thesis presents an in-depth case study to examine the factors that contributed to the innovation and adoption of Ripper Academy. This case study examines the applications of change management and system dynamics when developing and implementing new information technology systems in an organization like the USMC.

Findings and Conclusions

The Department of Defense (DoD) lacks case studies that investigate and detail change management, system dynamics, and even more specifically, the innovation and adoption of information technology systems. A limited understanding of the factors influencing the success, or failure, of new information technologies in the DoD creates this problem. This case study intends to close this identified gap, and that of recorded histories surrounding the successful implementation of new information technologies in large organizations. This is important because a close examination and study of change management and system dynamics will unlock a greater understanding of the processes required to develop and implement new information technology.

The purpose of this qualitative study was to develop an in-depth case study to explore the factors that contributed to the innovation and adoption of Ripper Academy, a video streaming platform that allows end users to create, share, and view user-generated video content, in the USMC. Focusing on change management and system dynamics, the research synthesizes the key elements surrounding innovation and adoption of Ripper Academy. Specifically, the research captured the interpersonal interactions of the primary actors of Ripper Academy in order to extract key elements that may prove useful to the success of future information technology innovations within the DoD.

This research is a qualitative case study relying on published literature, personal interviews, email communications, and archival data analysis. The research first examines the qualitative case study strategy as a means to determine the most appropriate approach to follow, given the various stakeholders of this particular case study. Research of the case study strategy will not be limited to the development of a case study, but will also include preparation recommendations, interview methodologies, and data analysis techniques. Following case study strategy research, a review of published literature on change management and system dynamics, by esteemed and distinguished authors, provides background to obtain an understanding of the various theories and their respective applications.

Because of the qualitative nature of this research, limited data was available prior to conducting research activities. Personal interviews are the most significant method used to collect information in this research. The primary method for interviews was in-person, with a secondary option of over-the-phone interviews. Research was conducted using semi-structured interviews with military, government, and contractor stakeholders based on their interaction and involvement in Ripper Academy. When possible, the interviews were recorded and later transcribed for analysis. If unable to coordinate interviews, the researcher corresponded with subjects via email communications. Archival data analysis of the MUE2 database and official reports provides a contextually based understanding of the concerns held by the MarineNet end user community prior to the implementation of Ripper Academy. Archival data analysis of Ripper Academy metrics provide data on the creation, sharing, and viewing of video content during the existence of Ripper Academy. Personal interviews, email communications, and archival data analysis provides information on the key factors surrounding Ripper Academy. With this information, a qualitative case study was developed on the innovation and adoption of Ripper Academy in the USMC.

Existing literature on the case study strategy, change management, and system dynamics drove the development and analysis of the case study. With this research, the Ripper Academy case study highlights the successes and failures of change management methods to innovate information technology within the USMC. Additionally, the case explores the application of system dynamics to help understand the successful, or failed, adoption of information technology systems within the USMC.

This research helps provide an analysis of how the principles of change management and system dynamics can be employed within the USMC, and the DoD, as a means to ensure the success of information technology innovations. With a limited number of case studies examining information technology in the DoD, this research provides a teaching case study that examines how change management and system dynamics can influence the innovation and adoption of information technology in large organizations like the USMC. Readers can generalize the lessons learned from this case study for use in future undertakings.

The availability of personnel involved in the design, development, implementation, and usage of Ripper Academy were a limitation to this case study. Because of permanent change of station moves, expiration of active service (EAS), and operational deployments, some of the original personnel involved in Ripper Academy were no longer be available for interviews. The researcher correlated statements and actions of available personnel to develop an in-depth case study.

Recommendations for Further Research

In finalizing this research, several opportunities exist for future research. First, additional research could be conducted to explore the factors that have led to some commands adopting MarineNet Video Services and others resisting. Conducting a further analysis on the adoption of MarineNet Video Services may identify additional variables relevant to the limits to growth archetype and modified Bass diffusion model. This analysis could provide additional areas for consideration when implementing future information technology systems within the DoD.

The second area for future research is capturing the actual benefits of the video streaming platform and user generated video content. At the time of this research, there was insufficient data available to determine whether Ripper Academy, now MarineNet Video Services, video content actually increased organizational and/or individual knowledge within the USMC. As organizations continue to adopt MarineNet Video Services, and the College of Distance Education and Training continues to upgrade MarineNet Video Services, additional metrics may become available to assist in measuring how/if user-generated video content has increased organizational and/or individual knowledge within the USMC. Lastly, case studies on the innovation and adoption of information technology systems within the USMC, and DoD, need to continue to be developed in order to highlight to leaders the importance of change management and system dynamics. The continued development and examination of case studies through the lenses of change management and system dynamics will unlock a greater understanding of the processes required to successfully innovate and ensure the adoption of future information technology systems.

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MARINE CORPS COMBAT DEVELOPMENT COMMAND (MCCDC)

NPS-N16-M163-A: 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 goal of this research was to investigate, develop, and design methods and software tools that enable broad-scale search for effective solutions for prosecuting a maritime campaign. Elements of the problem domain were represented in an agent-based simulation modeling platform, and the search for solutions exploits the power of evolutionary algorithms (EAs). 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 an optimal solution, EAs have been used successfully for decades to find good solutions relatively quickly, even over large, complex search spaces.

In this research, we developed a software package called ARTeMIS (Automated Red Teaming Multiobjective Innovation Seeker). Key features of ARTeMIS include that it is self-adaptive, both elitist and diversity preserving, suitable for multiple objectives, and focuses on yielding robust solutions. ARTeMIS was tested and refined using an Army Infantry Squad assault scenario, and then demonstrated on a scenario where convoy protection required Blue to identify and disrupt Red mobile anti-ship cruise missile (ASCM) launch teams.

Keywords: *evolutionary algorithms, genetic algorithms, data farming, simulation, design of experiments*

Background

The Marine Corps Combat Development Command (MCCDC) Operations Analysis Division (OAD) and Systems Planning and Analysis (SPA) Inc. recently conducted a study of the austere basing concept of operations (CONOPS) (Systems Planning and Analysis, 2015). This concept of operations (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. A2/AD threats complicate the planning for, and execution of, amphibious operations. As such threats grow more capable and widespread, the increasing importance of the littorals and the growing complexity of maritime operations demand continuous innovation, and new capabilities, to ensure success. Forward engagement and partnership building, power projection, assured littoral access, rapid response to crises, and the ability to sustain expeditionary operations from the sea are essential capabilities for the emerging national security environment.

Success in these operating areas requires innovative, low-cost, small footprint, forward engagement, and indirect approaches to combat. The process of identifying suitable approaches can be greatly assisted by effective simulation analysis techniques, including data farming and design-of-experiments (DOE) techniques. In this research, the NPS Simulation, Experiments and Efficient Design Center for Data Farming (SEED) Center expanded the portfolio of data farming tools by developing an evolutionary algorithm that automatically searches through the design space to identify a Pareto frontier of good (nondominated) alternatives.

A wide variety of EA methods have been proposed in the literature. These include the widely-used ($\mu + \lambda$) Evolutionary Strategies (ES) algorithm (see, e.g., Schwefel, 1995), the Strength Pareto Evolutionary Algorithm (SPEA) of Zitzler and Thiele (1999), and the Elitist Nondominated Sorting Genetic Algorithm (NSGA) developed by Deb (2001).

Findings and Conclusions

A new EA was developed, tested, and applied in proof-of-concept applications. Our EA is called ARTeMIS (for Automated Red Teaming Multiobjective Innovation Seeker (ARTeMIS), and is based on elements of ES, SPEA, and NSGA. ARTeMIS starts in Generation 0 with μ members of the initial population, where the gene values represent capabilities of the factors of interest.

These μ parents spawn λ children by mutation, then μ individuals from amongst the $\mu + \lambda$ are selected as parents for the next generation, and the process repeats. An overview of the overarching principles that guide ARTeMIS follow. Additional detail can be found in Upton & McDonald (2017).

- Self-adaptation: The mutation rate will increase if a sufficiently large number of children are better than their parents, and decrease if sufficiently small number of children are better than their parents.
- Elitism: Some criterion for choosing new parents are based on their performance, such as if they are better than all individuals on at least one performance measure (i.e., they are a Pareto nondominated solution).
- Diversity preservation: Choosing new parents is also partially based on diversity, as measured by the distance between two parents in the input space. This ensures that a variety of dissimilar alternatives can be achieved.
- Multiobjective performance evaluation: DoD applications, such as the austere basing CONOPS that motivated this project, are inherently multiobjective.
- Robustness: Many EA applications seek an optimal solution, such as maximum effectiveness, under specific conditions, without considering sources of uncontrollable uncertainty such as environmental conditions or enemy capabilities. In contrast, we explicitly seek to identify robust regions of the multiobjective response surface by minimizing the loss arising from uncertainty.

We tested and refined ARTeMIS using an Army Infantry Squad assault scenario (MacCalman, Sanchez, McDonald, Goerger, & Karl, 2016) using the software environment Map Aware Non-uniform Automata (MANA) (McIntosh, Galligan, Anderson, & Lauren, 2007). With OAD's concurrence, we then developed a proof-of-concept OAD scenario inspired by the austere basing study where convoy protection requires Blue to identify and disrupt Red mobile anti-ship cruise missile (ASCM) launch teams. Variables of interest include unmanned aerial vehicle (UAV) capabilities (e.g., number, speed, and maximum classification radius) and employment options (e.g., search pattern), as well as uncontrollable variables (e.g., the number of Red teams, and their prep-to-shoot time). We used two measures of effectiveness: (1)

the loss associated with failing to prosecute all Red ASCM launch-team targets, and (2) a notional cost associated with the set of capabilities for each particular alternative. The results show that the problem is extremely difficult, and that a moderate cost must be incurred in order to have any substantive impact on reducing loss. The proof-of-concept study shows that ARTeMIS can be applied successfully to MANA models, and that over many generations it identifies a diverse set of points along the Pareto frontier.

ARTeMIS is available at the SEED Center's website at <http://harvest.nps.edu> (SEED Center for Data Farming, 2017), along with additional resources and data farming tools.

Recommendations for Further Research

Two broad threads of additional research are possible. First is the application of EA to other simulation scenarios, either by applying the current version of ARTeMIS to new MANA applications, or by customizing ARTeMIS to work with other simulation modeling platforms. This is well-suited for future thesis research by students working with the SEED Center. Over 180 previous thesis studies have been conducted, but the vast majority have explored simulation scenarios using a series of single-stage designed experiments. Applying ARTeMIS could complement this type of analysis by directly identifying a set of robust, diverse, and effective alternatives for decision makers.

The second thread is methodological. Further research is underway as we continue to explore the impact of varying ARTeMIS's key parameters on the total number of nondominated solutions discovered, the quality of these nondominated solutions, and the coverage of the input and metric space. We are also seeking insights about the relative benefits of ARTeMIS or related EAs, single-stage designed experiments, or sequential design-of-experiments approaches.

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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 USMC, and Major 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 landing helicopter docs (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 programming 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 perform 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 1,000 times, and each time we randomly degrade the system due to weather, threats, reliability, demand shocks, etc. This generates a distribution for the unmet demand rather than just a point estimate. This allows 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 Operations Research (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 scenarios, 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.

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MARINE CORPS FORCES CYBERSPACE (MARFORCYBER)

NPS-T16-M123-A: Command and Control for the New Norm

Researcher(s): Dr. Luqi

Student Participation: LT Steven Fahey USN, 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 explored impacts on C2 as cyber operations evolve, and assessed 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 investigated 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 results based on policies and procedures, and make routine decisions and recommendations. People make decisions that are more important and validate system recommendations that have significant potential 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 addressed human-machine communication modes that will most effectively convey the identified relevant information to human decision makers.

Research explored the use of cognitive assistants to augment human-machine interfacing capabilities in order to increase the speed of cyber warfare OODA loops and achieve decision superiority over an adversary.

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.

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. This strategy is most effective when applied to independent information sources. 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 is 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 command and control (C2) and industrial control systems (ICS) security was initiated as part of this study [5]. This thesis contributes 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?
- 6) What characterization metrics should be organically incorporated in order to support cognitive modeling and machine-learning?

The technical report [6] describes additional results of the study.

Recommendations for Further Research

Two students participated in exercise Pacific Sentry 16-2, resulting in the following recommendations. Each of the 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 Norm, if Marines at

very low levels don't have appropriate clearances and authorizations, they risk increasing danger to themselves or accidentally interfering with other operations.

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NPS-17-M156-B: Developing, Simulating, and Training for Cyber Attacks on Adversary Networks

Researcher(s): Dr. Gurminder Singh, Dr. Alan Shaffer, Mr. John H. Gibson, and Mr. Charles Prince

Student Participation: LT Lou Ayebar USN, Capt Travis Swiatocha USMC, and LT Doran Duhart USN

Project Summary

A capability gap exists within the cyber domain in the ability of cyber forces to fully and adequately model and simulate cyber attacks against an adversary network. Other warfare areas are traditionally able to model adversary capabilities and responses, ensuring a more effective environment in which to conduct wargames and assess the effects of physical attacks prior to an actual conflict. However, offensive cyber operations (OCO) are often executed without the ability to simulate and test their effectiveness against a wholly accurate model of the target network. Launching cyber attacks and exploits on an adversary network before they have been thoroughly tested can lead to failed operations and unintended outcomes. Having the capability to fully test cyber attacks on an accurate representation of an adversary's network can aid cyber operators in better understanding their effects, including their impact on the adversary's networks and operations, as well as the anticipated extent of collateral damage and secondary effects. This research proposes a study of current and emerging network mapping tools and capabilities, as well as those of cyber attack scenario scripting, to develop a framework that will provide cyber operators with this critical capability.

Keywords: *cyber, OCO*

Background

The need for military forces to adequately plan and train for operations in the cyberspace realm, in support of both offensive and defensive objectives, has become well-understood in recent years.

According to Sheldon (2012), nation-state and terrorist-based cyber threats exist that can do serious harm to national security interests, and that proper defense against these threats requires “extensive, even onerous, preparations and resources.” Grant (2013) points out that the national strategies of most modern nations identify cyber operations, and the ability to perform network defense and exploitation, as critical to their national defense. Further, he highlights the need for proper infrastructure and training, among other criteria, to support these objectives.

Offensive cyber operations are divided generally into computer network attack (CNA) and computer network exploitation (CNE). CNA is focused on denying or degrading the ability of an adversary to use its own operational networks and the data stored within, i.e., attacking the network within the cyberspace (as opposed to a physical attack against the network infrastructure). CNA is most often associated with military operations. By contrast, CNE involves gaining access into an adversary network for the purposes of exploiting the sensitive or classified data stored therein, and is usually associated with cyber espionage (Rattray and Healer, 2010).

Findings and Conclusions

Conducting effective cyber-attacks against sophisticated adversaries requires the ability to develop, test, and refine cyber-attack scenarios before they are used operationally, a requirement that is not as well defined in the cyber domain as it is in the physical domain. This research introduces several concepts to address this need, and creates a prototype for cyber-attack scenario development and testing in a virtual test environment. Commercial and custom software tools that provide the ability to conduct network vulnerability testing are reviewed for their suitability as candidates for the framework of this project. Leveraging the extensible architecture of the Malicious Activity Simulation Tool (MAST) custom framework allowed for the implementation of new interaction parameters, and provided temporal specificity and target discrimination of cyber-attack scenario tests. The prototype successfully integrated a virtualized test environment used to simulate an adversary network and the enhanced MAST capability to demonstrate the viability of a cyber-attack scenario development platform to address the needs of modern offensive cyber operations.

Our research objectives were successfully accomplished. The derived requirements, modules, and research of existing frameworks yielded a capability that can be used for the development of offensive cyber-attack scenarios. The following examines the body of work produced by this research.

Research Questions

Primary Question: How can offensive cyber tools and exploits be developed and tested effectively in a controlled environment against virtualized models of adversary networks?

Conclusion: This research derived several new concepts, and a working prototype that was able to support the development and testing of cyber-attack scenarios. We successfully repurposed and extended MAST to execute scenarios and modules specifically developed for this project. Additionally, a virtualized test environment was constructed within the NPS CYBL, which allowed for the modeling of a scalable notional adversary network. The network consisted of hosts that were complete instances of Windows 7 virtual machines. This allowed for effective testing of the new SimWare modules developed during this research.

Secondary Question 2: What control mechanisms or methods would allow simulated malware to focus on a user-defined target set grouping (e.g., a single host or single subnet)?

Conclusion: One test module was developed and successfully tested to target a specific host by the Internet Protocol (IP) address or the media access control address (MAC) address addresses this question. The “TargetSpecificHost” module targeted one specific IP and one specific MAC address from among the eight virtual clients in the test environment. The system was able to successfully identify and infect that particular host, and only that host. The module is currently not able to target a single subnet (such as all hosts on 10.1.99.x), but can be extended later to support this capability.

Secondary Question 3: What methods can be used to perform temporal sequencing of malware mimics?

Conclusion: The development and implementation of two temporal specific modules, “LogicBomb” and “AttackWhenIdle,” provided a new capability that addresses this requirement. The “LogicBomb” module provided the ability to delay execution of subsequent modules in the scenario file to some pre-determined time in the future. The “AttackWhenIdle” module provided the ability to detect user inputs to a host machine, and delay attack until some author-specified idle time period had passed. Several test iterations were run based on various date/time inputs for the “LogicBomb” module, and various wait intervals for the “AttackWhenIdle” module. The “LogicBomb” module performed flawlessly across a series of clients. During one series of early tests, it seemed that it may have been performing incorrectly on some clients, but further analysis revealed that the system time on these VM hosts was not correct, and the module was performing as designed. Similarly, when the “AttackWhenIdle” module was tested across multiple hosts, the results showed some clients becoming infected much quicker than expected. Further analysis revealed that there had been no user input on those clients, across multiple test iterations, for more than five minutes (the threshold value used on the AttackWhenIdle testing) and thus the module had performed as intended.

Recommendations for Further Research

Although this research was able to achieve a number of important milestones toward the creation of an offensive cyber scenario development platform, it is only the first step in this process. Future research should focus on two areas for extending the framework: further development of attack scenario target parameters, and enhancement of the MAST framework to support more robust scenario development. We should extend the MAST framework to make it a more robust cyber-attack development platform, to include a menu of available SimWare modules that can be selected from a graphical user interface (GUI)-style menu and auto-loaded into a cyber scenario file shell. Other improvements will add support for common programming constructs to the scenario file, enabling the developer to essentially program or script a cyber-attack scenario. MAST currently allows linear processing of an attack scenario file, with no looping constructs, complex conditionals, or variable assignments within the current framework. These advanced programming features are common in modern scripting languages such as Java Script, Bash shell, and others. Extending the framework to allow advanced scripting constructs will allow the creation of much more complex scenarios. We feel these extensions will greatly increase the effectiveness of MAST as an offensive cyber-attack scenario development and testing platform.

Attack parameters such as skill, efficiency and stealth would add greater realism and nuanced behavior to the developed scenarios. These could be developed and integrated within the MAST framework and made selectable via user menus. In this way, the parameters could be applied to any of the scenarios developed within the framework. These improvements, if implemented, would greatly increase the effectiveness of MAST as an offensive cyber-attack scenario development platform.

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MARINE CORPS LOGISTICS OPERATIONS GROUP (MCLOG)

NPS-17-M005-A: Simulation System for Optimal Solutions for Resource Organization and Allocation for the MEB LCE in Support of Operation Assured Resolve

Researcher(s): Dr. Joshua Gordis

Student Participation: No students participated in this research project.

Project Summary

The simulation code under development for Marine Corps Logistics Operations Group (MCLOG) was originally developed for the simulation of fleet sustainment networks wherein a network of ships (nodes) and connectors (air, sea, land vehicles) are configured to deliver materiel and supplies to an objective on the beach or inland. The complex problem of modeling and performance simulation of supply networks is addressed by the development of a time-domain simulation tool which allows the user to define arbitrary networks of supply nodes, consumption nodes, and logistics capability for materiel movement. The simulation tool allows an arbitrary network to be defined, parameterized, and both the net throughput and fuel consumption of the network to be calculated. This simulation code can serve as a real-time tool for designing sustainment networks, responding to changing demand signals from operators, assessing choke-points or factors limiting the throughput performance of the network, and evaluating potential investment in improved systems and technology with the goal of maximizing network performance for dollars invested. In 2017, the code was rewritten and includes a graphical user interface for defining the network, the ability to represent different cargo types (fuel, ammo, food, water), the ability for connectors to move independently or as a convoy, and to deploy on-demand from a receiving node. Using realistic data provided by MCLOG, the code confirms that supplying water at a sufficient rate is the most challenging. This serves as an initial validation of the performance of the code.

Keywords: *combat, logistics, simulation, supply-chain*

Background

The U.S. Marine Corp (USMC) plans for operations where materiel is moved from supply bases (CSSAs) to intermediate bases and finally to ground combat elements (GCE). The materiel being moved to the GCE includes fuel, water, ammunition, and food. It is critical that the GCE maintain minimum levels of all materiel. This requires that the materiel be moved at a sufficient rate such that the supply on hand at the GCE of each materiel type (fuel, water, ammunition, food) does not fall below specified minima. This collection of bases (CSSAs, GCEs) and the modes of transportation between them (e.g. convoys of trucks) constitute a logistics network.

The effective design of the logistics network is a critical task to ensure the needs of the warfighter are met. To this end, a software tool has been developed which allows a logistics network to be defined, including the numerous defining parameters, and the performance of the network simulated in time. This software tool operates in the time domain, in that the network performance is simulated in time. The movement of materiel is calculated at each time step, and various logical tests are performed at each time step which determine the behavior of the network at each time step.

In order to model the network and simulate its operation, the software represents the topology of the network, what is “connected” to what, and the properties of each node in the network. Each CSSA and the GCE are considered stationary nodes, and the mode of transport of materiel, typically convoys of trucks are represented by moveable nodes. A moveable node moves from a send node to a receive node, and this connection is referred to as an Arc. Each node is defined by a set of node properties. Stationary nodes require significantly fewer properties than moveable nodes. Finally, the third component of the software is the logic rules which govern the operation of the network. For example, a truck will not depart its send node unless it is full, or if it’s not full, it will depart if the send node has no more cargo to load. Such a logic statement is coded in the software.

Findings and Conclusions

The simulation code has been significantly expanded and enhanced with additional capabilities reflecting the needs of the U.S. Marine Corp Logistics Operations Group (MCLOG). The original version of the code did not distinguish between cargo types. The ability to represent arbitrary numbers of cargo types has been added. For example, fuel, ammo, food, and water are individually represented in the code, each cargo type having unique load and unload transfer rates, and each node and connector having unique capacities for each cargo type. The behavior of connectors (trucks moving between stationary nodes) has been greatly expanded. The trucks can move continually (load-transit-unload-transit) or can move on-demand, where a demand signal is sent by a receiving node if the level of any of the cargo types falls below a user-specified minimum for that node and cargo type. Data for a scenario involving two supply bases (CSSA) and a single ground combat element (GCE) was provided by MCLOG. This data was inputted to the simulation code and the adequacy of the supply network evaluated. The code confirmed the expectation of MCLOG that maintaining adequate supplies of water to the GCE was the most challenging.

Recommendations for Further Research

Continuing work includes the further enhancement of connector characteristics and behaviors. The current version of the code has a single truck type, which carries a mix of all cargo types. While on average, this can represent the overall behavior of the network, the code is being expanded to include specific truck types, i.e. each truck will have a specific cargo type, which is more realistic. The transit on-

demand behavior of the trucks is also being made more realistic. These enhancements will allow the ability to represent attrition, or the loss of personnel/assets due to planned and unplanned maintenance and due to combat losses.

References

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MARINE CORPS MODELING AND SIMULATION MANAGEMENT OFFICE (MCM سمو)

NPS-N16-M158-A: LVC Simulation for Training and Analysis 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.

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 disjoint 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 (MCP) as described in Marine Corps Warfighting Publication (MCWP) 5-1 for a Marine Expeditionary Unit (MEU).

No TA existed for MCP, 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 MCP:

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 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, 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 not 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 virtual environment (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, 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, along with how many times he would like the simulation to be run. If the user chooses to run the simulation more than one time, the constructive sim will run multiple times using a different seed for random number generation as well as modifying the starting location of the red forces, to account for “the fog of war,” e.g., red forces locations are rarely precisely known or may be time late. The constructive sim evaluates the plan and returns the results in terms of casualties, resource expenditures, etc. The user can examine the results of each run. This effectively conducts step 3 of the MCPP: COA Wargaming.

Finally, the user can replay any of the runs in the VE, showing what happened in each 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. One USMC intel officer is considering using it as a tool to improve briefings given to pilots prior to missions. Additionally, it will be used as the basis for development of an air operations planning tool.

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 FY17.

Recommendations for Further Research

This project demonstrated that it is possible to merge virtual and constructive technologies to create a tool which can be used by Marines in a live environment (mission planning). In fact, this tool combined the best of both virtual (ease of use, excellent displays and visualizations) and constructive (validated TTP's applied to produce highly accurate predictions) to produce a proof of concept which can add significant value to Marines in the field.

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. It will already be used as the basis for an air planning tool to be constructed in FY18/19.

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.

NPS-17-M175-A: Investigate and Inform the Development of Modeling and Simulation Topics to Meet Naval Officer Education Requirements

Researcher(s): LTC Glenn Hodges PhD and LTC John Morgan

Student Participation: Capt Nicholas Arthur USMC, MAJ John Dvorak USA, Maj John Gibson USMC, Capt Pierce Guthrie USMC, Capt Kathleen Haggard USMC, Maj Faisal Rashid PAF, 1LT Ahmet Saglam TAF, Capt James Sheatzley USMC, and Maj John Wray USMC

Project Summary

This project investigated fundamental and advanced Modeling and Simulation subjects to identify topics, materials, examples, and projects necessary in order to meet new educational skill requirements (ESRs) for Marine and Navy Modeling and Simulation (M&S) officers. The tasks involved research to address several of the issues identified during a 2015 study conducted by the Marine Corps Modeling and Simulation Management Office (MCMSO) and the Navy Modeling and Simulation Office (NMSO) to evaluate the education that graduates receive in the MOVES program. The results and recommendations of this project are documented in the final report and are provided to MCMSO and NMSO as recommendations. The over-all goal of this project was to improve the education and development of intellectual capital of uniformed personnel that perform M&S work for the Department of Defense (DoD).

Keywords: *model, simulation, MOVES, LVC, CAI, intelligent systems, military systems and processes, combat modeling, SSTR, human terrain, DIME, PMESII, social behavior, cultural behavior, conceptual modeling*

Background

The Naval Postgraduate School (NPS) in conjunction with Deputy Assistant Secretary of the Navy Research, Development, Test and Evaluation (DASN(RDT&E))/NMSO has established a degree program, the Modeling, Virtual Environments and Simulation (MOVES) curriculum and a research institute, the MOVES Institute. The degree program fulfills graduate education requirements for Navy, Marine Corps, and Army officers. Navy officer graduates are qualified to fill 6202-P coded billets. Marine Corps officers serve in 8825-designated billets. Army officers serve as Functional Area 57 Simulation Operations Officers. The degree program has a strong basis in computer science and operations analysis with additional content specifically and continually developed to anticipate and meet the needs of the rapidly evolving military M&S community. Graduates gain a defense-focused in-depth understanding of the mathematics, technology, methodology, and management issues behind modern modeling and simulation systems. Officers arrive at NPS with proven operational leadership experience. At NPS they gain a technical and defense-oriented M&S education. The graduates' blend of operational experience and M&S education make them uniquely and ideally suited to manage the development and application of future M&S systems within the DoD.

This research effort was undertaken as a result of several events over a period of several years. The first was a requirement to shorten the length of the degree program from 27 to 24 months. This action resulted in a fixed 24-month, 7-quarter degree that allows for little if any flexibility. The reduction eliminated all electives and compressed courses where content was taught over two or more quarters. This was the first time where a considerable rework of the curriculum was executed.

The second event was an independent study sponsored by the Marine Corps Modeling and Simulation Office in conjunction with Johns Hopkins Applied Physics Laboratory to assess the state of the MOVES curriculum in 2015. In February 2015, the Marine Corps Modeling and Simulation Management Office (MCMSMO) and Navy Modeling and Simulation Office (NMSO) produced a report titled "Modeling Virtual Environments and Simulation Curriculum Assessment FY2015 Initial Assessment" as part of a biennial assessment of the MOVES curriculum. The Johns Hopkins University Applied Physics Laboratory conducted the assessment and provided recommendations to address many identified deficiencies. The study and series of meetings that followed produced a new set of educational skill requirements (ESRs) for the MOVES program. The new ESRs are greatly expanded from the previous ESRs, reflecting the rapidly developing field of M&S and the ever-increasing expertise required of personnel serving in M&S positions within the DoD.

Findings and Conclusions

This project leveraged several professors and research associates currently involved in research in several of the areas already discussed, as well as, students that were participating in the MOVES curriculum during the period of performance. Several systematic studies and excursions were executed to better understand the means to meet the ESRs of M&S Officers in areas identified in the 2015 MCMSO/NMSO report. NPS faculty members with the appropriate expertise were assigned as the leads for each of the tasks identified in the research proposal. As a result of this research effort, the faculty has expanded and applied new knowledge in their unique subject areas through a variety of means to develop useful materials and methods for meeting the expanded M&S Officer ESRs. MOVES students participated in this project by providing feedback and suggestions where appropriate. The effort investigated the fundamental and advanced M&S topics that are requested to meet the ESRs of Marine and Navy M&S Officers. Efforts included determining the sub-topics which need to be addressed, investigating the state-of-the-art in the

field, finding up-to-date and militarily relevant examples, and recommending appropriate educational methods for presenting each topic to students. Specific topic areas from the FY15 MCMSMO and NMSO assessment report of MOVES that were addressed in this effort include the impacts of integrating Command and Control and Simulation programs of record to the curriculum, intelligent systems, modeling of military systems and processes, combat modeling, and stability, security, transition, and reconstruction (SSTR) operations. The point of investigating these topics was to determine the conditions needed to make the connections between the theoretical aspects of the degree program with real world applications of modeling and simulation to better prepare students to execute their roles as M&S officers and subject matter experts (SMEs).

Two analysis questions stimulated this research. The first *“What is the appropriate frequency, level of interaction, feasibility, and impacts of including operational site visits as part of graduate education?”* and the second *“What is the most effective way to synchronize lab intensive graduate curricula with Operational Sponsor rapidly evolving needs?”*

The approach taken to investigate these questions was direct inquiry, action, and experimentation. This was accomplished by engaging in an activity that fit the description of the question and obtaining informal qualitative feedback from the participants of the activity. One exposure to a live/virtual/constructive (LVC) environment across a 2-day period was provided to one class of students. This particular group of students enjoyed the opportunity and the feedback about repeating the outing and the value were very positive. Intuitively, given the reaction to the event by the participants we believe that sustaining this type of event will provide students with some much-needed context to view the application and issues involved with the use of Live, Virtual and Constructive simulations and networks to support human performance activities, specifically training. The issue of appropriateness is one that has been debated by both faculty and students. We are currently unaware of any other graduate programs in M&S that include field trips as part of their classes. An exception to this might be lab work that may be conducted at an offsite location or as part of a class or individual student research. NPS and MOVES are unique in so far as our graduates apply what they have learned in a very broad domain upon graduation. Understanding that, we believe that providing real-time operational examples that provide context and clarity to some of the complex issues within the defense modeling and simulation space make this type of exposure appropriate.

The analysis done on both simulation and mission command system programs of record resulted in the conclusion that under the current resource constraints, MOVES is unable to sustain any simulation or mission command program of record (POR) for teaching purposes. The training needed to setup and operate a simulation POR is extensive. Networking mission command systems and configuring them within tactical organizations requires teams of specially trained personnel. Professors in MOVES do not have the time nor the expertise to be responsible for the setup, operation, and maintenance of simulation and mission command PORs as well as maintaining and updating the currency in their fields of expertise and course materials. The ESRs that require the use of both simulation and mission command PORs are not tied to any particular system for graduate level education. The concepts and deep understanding of interoperability, cyber vulnerabilities, and networks can all be learned using assets that require less overhead and cognitive load on the student and are in line with the time limits for classes taught on a quarter system.

Recommendations for Further Research

A careful analysis of the curriculum has generated a multitude of questions many of which are related but beyond the scope of this report. Currently work is ongoing to investigate significant curriculum adjustments that will reduce the workload on students, increase theoretical and conceptual understanding of modeling and simulation in science, and provide a coherent practicum experience that will provide students with ample exposure to the development, evaluation, and use of modeling and simulation in a military context. To date the degree has consisted of an amalgam of computer science, operations research, mathematics, and human factors elements that over time have become desynchronized or unnecessary given the maturation of technology and required changes to the curricula. We believe that the current degree offering may be lacking in consistent relevant context in and between courses, which allow students to realize the bigger picture. We are moving to formalize what makes MOVES unique through the combination of stable core classes, military student body, DoD focus, and practical application of the M&S education in our curriculum through our practicums. Finally, we are investigating the rules governing various NPS/MOVES activities and are questioning their relevance given changes that have occurred in the Department of Defense and U.S. Navy. Given the fast-moving world, maintaining operational relevance in an academic setting continues to be a challenge. Working with all stakeholders, integrating new research ideas, maintaining course currency, leveraging student experience and professor knowledge, are the keys to continuing MOVES reputation as the “Gold Standard” amongst modeling and simulation degrees within and outside of the Department of the Navy and Defense.

MARINE CORPS SYSTEMS COMMAND (MCSC)

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 W. Courtney USN and Maj Thomas Haakensen USMC

Project Summary

Low-power wireless networks use the Institute of Electrical and Electronics Engineering (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 Internet Engineering Task Force (IETF)’s *Low-power Wireless Personal Area Networks* (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/MS-C-77, contains working spaces for two individuals to work inside of it (Corps, 2008). The AN/MS-C-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, Electrical Engineering (MSEE) students 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.

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 Electrical and Computer Engineering (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 Fig. 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 Fig. 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.

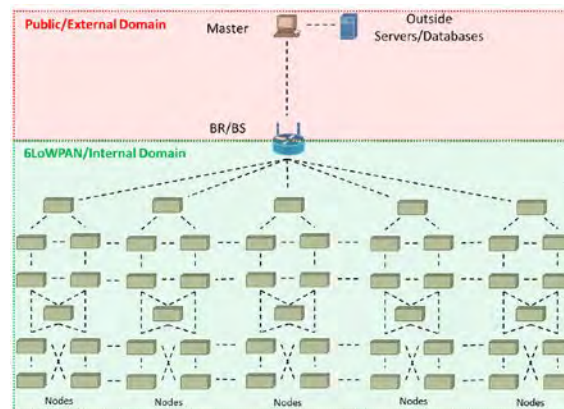


FIG. 1. THE DEVELOPED 6LOWPAN NETWORK DESIGN

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.

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 Fig. 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 Fig 3.

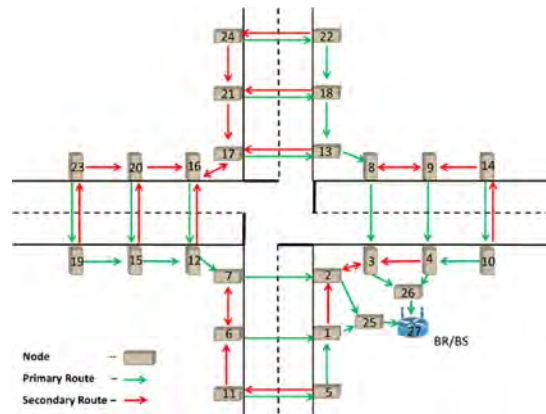


FIG. 2. NETWORK SIMULATION TOPOLOGY THAT DEPICTS NODE PLACEMENT AND SHOWS THE PRIMARY AND SECONDARY PATHS FOR EACH NODE, AS DEVELOPED IN THE CENTRALIZED ROUTING SCHEME.

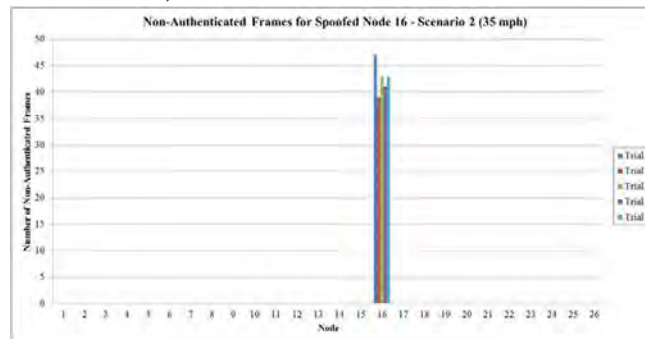


FIG. 3. NUMBER OF NON-AUTHENTICATED FRAMES RECEIVED BY THE MS IN EACH OF THE FIVE TRIALS FOR SCENARIO 2 SIMULATING A SPOOFING ATTACK ON NODE 16

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 Fig. 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.

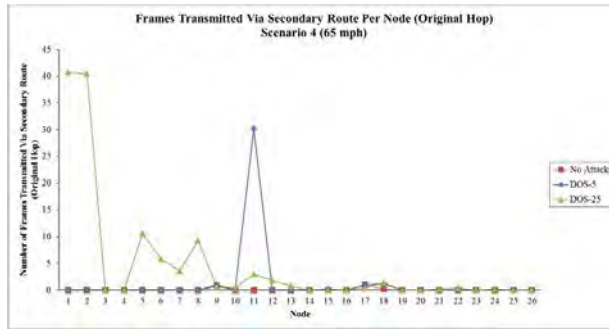


FIG. 4. FRAMES TRANSMITTED VIA SECONDARY ROUTE PER NODE (ORIGINAL HOP) IN SCENARIO 4 (TRAFFIC AT 65 MPH) FOR NO ATTACKS AND DOS ATTACKS AT NODES 5 AND 25

The results shown in Fig. 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.

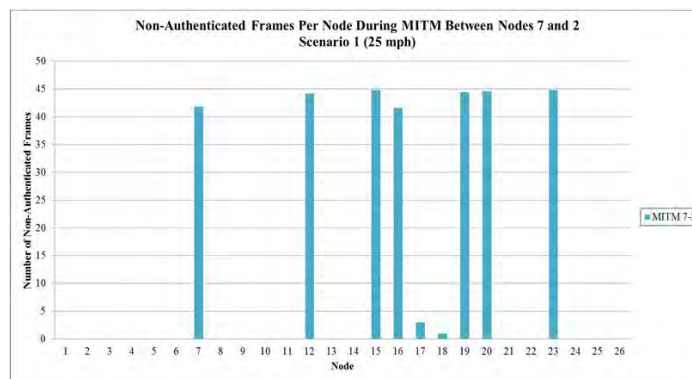


FIG. 5. NUMBER OF NON-AUTHENTICATED FRAMES RECEIVED BY THE MS FROM THE ORIGINATING NODE DURING A MITM ATTACK BETWEEN NODES 7 AND 2.

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).

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 Fig. 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.

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NPS-17-M190-A: Automated Testing of Virtualized MCEN

Researcher(s): Dr. Gurminder Singh and Mr. John H. Gibson

Student Participation: Capt Jaspreet Blevins USMC

Project Summary

The purpose of this research is to assist Marine Corps Tactical Systems Support Activity (MCTSSA) with the creation of a virtualized test environment by developing an algorithm that identifies a mathematical distribution that can be used to model network traffic that is unique to the Marine Corps Enterprise Network (MCEN). By capturing and analyzing samples of network traffic provided by MCTSSA in the form of .pcap files, this will allow us to determine a statistical distribution to model the traffic.

Keywords: *Networking, MCEN, Network Virtualization*

Background

Today, nearly every organization, small or large, relies on communication networks to accomplish daily tasks. These networks are made up of a substantial number of computers and various communication tools, which go through regular software and hardware updates. Sometimes, these changes can cause service disruptions that were not anticipated by the network administrators. To accurately measure the impact of these changes, we must evaluate them in a virtual testbed that accurately emulates the operational network. Creating these virtual testbeds that appropriately emulate the operational network can be a challenging task for many reasons. Since these networks can be large and complex, virtualizing the entire network is infeasible. This requires us to develop a reduced order topology that is functionally equivalent to the actual network topology. This topology will allow us to build a virtual replica of the target network, but it will not be truly representative of the actual network until we accurately recreate network traffic as observed on the target network.

Traffic can be generated using various existing tools, but it will not be representative of the actual traffic on the network. Generating realistic traffic requires a deep understanding of the actual traffic and identifying the key characteristics. Currently, no existing model can be used to generate traffic that represents the real traffic characteristics. Therefore, we research how we can regenerate realistic network traffic, which will allow us to observe the effects of the changes introduced to the operational network. To accomplish this task, we can record actual network traffic to identify the characteristics are unique to this network, which can be used to recreate realistic traffic.

Muslhtag and Azhar [1] conducted statistical analysis on the data collected from six different datasets to model the traffic using the packet inter-arrival times as well as the packet size. They parsed the traffic for various characteristics to include inter-arrival times and packet size. To model the traffic, they plotted the histogram and probability distribution function (PDF) for the packet inter-arrival times and a cumulative distribution function (CDF) and a normalized PDF for the packet size. They concluded that the packet-interarrival from the six data sets could be modeled using the Pareto distribution.

Garsva et al. [2] conducted a similar study for traffic in an academic computer environment. They focused their efforts on identifying the statistical distribution to model the inter-arrival time distribution concerning the two popular transport protocols, Transmission Control Protocol (TCP) and User

Datagram Protocol (UDP). They reused network traffic that they had collected for another project. They divided the network traffic into four sections based on the network usage times. They parsed the traffic to collect statistics about TCP and UDP for incoming and outgoing traffic. The distribution of the packet-inter-arrival times was analyzed, and they used the Kolmogorov-Smirnov test to determine goodness-of-fit. They concluded that the Pareto Second Kind distribution best represented the TCP and UDP traffic from the test network [2].

This research follows the approaches presented in [1] [2] to characterize and model the network traffic. Additionally, we study the degree of self-similarity of the traffic.

Findings and Conclusions

In this research, we developed and tested a methodology that can be used to characterize network traffic, which we believe to be the key for generating representative traffic from the desired network. We analyzed real traffic from the MPY 17-1 network and the NPS network. For each sample, we examined the traffic distributions of protocols, source and destination ports, packet inter-arrival times, packet sizes, and flow sizes. To model the packet inter-arrival times, packet sizes, and flow sizes, we fitted the data to the following three heavy-tailed distributions: the Pareto distribution, the Weibull distribution, and the log-normal distribution.

To examine various aspects of traffic, we learned about different traffic analysis tools as well as statistical tool to process the data. We quickly determined that tools like Wireshark are not a good candidate for examining large traffic samples. To solve this issue, we wrote a custom script using Python to parse and examine the traffic data. The next issue involved gaining access to meaningful network traffic data to validate our methodology. We obtained 17GB of data from the MPY 17-1 network, but we were only able to examine three files because the others included encrypted traffic. In addition to the MPY 17-1 traffic, we were also able to gather and examine data from the Naval Postgraduate School (NPS) network.

NOTE: The final conclusions from this work are being drafted and will be available in the 2018 NRP Annual Report.

Recommendations for Further Research

An interesting follow-on research angle would be to answer the following question:

How can we use the degree of self-similarity in network traffic to look for anomalies, which may point to either insider threats or offensive cyberattacks?

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MARINE FORCES RESERVE (MARFORRES)

NPS-17-M366-A: Reserve Training Center Decision Support Tools – Hurricane Preparation Trainer

Researcher(s): Dr. Eva Regnier and Dr. Alejandro Hernandez Col USMC Ret.

Student Participation: CPT Sean R. Christopherson USA

Project Summary

In FY15 and FY16, the Naval Postgraduate School (NPS) developed a hurricane decision simulator (HDS) for the Marine Corps Forces Reserve (MFR) in New Orleans that allows users to step through many synthetic storms and forecasts to gain a familiarity with the hurricane evolution, forecast quality, and the critical decision points, together with follow-on actions and decisions by other local agencies that affect the execution of hurricane preparation actions. The MFR in New Orleans use the HDS in individual and table-top exercises, and wanted to expand it to Marine Forces Reserve Headquarters Training Centers (MFRHTC) located elsewhere on the Atlantic and Gulf coasts of the U.S. In FY17, we developed a general system to be able to create new scenarios appropriate to each MFRHTC, which is called the HDS v. 2.0.

CPT Sean Christopherson's MS thesis research included working with the in Hialeah, Florida to develop the details of their scenario. We adapted the MFR headquarters scenario to v. 2.0 and developed a storm selector to help key personnel identify synthetic storms suitable for tabletop exercises. In addition, our partners at the Department of Energy Ames Laboratory conducted experiments to test that individual use of the simulator affects hurricane-preparation decision making. The MS thesis proposes to continue maintaining this with updates per requests from MFR in New Orleans, including adding functionality. In addition, to support the use of this tool by other MFR training centers on the U.S. eastern seaboard, we propose to update the storm and forecast model with input from National Oceanic and Atmospheric Administration (NOAA) meteorology organizations, and develop a capability to use a U.S. Atlantic or Gulf coastal location other than New Orleans as the location of interest.

Keywords: *simulation, training, decision making, risk, hurricanes, tropical cyclones*

Background

MFR and Marine Forces North have approximately 3,000 personnel working in New Orleans. The facility location is highly vulnerable to hurricanes and tropical storms. In order to protect the safety of personnel and their families while maintaining mission capability, the Commander and other key staff must make high-stakes decisions with lead times of up to 96 hours. False alarms can cost millions of dollars and unnecessarily risk traffic fatalities. However, the forecasts available at the relevant lead times have a high degree of multidimensional uncertainty, and forecast information changes with each forecast update. All factors have been shown to increase the difficulty of the decision problem and decrease both decision quality and the ability to learn through experience (Shanteau 1992). Prior work by Taylor (2007) shows that optimal hurricane preparation decisions are not necessarily obvious, and Regnier and Harr (2006) suggest that decision makers should sometimes wait to commit to precautions like evacuation until they

receive a more accurate forecast. New Orleans is particularly vulnerable to storms whose threat is not forecast with a high probability until lead times are 48 hours or less (Regnier 2008).

In FY15 and FY16, a team of researchers at NPS developed a training tool that allows users to practice making MFR's key preparation decisions in a simulated context (MacKenzie & Regnier, 2015). The decisions and the outcomes are based on MFR Hurricane preparation processes and impacts. Currently, the simulator contains over 500 simulated storms, generated using a statistical model that replicates key features of storms. The model is fitted to storms in a National Hurricane Center (NHC) historical database (Jarvinen et al, 1984), plus the most recent five years of track and intensity errors from the National Hurricane Center (NHC). Users receive feedback on the outcomes of their decisions and gain expertise in interpreting forecast uncertainty and appropriately balancing the conflicting objectives of minimizing the cost of preparation and mitigating the consequences of a hurricane.

The simulator was migrated online in 2016, and has been used in individual training by members of the MFR Crisis Action Team and Emergency Response Team, as well as in a tabletop exercise, in August 2016.

Findings and Conclusions

Due to the success of the HDS at the MFR Headquarters in New Orleans, MFR sought to expand the simulator to Headquarters Training Centers (HTCs) elsewhere on the Atlantic and Gulf Coasts that are vulnerable to hurricane-related impacts. The code underlying the HDS v. 1.0 was purpose-built for New Orleans. While the user interface worked very well for MFR, in order to enable the development of new scenarios – for additional HTCs – the code behind the user interface needed to be redesigned and rebuilt. The architecture of the system for v. 2.0 allows for the decision context – reflecting key command decisions, follow-on actions, storm impacts and other information – to be input using human-readable .xlsx files. The storm model was also altered to allow it to produce storms that are relevant to Hialeah, rather than New Orleans.

The process for turning these input files into a usable HDS scenario is now much shorter and easier, and in FY18 it is planned that this capability will be delivered to MFR which will be able to create its own scenarios. As part of his thesis research, Captain Sean Christopherson worked closely with the Hialeah HTC staff to develop their hurricane preparation planning. Captain Christopherson built the .xlsx files for the Hialeah scenario. A beta version of the Hialeah scenario was used in the Command handover at the Hialeah HTC in June 2017.

As the purpose of the HDS is to allow users to gain experience with synthetic storms that are realistic, an enhancement in FY17 was to use the code that the NHC uses to generate its graphical products to generate the graphics used in the HDS.

The MFR has begun to use the HDS in its individual and team-based hurricane preparation exercises. To support tabletop exercises, in FY17 a Storm Selector was introduced that allows the staff organizing the tabletop exercise to preview storms, filter, and sort them based on characteristics such as maximum storm wind speed, distance of closest approach to the target location, and maximum probability of hurricane-force winds at the target.

In FY17, the HDS was used in the spring functional exercise with approximately 40 mid-level to senior-level officers responsible for functional areas including personnel, operations, and logistics. It was also used in the August tabletop exercise with more senior participants—principals and deputies from various directorates. Their experiences show the value of the HDS in improving MFR’s hurricane preparation training and decision processes by:

1. increasing the number of storms individuals can experience – a storm that is a threat level experienced approximately once per year in reality can be experienced in 10-15 minutes in the HDS;
2. generating synthetic storms for tabletop exercises at lower cost – storms in the HDS can be pulled up almost instantaneously while the Emergency Manager previously spent about 30 hours to prepare storms for tabletop exercises; and
3. focusing training on uncertainty and ambiguity inherent in the decision process, as the simulated storms, which improves MFR personnel’s understanding of the forecast products.

These improvements in the training process, provided in a realistic environment with rich, specific, decision-dependent feedback, can be expected to reduce known biases in decision-making under uncertainty. Further documentation is available in Regnier & MacKenzie (2017).

Assistant Professor Cameron MacKenzie, currently at Iowa State University and the Department of Energy Ames Laboratory and formerly on the faculty at the Naval Postgraduate School, and a participant in the FY15 NRP effort, conducted experiments to evaluate the impact of the use of the HDS on risk-based decision making. Results showed a significant difference in decision-making and risk judgement following running through five storms in the HDS. In particular, experience using the HDS seems to influence people to wait to evacuate or shelter, especially for difficult decisions. In October 2017, Dr. MacKenzie presented preliminary analysis of these results at the annual meeting of the Institute for Operations Research and the Management Sciences in Houston, TX.

Recommendations for Further Research

Future work to study the impact of the HDS on decision-making in environments with challenging uncertainty and changing risk information is recommended. In addition, research to study the impact of shortening the timelines for implementing hurricane preparations to allow Commanders to take advantage of more accurate forecasts is recommended.

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NPS-17-M367-A: Extension of I-I Hybrid Knowledge Transfer Modules to Health Service Support Operations

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Project Summary

The Naval Postgraduate School (NPS) team has delivered a set of online modules to support Marine Forces Reserve Health Service Support (HSS) training. The intent of the project is to create a durable training program for the HSS division to support knowledge acquisition that is required for Marine Reservists, Commanders, and support personnel. In tandem, NPS would work with Marine Corps Forces Reserve (MARFORRES) subject matter experts (SMEs) to construct online training modules that users would study. Users must pass an online test before attending resident training. The intent is for resident training to focus on application of pre-acquired knowledge with scenario-based workshops that require participants to apply skills in new contexts. The vision for HSS is that HSS personnel would ultimately manage and administer the online courses.

Background

HSS personnel, commanders and staff must be knowledgeable and prepared to provide a responsive health service support capability. Active duty Navy Corpsmen who are newly assigned as Medical Duty Representatives to MARFORRES require reserve specific knowledge. The challenge of having a distributed population is the need to have ongoing training. The Training and Education Command or other Marine Corps schoolhouses do not offer such continuous learning. The result is a knowledge gap for HSS personnel.

Findings and Conclusions

The project task was to work with MARFORRES SMEs to build online modules that cover approximately 19 topics (these were subsequently winnowed down to 8 modules) within a Sakai framework hosted at NPS. Working collaboratively with the Center for Educational Design, Development and Distribution (CED3), the goal was to help MFR SMEs develop and maintain their own course modules. NPS tasked CED3 instructional designers with identifying pedagogically apt approaches to facilitate effective knowledge acquisition, including applying instructional design principles to knowledge architecture, identifying/designing supportive media and interactive exercises, in support of the project.

CED3 tasks specifically included:

- Meet with SMEs to outline key content items for modules
- Review SME narratives to provide pedagogical and technical guidance and support
- Design interactive media, video, assessments, graphics and interface design
- Design Sakai skin and course architecture

The mechanics to develop the modules included:

- Attending the HSS quarterly training
- Course module proof of concept development by NPS personnel
- Module evaluation and refinement (via telephone conferences, emails, etc.)
- Coach selected MFR personnel to develop additional modules
- Providing pedagogic and technical guidance and support of development
- Developing a DL student handbook and administrative processes for course sustainment

Project Status: HSS SME and NPS identified topic areas and learning objectives to create a global course outline to support building out the modules. NPS recruited two NPS graduate students with experience in the topic area to curate content for review for HSS SMEs. The project currently has:

- Eight online modules
 - Sakai site with custom skin
 - Course architecture built out and all content loaded into course
- Custom graphics and interactions added to course
- Instructor resource page

Phase one is complete. Follow-on phases require direct engagement by HSS personnel and SME. The final package has been delivered to MARFORRES for review and comments. The following list are items that have hindered the project and should be resolved before pursuing it any further.

- HSS staff frequently travel for inspections. Turnaround time for requests for information and content review was neither timely nor reliable.
- The HSS staff serve as the subject matter experts (SME) for the online course. SMEs were not engaged in the development of the content. NPS team ultimately served as the content writers and curriculum developers (NPS students). Feedback and edit requests were minimal and not well aligned with course structure.
- There is currently no timeline to train HSS staff on student management and course maintenance. Their availability to receive such training is unknown. Additionally, the personnel responsible for student/Sakai management have not yet been identified.
- The online course was intended to provide a basic understanding of HSS matters so that complex matters can be covered during the residential period of instruction. SMEs have not yet adjusted their content to remove redundancies.
- The online course assessments and final assessments have not been validated by SMEs and a grading criteria has not been established.

In addition to reviewing the delivered products, HSS personnel and course SME must:

- Validate all the test questions
- Build out the final assessment

The information a SME would need to complete this task can be found in the “Instructor Resources” page of the course.

Recommendations for Further Research

This project should not be pursued until a Champion from MARFORRES is willing to ensure that HSS requirements are valid and that the SMEs required to make the HSS course useful are available.

LIST OF ABBREVIATIONS AND ACRONYMS

14WS - U.S. Air Force 14th Weather Squadron	ASB - air-sea battle
3D - three-dimensional	ASCM - anti-ship cruise missile
3M - maintenance and material management	ASN(RDA) - Assistant Secretary of the Navy Research, Development and Acquisition
6LoWPAN - low-power wireless personal area networks	ASVAB - Armed Services Vocational Aptitude Battery
A2/AD - anti-access and area denial	ASW - anti-submarine warfare
AAFS - amphibious assault fuel system	ATG - Afloat Training Group
ABLTS - Amphibious Bulk Liquid Transfer System	ATR - automatic target recognition
ACOL - Average Cost of Leaving	AUVs - autonomous underwater vehicles
ACOMMS - acoustic communications	BDAA - Big Data Architectures and Analytics
ACTUV - ASW Continuous Trail Unmanned Vessel	BDP - Big Data Platform
ADC - analog-to-digital converter	BL - block learning
ADOC - Advanced Division Officer Course	BMAs - battle management aids
ADS-B - Automatic Dependent Surveillance-Broadcast	BOM - Australian Bureau of Meteorology
AES - Advanced Encryption Standard	BOSC - Battlegroup Optimum Speed Calculator
AFCEA - Armed Forces Communications and Electronics Association	BPSK - Binary Phase-Shift Keying
AFP - adaptive force package	BRS - blended retirement system
AFQT - Armed Forces Qualification Test	BS - base station/border router
AI - artificial intelligence	BSC - Battle Simulation Center
AIP - air-independent propulsion	BSVE - base support, vehicle and equipment
AIS - automatic identification system	C2 - command and control
ALM - autonomous loitering mine	C4I - command, control, communications, computers and intelligence
ALMDS - Airborne Laser Mine Detection System	CAC - contextual autonomous capabilities
AM - additive manufacturing	CAD - computer-aided design
AMRAAM - Advanced Medium-Range, Air-to-Air Missile	CAD/CAM - computer-aided design and manufacturing
AMSEWG - Architecture Modeling for Systems Engineering Working Group	CAN - computer network attack
AO - adaptive optics	CANES - Consolidated Afloat Networks and Enterprise Services
AO - Authorizing Official	CASoS - complex adaptive systems of systems
AoA - Analysis of Alternatives	CASREP - Casualty Report
AOI - area of interest	CAWP - Code Assessment Web Portal
AOR - area of responsibility	CBA - cost-benefit analysis
APAN - All Partners Access Network	CCCC - China Communications Construction Company
API - application program interface	CDET - College of Distance Education and Training
ARG - amphibious ready group	CDF - cumulative distribution function
ARTeMIS - Automated Red Teaming Multiobjective Innovation Seeker	CDOSS - cyber defense operational sequencing system

CED - Civil Engineer Corps
 CED3 - Center for Educational Design, Development and Distribution
 CFA - confirmatory factor analysis
 CFD - computational fluid dynamics
 CFE Treaty - Conventional Armed Forces in Europe Treaty
 CG - Guided Missile Cruiser
 CH53E - Sikorsky CH-53E Super Stallion, heavy-lift helicopter
 CIC - Combat Information Center
 CICA - Conference on Interaction and Confidence-Building Measure in Asia
 CID - combat identification
 CIV - civilian
 CIV INT - civilian intern
 CIVINS - civilian educational institutions
 Cn2 - refractive index
 CNDSP - Computer Network Defense Service Provider
 CNE - computer network exploitation
 CNO - Chief of Naval Operations
 CNRMC - Commander, Navy Regional Maintenance Centers
 CNSF - Commander, Naval Surface Forces
 CNSP - Commander, Naval Surface Force, U.S. Pacific Fleet
 CO - commanding officer
 CO/OOD - commanding officer/officer of the deck
 COAs - Course of actions
 COC - Combat Operations Center
 COIs - critical operational issues
 COMLOG WESTPAC - Commander, Logistics Group Western Pacific
 COMSEVENTHFLT - Commander of the 7th Fleet
 CONOPS - concepts of operations
 CORE - common operational research environment
 COSCO - China Ocean Shipping Company
 COTS - commercial off-the-shelf
 COVE - Conning Officer Virtual Environment

COVE-ITS - Conning Officer Virtual Environment intelligent tutoring
 CPC - Climate Prediction Center
 CPU - central processing unit
 CRIC - Rapid Innovation Cell
 CRUSER - Consortium for Robotics and Unmanned Systems Education and Research
 CSG - carrier strike group
 CSOSS - Combat Systems Operational Sequencing System
 CSSA - supply base
 CSV - comma-separated values
 CT2 - temperature structure parameter
 CTAP - common tactical air picture
 CTB - Combined Test Bed
 CTD - conductivity temperature detector
 CTF - Commander, Task Force
 CTP - common tactical picture
 CVAR - value at risk
 CVN - nuclear aircraft carrier
 D3 - data-driven documents
 DADMS - DON Application and Database Management System
 DAQ - data acquisition
 DARPA - Defense Advanced Research Projects Agency
 DASN RDT&E - Deputy Assistant Secretary of the Navy Research, Development, Test and Evaluation
 DCGS - distributed common ground systems
 DCL - detection, classification, and localization
 DCMP - Data Collection and Management Plan
 DCO - defensive cyber operations
 DDG - Guided Missile Destroyer
 DE - directed energy
 DEF - Defense Entrepreneurs Forum
 DEOCS - Defense Equal Opportunity Climate Survey
 DEP - Delayed Entry Program
 DFFT - discrete Fourier transform
 DFL - digital flashing light
 DFS - departure from specifications
 DIACAP - Department of Defense Information Assurance Certification Process

DIB - Defense Intelligence Database
 DIME - diplomatic, information, military, and economic
 DISA - Defense Information Systems Agency
 DITSCAP - Department of Defense Information Technology Security Certification and Accreditation Process
 DIUx - Defense Innovation Unit Experimental
 DIVE - Dynamic Interface Virtual Environment
 DL - Distributed Lethality
 DM2 - DODAF Meta Model
 DMDC - Defense Manpower Data Center
 DNS - domaine name servers
 DoD - Department of Defense
 DoDAF - Department of Defense Architecture Framework
 DOE - data farming and design-of-experiments
 DoN - Department of the Navy
 DoS - denial of service
 DOTMLPF - doctrine, organization, training, materiel, leadership and education, personnel and facilities
 DRM - Dynamic Retention Model
 DSB - Defense Science Board
 DT - Design Thinking
 DT - digital thread
 DUSN(M) - Office of the Deputy Under Secretary of the Navy (Management)
 DVAF - data vulnerability assessment framework
 EA - evolutionary algorithm
 EAS - expiration of active service
 EBSD - hardness and electron backscatter diffraction
 EC - environmental complexity
 ECCM - electronic counter-countermeasures
 ECDIS-IN - Electronic Chart Display and Information System - Navy
 ECE - Electrical and Computer Engineering
 ECMWF - European Centre for Medium-range Weather Forecasting
 EDS - X-ray spectroscopy
 EE - Enterprise Engine
 ELT - extraction transformation loading

EM - electromagnetic
 EMO - Enhanced Marine Air Ground Task Force Operations
 EO - electro-optical
 EO/IR - electro-optical infrared
 EODES - Electro-Optical Detection and Simulation model
 EOSS - Engineering Operational Sequencing System
 ERB - Executive Review Board
 ERP - Enterprise Resource Planning
 ESCs - electronic speed controls
 ESM - electronic support measures
 ESRs - educational skill requirements
 ESS - Epworth Sleepiness Scale
 ESWC - Expeditionary Warfare Command
 ET-M&S - Enhanced Shock Qualification, Surrogate Testing and Modeling and Simulation
 EUP - effective utilization parameter
 EW - electronic warfare
 F-35B - Lightning II STOVL aircraft
 FABLABS - fabrication labs
 FARPS - Forward Arming and Refueling Posts
 FEL-INP - Free Electron Laser Innovative Naval Prototype
 FFT - fast Fourier transform
 FITREPs - fitness reports
 FLC - Fleet Logistics Center
 FLOSS - Free/Libre OSS
 FMR - Financial Management Regulation
 FNMOC - Fleet Numerical Meteorology and Oceanography Center
 FOM - figure of merit
 FORTRAN - Formula Translation
 FOSS - Free Open Source Software
 FPV - first-person view
 FRCMA - Fleet Readiness Center Mid Atlantic
 FSF - Free Software Foundation
 FSI - fluid structure interaction
 FSO - free-space optics
 FSS - Fatigue Severity Scale
 FSST - Full Ship Shock Trial
 FST - fleet survey team

FST - Fleet Synthetic Training	IFF - identification friend or foe
FTAP - First Term Alignment Plan	ILQR - linear-quadratic regulator
FUSED - Fuel Usage Study Extended Demonstration	IM/KM - information management/knowledge management
FVEYS - Five Eyes	IMO - International Maritime Organization
GAO - Government Accounting Office	IMU - inertial measurement unit
GCE - ground combat element	INF - Intermediate-Range Nuclear Forces
GDEM - Generalized Digital Environmental Model	INSCOM - Intelligence and Security Command
GenOC - generalized optimal control	INSURV - Board of Inspection and Survey
GIG - Global Information Grid	IO - digital input and output
GP - Gaussian process	IOCs - indicators of compromise
GSA - General Services Administration	IOD - Indian Ocean Dipole
GTSP - Global Temperature and Salinity Profile Programme	IoT - internet of things
GUI - graphical user interface	IP - Internet Protocol
HDS - hurricane decision simulator	IR - incident response
HELs - high energy lasers	IRAM - Marine Corps Individual Records Administrative Manual
HI - human independence	IRB - Institutional Review Board
HIDEX - High Intake Defined Excitation	IRC - internet relay chat
HPC - high-performance computing (HPC)	IRI - International Research Institute for Climate and Society
HRI - human-robot interaction	ISI - Insomnia Severity Index
HRS - Hose Reel System	ISR - intelligence, surveillance, and reconnaissance
HSS - Health Service Support	IT - information technology
HTCs - Headquarters Training Centers	I-TRAIN - Installation Training Readiness Aligned Investments
I&W - indications and warnings	ITS - intelligent tutoring system
IA - Information Assurance	IUSS - Integrated Undersea Surveillance System
IAEA - International Atomic Energy Agency	IUU - illegal, unregulated, and unreported fishing
IAM - Information Assurance Manager	JAX - Jacksonville
IAMD - integrated air and missile defense	JCAS - Joint Close Air Support
IC - intelligence community	JIFIX - Joint Interagency Field Experimentation
ICAO - International Civil Aviation Organization	JITT - Junior Innovation Think Tank
ICBMs - Intercontinental ballistic missiles	JO - junior officer
ICS - industrial control systems	JOAC - Joint Operational Access Concept
IDA - Institute for Defense Analysis	JSF - Joint Striker Fighter
IDE - interface development environment	JSON - JavaScript Object Notation
IED - improvised explosive device	JWICS - Joint Worldwide Intelligence Communications System
IEEE - Institute of Electrical and Electronics Engineering	KCs - kill chains
iENCON - Shipboard Incentivized Energy Conservation	KML - Keyhole Markup Language
IETF - Internet Engineering Task Force	LCAC - landing craft, air cushion
IF - Integrated Fires	

LCS - littoral combat ship
 LCU - landing craft, utility
 LD - laser designators
 LDA - latent Dirichlet allocation
 LE - law enforcement
 LHA - amphibious assault ship
 LHD - landing helicopter dock
 LI - laser illuminators
 LiDAR - light detection and ranging
 LiFi - light fidelity
 LLA - Lexical Link Analysis
 LLA/CLA - Lexical Link Analysis/Collaborative Learning Agents
 LLL - low light level
 LML - Lifecycle Modeling Language
 LoA - levels of autonomy
 LP - laser pointers
 LPD - landing platform/dock
 LPI - low-probability-of-intercept
 LREs - Launch and Recovery Envelopes
 LRF - laser rangefinders
 LRF - long-range forecast
 LSD - landing ship, dock
 LTM - laser target markers
 LVC - live/virtual/constructive
 M&S - modeling and simulation
 MAC - media access control address
 MACS - MEU Amphibious Connector Scheduler
 MAGID - Magnetic Intrusion Detector
 MAGTF - MAGTF Tactical Warfare Simulation
 MAGTFTC - Marine Corps Air Ground Task Force Training Command
 MANA - Map Aware Non-uniform Automata
 MARFORRES - Marine Corps Forces Reserve
 MarineNet - Marine Corps Distance Learning Network
 Mark VI PB - Marki Vi patrol boat
 MARMC - Mid-Atlantic Regional Maintenance Center
 MAST - Malicious Activity Simulation Tool
 MAWG - MOVES Research Working Group
 MAWT-1 - Marine Aviation Weapons and Tactics Squadron-1

MBITR - Thales Multiband Inter/Intra Team Radios
 MBSE - model-based systems engineering
 MC - mission complexity
 MC SYSCOM - Marine Corps Systems Command
 MCAGCC - Marine Corps Air Ground Combat Center
 MCCDC - Marine Corps Combat Development Command
 MCEN - Marine Corps Enterprise Network
 MCLOG - Marine Corps Logistics Operations Group
 MCM - mine countermeasures
 MCMSO - Marine Corps Modeling and Simulation Management Office
 MCPP - Marine Corps Planning Process
 MCTSSA - Marine Corps Tactical Systems Support Activity
 MCWP - Marine Corps Warfighting Publication
 MD - metadata
 MDA - Maritime Domain Awareness
 MDUSV - Medium Displacement Unmanned Surface Vessel
 ME - Morningness-Eveningness Questionnaire
 MEF - Marine Expeditionary Brigade
 MEMS - microelectromechanical system
 MEPS - Military Entrance Processing Station
 MEQ-SA - Morningness-Eveningness Questionnaire
 METOC - meteorology and oceanography community
 MEU - Marine Expeditionary Unit
 MFR - Marine Corps Forces Reserve
 MFRHTC - Marine Forces Reserve Headquarters Training Centers
 MGTAF - Marine Air Ground Task Force
 MI - Director, Manpower Information Systems Division
 MI - motion imagery
 MIMO - multiple input, multiple output
 MIT - Massachusetts Institute of Technology
 MITM - man-in-the-middle
 MIW - mine warfare

ML - machine learning
 MLOs - mine-like objects
 MLT - mobile learning technology
 MMOWGLI - Massive Multiplayer Online
 Wargame Leveraging the Internet
 MMRP - Manpower Management Records &
 Performance
 MOC - meridional overturning circulation
 MOEs - measures of effectiveness
 MOF - meta-object framework
 MOPs - measures of performance
 MOS - military occupational specialties
 MOVES - Modeling, Virtual Environments and
 Simulation
 MP - Monterey Phoenix
 MPS - maritime pre-positioning ships
 MPTE - manpower, personnel, training and
 education
 MQTT - Message Queuing Telemetry Transport
 MRI - modified refractive index
 MRS - Maintenance Resource System
 MS - Master of Science
 MS - master station
 MSEE - Master of Science, Electrical Engineering
 MST - Maritime Strike Tomahawk
 MUE2 - MarineNet User Engagement Exercise
 MV-22 - merchant vessel - Osprey
 MVC - model view controller
 N50 - Strategy Division of N5
 NAF - Navy Availability Factor
 NAMTI - Naval Additive Manufacturing
 Technology Interchange
 NAS - Naval Air Station
 NASA - National Aeronautics and Space
 Administration
 NASC - New Asian Security Concept
 NASIC - National Air and Space Intelligence
 Center
 NAVAIR - Naval Air Systems Command
 NAVFAC - Naval Facilities Engineering
 Command
 NAVMAC - Navy Manpower Analysis Center
 NAVO - Naval Oceanographic Office

NAVSEA - Naval Sea Systems Command
 NAVSLaM - Navy Atmospheric Vertical Surface
 Layer Model
 NAVSSI - Navigation Sensor System Interface
 NCCOSC - US Naval Center for Combat and
 Operational Stress Control
 NCDOC - Navy Cyber Defense Operations
 Command
 NCEI - National Centers for Environmental
 Information
 NDM - Naval Maintenance Database
 NEC - Navy Enlisted Classification
 NETC - Naval Education Training Command
 New START - New Strategic Arms Reduction
 Treaty
 NFO - naval flight officer
 NGA - National Geospatial-Intelligence Agency
 NHC - National Hurricane Center
 NIAC - Naval Innovation Advisory Council
 NIFC-CA - Navy Integrated Fire Control -
 Counter Air
 NIH - National Institutes of Health
 NLWs - non-lethal weapons
 NMCI - Navy Marine Corps Intranet
 NMSO - Navy Modeling and Simulation Office
 NOAA - National Oceanic and Atmospheric
 Administration
 NORAD - North American Aerospace Defense
 Command
 NOW - Network Optional Warfare
 NPS - Naval Postgraduate School
 NPT - Treaty on the Non-Proliferation of Nuclear
 Weapons
 NPV - net present value
 NRC - Navy Recruiting Command
 NRL - Naval Research Laboratory
 NRP - Naval Research Program
 NRPOM - Navy Recruiter Prediction and
 Optimization Model
 NRWG - Naval Research Working Group
 NSA - National Security Agency
 NSB - Naval Submarine Base

NSGA - Nondominated Sorting Genetic Algorithm
 NSS - naval simulation software
 NSW - naval special warfare
 NSWC - Navy Surface Warfare Center
 NSWCCD - Naval Surface Warfare Center, Dahlgren Division
 NSWW - Navy Standard Work Week
 NTFSM - Navy Total Force Strength Model
 NUWC - Naval Undersea Warfare Center
 NUWC DIVNPT - Naval Undersea Warfare Center, Division Newport
 O&M - operation and maintenance
 OAD - Operations Analysis Division
 OARS - Open Architecture Retrieval System
 OccFld - Occupational Field
 OCM - optimal control model
 OCO - offensive cyber operations
 OEM - original equipment manufacturer
 OMG - Object Management Group
 ONI - National Maritime Intelligence-Integration Office
 ONI - Office of Naval Intelligence
 ONR - Office of Naval Research
 OPAREAS - operating areas
 OPDS - offshore petroleum discharge system
 OPNAV - Office of the Chief of Naval Operations
 ORA - Organization Risk Analyzer
 OS - operating system
 OS - Operational Specialist
 OSAM - Officer Strategic Analysis Model
 OSD - Office of the Secretary of Defense
 OSD - optimal spectral decomposition
 OSM - orchestrated simulation through modeling
 OSS - open source software
 OTTER - Optimized Transit Tool and Easy Reference
 P-8 - P-8A Poseidon
 PAI - publicly available information
 PAM - program area manager
 PBFAM - powder bed fusion additive manufacturing
 PCB - printed circuit board

PDE - Person-Event Data Environment
 PDF - probability distribution function
 PEO U&W - Program Executive Office, Unmanned Aviation and Strike Weapons
 PET - performance evaluation transformation
 PHNS - Pearl Harbor Naval Shipyard
 PI - principal investigator
 PII - personally identifiable information
 PIR - passive infrared
 PLUSNet - Persistent Littoral Surveillance Network
 PMA - post-mission analysis
 PMAD - power management and distribution
 PNT - timing
 PoF - power over fiber
 POM - Program Objectives Memorandum
 POMS - Profile of Mood States
 POR - program of record
 PRO - Production Resource Optimization
 PROM-WED - Production Resource Optimization Model With Experimental Design
 PSC - Port State Control
 PSQI - Pittsburg Sleep Quality Index
 PTFSM - Probabilistic Temporal Finite-State Machine
 PTSD - Post-Traumatic Stress Disorder
 PVT - psychomotor vigilance tests
 QPSK - Quadrature Phase-Shift Keying
 QR - quick response
 R&D - research and development
 RAD - rapid application development
 RCA - Recruiter Calculator Algorithm
 RDT&E - Research Development Test and Evaluation
 RF - radio frequency
 RFID - Radio-frequency Identification
 RID - reacquisition and identification
 RIPP - rapid integration and platform provisioning
 RL - reinforcement learning
 RL - Restricted Line Officers
 RMF - Risk Management Framework
 RMSEA - root mean square area of approximation

ROEs - rules of engagement
 ROI - return on investment
 ROS - robot operating system
 RRL - ready, relevant learning
 RRT - rapidly exploring random tree
 RSA - Rational Software Architect
 RTC - Recruit Training Course
 RTE - radiative transfer equation
 S2 - intelligence officer
 S2S - subseasonal to seasonal
 S3 - operations officer
 SAG - surface action groups
 SAIC - Scienc Applications International Corporation
 SALT - Strategic Arms Limitation Talks
 SAR - Search and rescue
 SATVUL - Satellite Vulnerability
 SBIR - Small Business Innovation Research Program
 SC(X)R - Surface Connector (X) Recapitalization project
 SCADA - supervisory control and data acquisition
 SCS - South China Sea
 SDL - System Description Language
 SDTS - Self Defense Test Ship
 SEACAT - Southeast Asia Cooperation and Training
 SECAT - Ship Energy Conservation Assistance Training
 SECNAV - Secretary of the Navy
 SEDU - Swedish Defence University
 SEED Center - Simulation, Experiments and Efficient Design Center for Data Farming
 SET - Servicemember Evaluation Tool
 SFs - Security Forces
 SHIPMAIN - ship maintenance
 SIEM - Security Information and Event Management
 SIMEX - simulation experiment
 SINKEX - Sink Exercises
 SIP - still image photo
 SITT - Senior Innovation Think Tank
 SLBMs - submarine-launched ballistic missile

SME - subject matter expert
 SMEs - subject matter experts
 SMG - synoptic monthly gridded
 SMG-WOD - Synoptic monthly gridded World Ocean Database
 SMG-WOD-V - synoptic monthly gridded WOD Absolute Geostrophic Velocity
 SMRT - Ship Maintenance Review Team
 SNA - social network analysis
 SNR - signal-to-noise ratio
 SOCOM - Special Operations Command
 SOEs - state-owned enterprises
 SoS - system of systems
 SOSUS - Sound Surveillance System
 SPA - Systems Planning and Analysis , Inc.
 SPAWAR - Space and Naval Warfare Systems Command
 SPEA - Strength Pareto Evolutionary Algorithm
 SPOTR - Surveillance, Persistent Observation and Target Recognition
 SS - security services
 SSC - Ship to Shore Connector
 SSGs - Strategic Studies Group
 SSL-TM - Solid State Laser Technology Maturation
 SSNs - nuclear submarines
 SSP - sound speed profile
 SSTA - surface temperature anomalies
 SSTR - stability, security, transition, and reconstruction
 STEM - science, technology, engineering and mathematics
 STORM - Synthetic Theater Operations Research Model
 STTR - Small Business Technology Transfer
 sUAS - small unmanned aerial system
 SURFMEPP - Surface Maintenance Engineering Planning Program
 SURTASS - Surveillance Towed Array Sensor System
 SUW - surface warfare
 SWAP - size, weight, and power
 SWO - surface warfare officer

SWOS - Surface Warfare Officers School	UNDEX - underwater explosion
T&E - test and evaluation	URL - Unrestricted Line
T, S - temperature and salinity	USA - United States Army
TA - task analysis	USMC - United States Marine Corps
TACTRAGRUPAC - Tactical Training Group, Pacific	USN - United States Navy
TAFDS - Tactical Airfield Fuel Dispensing System	USV - unmanned surface vehicles
TaLEUAS - Tactical Long Endurance Unmanned Aerial	USW - undersea warfare
TANG - Tactical Advancements for the Next Generation	UTACC - Unmanned Tactical Autonomous Control and Collaboration
TAO - Tactical Action Officer	UUV - unmanned underwater vehicles
TAPAS - Tailored Adaptive Personality Assessment System	Uvs - underwater vehicles
T-CAME - Testbed for Characterization and Assessment of Marine Electronics	UxS - unmanned systems
TCP - Transmission Control Protocol	V&V - verification and validation
TCRI - Tactical Cloud Reference Implementation	VAS - visual augmentation systems
TCRI - Tactical Cloud Reference Implementation	VBA - Visual Basic for Applications
TDA - tactical decision aid	VE - virtual environment
TDOA - time difference of arrival	VMS - Electronic Navigation and Voyage Management System
TERN - Tactically Exploited Reconnaissance Node	VOI - vessel(s) of interest
TFDW - Total Force Data Warehouse	VRML - Virtual Reality Modeling Language
TFI - Task Force Innovation	WISDM - Warfighting Impact of Simulated Decision Makers
TFP - Transit Fuel Planner	WOD - wind over deck
TIO - Technologies for Information Operations	WOD01 - World Ocean Database 2001
TL - transmission loss	WRENCH - Workbench for Refining Rules of Engagement against Crowd Hostiles
TMD - Total Mood Disturbance	WSNs - wireless sensor networks
TOC - Total ownership cost	WTI - Weapons and Tactics Instructor
TRB - Topics Review Board	X3D - Extensible 3D
TSC - Training Support Center	XML - eXtensible Markup Language
TTPs - tactics, techniques, and procedures	XO - executive officer
UAC - underwater acoustic communication	XRD - X-ray diffraction
UAM - user activity monitoring	ZCTA - ZIP Code tabulation area
UAS - unmanned aircraft system	
UAV - unmanned aerial vehicle	
UCINET - University of California Irvine Network	
UDP - User Datagram Protocol	
UGV - unmanned ground vehicle	
UKMO - UK Met Office	
UML - Unified Modeling Language	
UN - United Nations	

Military & Government Services:

HN - Hellenic Navy
IDF - Israel Defense Forces
PAF - Pakistan Air Force
PN - Pakistan Navy
RAN - Royal Australian Navy
RNN - Royal Netherlands Navy
RSA - Republic of Singapore Army
SAF - Singapore Armed Forces
SG DSTA - Defence Science and Technology Agency, Singapore
SMoD - Swedish Ministry of Defense
TAF - Tunisian Air Force
TNF - Turkish Naval Forces
TNI AL - Indonesian Navy
USMC - United States Marine Corps
USN - United States Navy
USA - United States Army
USAF - United States Air Force
ZSU - Ukraine Army

Navy Structure:

N1 - DCNO for Manpower, Personnel & Training
N2/N6 - DCNO for Information Warfare
N3/N5 - DCNO for Information, Plans & Strategy
N4 - DCNO for Material Readiness & Logistics
N415 - DCNO for Additive Manufacturing Office
N45 - DCNO for Energy & Environmental Readiness
N8 - DCNO Integration of Capabilities & Resources
N81 - DCNO for Integration of Capabilities and Resources, Assessments
N9 - DCNO for Warfare Systems
N96 - DCNO for Surface Warfare Directorate
N97 - DCNO for Warfare Systems, Director for Undersea Warfare
N98 - DCNO for Air Warfare Division



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