

ASP, Art and Science of Practice: Educating Military Operations Research Practitioners

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The 2013 UPS George D. Smith Prize was awarded to the Naval Postgraduate School's (NPS) Operations Research (OR) department for "effective and innovative preparation of students to be good practitioners of operations research, management science, or analytics." In the spirit of the prize, this paper shares details about our degree program. The program is closely linked to its military sponsor, the United States Department of Defense, in a unique relationship that ensures NPS students and faculty are focused on critical and important problems facing the military. Our students bring firsthand knowledge of the challenges our organization faces, and leave our academic program as OR practitioners prepared to immediately meet those challenges.

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The Naval Postgraduate School's (NPS) Operations Research (OR) department is pleased to have received the 2013 INFORMS UPS George D. Smith Prize for "effective and innovative preparation of students to be good practitioners of operations research, management science, or analytics." In this paper, we discuss how we

1. maintain a close relationship with the U.S. Department of Defense (DoD);
2. prepare our students to be good practitioners of OR; and
3. impact DoD military operational efficiency and effectiveness by expanding the competent practice of OR throughout DoD.

The NPS OR program is designed from the ground up to strengthen the bonds between our students and DoD (Air Force, Army, Marine Corps, and Navy), the Department of Homeland Defense (Coast Guard), and other government agencies. DoD is the largest business or governmental organization in the free world. NPS OR has many unique attributes; perhaps one of the most distinguishing characteristics, when compared to other universities, is that our faculty and students are all members of the industry we support. Our students are mid-level employees of this organization; they have already served operationally (most

have served in the military) from five to 15 years prior to attending NPS and will be employed immediately by our organization following graduation. They bring firsthand knowledge of the challenges our industry faces, and leave as OR practitioners ready to immediately meet those challenges.

Our foundation is our curricula that are specifically designed to meet the needs of DoD. Each curriculum within our department is sponsored and overseen by a DoD organization and is critically reviewed biannually by its sponsor to ensure rigor, applicability, and especially relevancy. Our curricula require additional organization-specific and DoD-relevant coursework not found in traditional OR programs, such as combat modeling, campaign analysis, strategy and policy, cost analysis, and search theory – skills that are both critical to our sponsors and are in keeping with the foundational roots of OR.

NPS OR students arrive as accomplished mid-level leaders and professionals who have achieved early success sufficient to earn them assignment to NPS and have much to contribute to our research and the DoD. Classes are held 48 weeks a year with two weeks off in July and December. Our more than 4,300 OR alumni represent all four U.S. military services and those of 56 other countries.

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Next, we provide background on NPS and our students, and discuss a representative degree program, our faculty, and brief summaries of some recent research.

About the Naval Postgraduate School

The Naval Postgraduate School was founded in 1897 as a graduate school in marine engineering at the Naval Academy in Annapolis, Maryland. It moved to its current location in Monterey, California in 1951.

The institution has four graduate schools and, in addition to OR and traditional engineering sciences, students may study operational and information sciences, information security, space systems, business and public policy, civil-military relations, stabilization and reconstruction, and regional studies. The mission of NPS (by law) is “to provide relevant and unique advanced education and research programs to increase the combat effectiveness of the United States and allied armed forces and to enhance the security of the United States.”

The resident student body is predominantly active-duty U.S. military officers (approximately 1,500 at any given time) drawn from all military services. It also includes approximately 300 foreign military officers from more than 50 countries and a small but growing contingent of mainly U.S. government civilians. NPS also has a large distance-learning program, with more than 1,000 degree-seeking students located all over the world. Most of our students are enrolled in Master of Science (MS) degree programs; PhD programs have long been offered to small numbers of students, however these programs are growing.

One distinguishing feature of NPS is that the vast majority of students are working military professionals (see Figure 1). On the days when they do not wear their uniforms, they look pretty much like students anywhere else—but they are not. NPS students fly jets and pilot ships and submarines. They are military acquisition specialists, logisticians, and engineers. Prior to coming to NPS, many deployed to dangerous places throughout the world, and after completing their education at NPS, many will deploy back to those dangerous places.

Within the OR department, we offer both MS and PhD degrees. In keeping with the structure and purpose of NPS, we have no undergraduates. Our degree

program started in 1951, making it the first OR degree program in the United States; see Assad and Gass (2011, Chap. 7) and Schrady (2001). Our programs are without peers in terms of the extent to which they integrate graduate education with a commitment to solving real military problems, and our programs have already been documented in the open literature; examples include Fricker (2008), Rosenthal (2007), and Washburn (1996).

In this paper, we focus on our typical student, enrolled in a resident Master of Science in operations research (MSOR) degree program. There are slight variations in the MSOR degree program depending on the student’s service (e.g., Army, Marine Corps, Navy, and occasionally Air Force and Coast Guard) and when that student enrolls in the program. We review and potentially update our program every two years; however, the variations are not major, so we describe a representative curriculum.

The operations analysis (OA) curriculum consists of eight quarters of coursework that can be preceded by a refresher quarter (see Figure 2). Most of the courses in our curricula cover topics similar to courses in civilian OR programs—computational methods, statistics and data analysis, stochastic models, linear and nonlinear optimization, network flows, simulation, and decision analysis; however, in our program, we enrich all of these with examples that relate to the students’ experience and the professors’ research. We also have topics that are not commonly found in other programs. In direct response to the needs of the organization that employs our graduates, these include combat modeling, campaign analysis, strategy and policy, cost analysis, and search theory. These courses help directly prepare our graduates to be practitioners. A recent *OR/MS Today* article (Kline 2012) describes the practical value of one of these courses.

A student must complete the core course requirements in the first five quarters. After completing this coursework, each student has a three-week period to travel to a military or other government activity to conduct research in person and collect data, gaining firsthand experience to support the thesis that the student must write. In the remaining three quarters, the student works on the thesis, while completing advanced coursework.



Figure 1: The NPS students pictured are (from left to right): a Chilean Navy Lieutenant, a U.S. Army Captain, a U.S. Navy Lieutenant Commander, a U.S. Marine Corps Captain, and a U.S. Air Force Captain. NPS students are from all U.S. military services and military services around the world; some are civilian government professionals.

It is essential that our graduates depart NPS not only with a strong theoretical grounding in all areas of OR, but also with experience in solving real problems, because many of our graduates will move directly into positions of responsibility in which they are immediately viewed as the subject matter experts in analysis.

NPS OR Students

As of September 2013, 128 students were enrolled in the resident MSOR degree program (113 officers from the U.S. Army, Navy, and Marine Corps and 15 international officers from six countries: Germany, Israel, Portugal, Taiwan, Tunisia, and Turkey). These resident “on board” numbers have remained consistent over the past decade. Approximately 55 students graduate from the MSOR program each year. Given our exceptional students, graduation rates at NPS are high when compared to most civilian universities. About 90 percent of our enrolled resident students complete the degree requirements. Many of those who do not complete the program are identified early in their studies and allowed to transfer to a curriculum viewed as a better fit.

Our students are unique in that we know a great deal about each of them when they arrive; we have detailed career and academic records and we know

what kind of work they will be doing when they graduate. While at NPS they receive full salary and benefits, including housing and healthcare for their families, and their duties are focused exclusively on graduate study. For most of these students, this will be the only time in their careers when their duties are so restricted. Their employers maintain close contact with us, providing regular feedback on the effectiveness of our graduates.

NPS OR students take their studies extremely seriously for many reasons. Two in particular stand out: First, many know that upon graduation they will be expected to practice OR in support of critical operations and potentially life-threatening situations. Second, their performance in the program directly impacts their career success and progression.

Our students have the opportunity to learn much from their classmates about other services, combat specialties, and countries. Each year, we start one cohort in the fall and another in the spring. The cohorts stay largely together, so strong friendships develop during classes, study sessions, and after-work social events that bridge military, service, and country differences. Because of student cohort cohesiveness, our faculty has an unusually clear view of material these students have already seen, who may be struggling, and who is excelling. Each cohort has a section leader—the senior U.S. military officer—who is responsible for his (her) classmates; therefore, communication with the faculty is quick and effective.

Our faculty treats teaching with as much urgency and importance as our students view their studies. Long office hours are the norm and we do not use teaching assistants. NPS OR faculty appreciates the investment being made in our students. To earn and keep the admiration and trust of students such as ours, faculty members must exhibit an extraordinary mastery of their scholarship and profession, as well as an intimate working knowledge of all military affairs. Faculty members frequently join students on experience tours and other travel.

When a faculty member addresses a classroom cohort of students, he (she) can be certain that sooner or later one or more of these students will be in a senior position to that of the faculty member. As an extreme example, one of our former students, Admiral Mike Mullen, was the chairman of the Joint Chiefs

Q0	MA 1113 (4-0) Single Variable Calculus	MA 1114 (4-0) Single Variable Calculus II	MA 1025 (4-0) Finite Math	OA 1600 (2-2) Introduction to Operations Research	
Q1	MA 3042 (4-0) Linear Algebra	MA 1118 (4-0) Multivariable Calculus	OA 3101 (4-1) Probability	OA 2801 (4-1) Computational Methods for OR	OA 2900 (1-0) Workshop
Q2	OA 3201 (4-0) Linear Programming	OA 3102 (4-2) Statistics	OA 3301 (4-0) Stochastic Models I	OA3304 (4-0) Decision Theory	OA 2900 (1-0) Workshop
Q3	OA 4202 (4-0) Network Flows and Graphs	OA 3103 (4-1) Data Analysis	OA 4301 (4-0) Stochastic Models II	OA 3302 (4-0) Simulation Modeling	OA 2900 (1-0) Workshop
Q4	OA 4201 (4-0) Nonlinear Programming	OA 4106 (3-1) Advanced Data Analysis	OA 4702 (4-0) Cost Estimation	OA 4333 (4-0) Simulation Analysis	OA 2900 (1-0) Workshop
Q5a	OA 4655 (4-0) Joint Combat Modeling	OA 4801 (3-2) Spreadsheet Modeling for Military OR	OA 3602 (4-0) Search Theory and Detection		
Q5b		OA 3900 (0-8) Experience Tour			
Q6	OA 0810 (0-8) Thesis Research	OA 4656 (4-0) Studies in Defense and Military OR	OA 4602 (4-0) Joint Campaign Analysis	NW 3230 (4-2) Strategy and Policy	
Q7	OA 0810 (0-8) Thesis Research	OA 4XXX Elective (4-0)	OA 4910 (4-0) Human Factors Case Studies in OR	NW 3275 (4-0) Joint Maritime Operations I	
Q8	OA 0810 (0-8) Thesis Research	OA 4XXX Elective (4-0)	NW 3285 (4-0) National Security	NW 3275 (4-0) Joint Maritime Operations II	

Figure 2: A typical MS degree requires eight quarters (two years), as this representative NPS OA curriculum course matrix shows. The first row shows a refresher quarter (Q0) for those students needing such. The following rows show each of the following eight quarters, with numbers such as (3-2) indicating three hours of instruction and two hours of laboratory weekly.

of Staff from October 2007 to September 2011. This provides a rather unique and very effective long-term quality-control feedback device.

We have other effective quality-control procedures. Each student must complete a detailed student opinion form (SOF) at the end of each course. The course evaluation system is double-blind; that is, faculty must submit grades before viewing the SOFs and students cannot see their grades until they have submitted their SOFs. Given that our students routinely evaluate subordinates for promotion and retention, we find the student feedback to be both meaningful and useful. Institutionally, these SOF scores are collected and compared among faculty and departments, and have consequence on faculty pay, promotion, and even retention. Outstanding faculty members are heralded.

Finally, each student is interviewed confidentially upon departure to elicit an overall view of the NPS

OR experience. These quality control measures are very effective in highlighting any situation or person needing attention.

After our students graduate, we expect that they will contact us later in their careers when problems arise that may benefit from the attention and experience of our faculty and current students. We encourage such reach back, and make it easy by the ready availability of phone, video teleconference, and email systems at unclassified and classified levels. Faculty, students, and graduates also actively participate with INFORMS and the Military Operations Research Society (MORS).

Experience Tour and Thesis

After completing core coursework for the first five quarters, each student has an opportunity to participate in a three-week experience tour at DoD or

other governmental organization. This is the student's opportunity to apply theory to a real-world problem, and it is a direct connection from the classroom to our industry. The student then spends the remaining time at NPS in advanced coursework and thesis research under the direct supervision of a faculty member. This combination of an experience tour with a thesis helps the student understand how to conduct independent analytical studies of military problems, provides low-cost support to various interested analytical organizations, requires the student to produce a complete and coherent document describing the work accomplished, and connects us with the military analytical community. The unique set of circumstances we have created at NPS makes this possible and prepares our graduates to be practitioners. Many other programs have described the benefits of such practical experience. We recommend a recent two-part special issue published in *INFORMS Transactions on Education* for more details; see Lowe and Armacost (2012, 2013) for summaries.

A wide variety of experience tours is available to our students; these broadly fall into three categories: First, some experience tours are based on long-standing relationships between our department and various DoD analytical agencies. Second, some tours are based on the student's past experience. Many students arrive at NPS with a desire to improve some aspect of a past assignment, or an early classroom experience coupled with their professional experience suggests a topic. Third, some tours are based on faculty research efforts. NPS faculty members conduct DoD-sponsored research for a wide range of organizations, and frequently send students they advise to these organizations to develop thesis topics that support the broader research efforts of faculty members.

Several conditions exist at NPS that enhance our students' practical experience. First, the faculty recognizes and embraces the value of applied work. This appreciation for the applied permeates the entire school and has created a culture that makes the experience tour and thesis a main effort in the department. Without this culture, the process would not work. Second, over the years, we have established strong working relationships throughout the DoD analytical community. These efforts have taken time and energy and continue to require our attention; however, they

provide invaluable advantaged access for both our students and faculty. Third, we provide students the time necessary to experience the real world and solve their chosen problem. This entails a significant cost. For example, because of the time away for the experience tour and the thesis research hours at NPS, students miss the opportunity to take additional courses. In addition, our faculty spends a lot of time tutoring and advising our students; we view this as an essential investment.

The department celebrates student OR practice each quarter with a competition among graduates for the MORS-Tisdale award for the student whose thesis demonstrates the greatest impact of OR on DoD. (The award is named for Navy Commander Stephen Tisdale, a distinguished graduate of our program and aviator who died in an operational accident.) The MORS-Tisdale competition involves the nomination of worthy students and culminates in an oral presentation of each nominated student's thesis research to the entire department student body and faculty.

The recent MORS-Tisdale winners listed next and their associated thesis topics (the one marked "C" is classified) represent a sample of the breadth, range, and relevancy of their research. Note the following abbreviations: Lieutenant Commander (LCDR), First Lieutenant (1stLt), Major (Maj), Lieutenant (LT), Captain (Cpt), U.S. Navy (USN), Air Force (AF), and U.S. Marine Corps (USMC).

- LCDR J. Ryan McLaughlin, USN: Optimizing Adversary Training and the Structure of the Navy Adversary Fleet.
- 1stLt Begum Ozcan, Turkish AF: Effectiveness of UAVs in Helping Secure a Border Characterized by Rough Terrain and Active Terrorists.
- LCDR Walter Kulzy, USN: Modeling and Evaluating Indigenous Populations' Support for their Government and Life Satisfaction.
- Maj Michael Kevin Chankij, USMC: Assessing Resiliency of the JP-8 Distribution System on Guam (C).
- LT Matthew T. Yokeley, USN: Effects of Sleep Deprivation on U.S. Navy Surface Ship Watchstander Performance using Alternative Watch Schedules.
- LT Leslie A. Sloomaker, USN: Countering Piracy with the Next Generation Piracy Performance Surface Model.

- Cpt Maro D. Enoka, USMC: Optimizing Marine Security Guard Assignments.
- Cpt Joseph D. Rix, USMC: Modeling and Visualizing Complex Survey Results: An Application to Counter Terrorism in the Sahel.

Curriculum Sponsor Reviews

Every two years, our sponsor, the Assessments Division in the Office of the Chief of Naval Operations (i.e., OPNAV N81), reviews the content of the OA curriculum in a formal, two-day, on-site session. The curriculum review, which includes an evaluation and assessment of all facets of the program, serves a variety of purposes, the most important of which is ensuring that our program continues to meet the needs of the primary industry we support—the U.S. Navy. Results of the curriculum review have high-level visibility; the NPS president validates and approves them and the NPS provost has oversight responsibility for the entire process.

Prior to the on-site session, as part of the curriculum review, the department and sponsor conduct an assessment and validation of sponsor and other Navy stakeholder requirements, a review of current educational goals and degree requirements, and an evaluation of the design and execution of the existing curriculum. A particular focus of this part of the curriculum review is an assessment of our educational skill requirements (ESRs), which explicitly codify the educational goals of the OA curriculum. These ESRs—there are currently eight—define the broad areas of knowledge and skills a graduate should possess to function effectively as an OR professional for our sponsor. Simply put, the ESRs state that we and our sponsor agree on that our graduates will be able to do as practicing OR professionals; thus, in large part, they define the minimum scope of our curriculum. In terms of the UPS George D. Smith Prize, we note that OR practice has always been an ESR in the OA curriculum. The current practice ESR reads: “The graduate will have gained experience working in all aspects of an analytical study and will demonstrate the ability to conduct independent analytical studies and proficiency in presenting the results both orally and in writing.”

Once complete, the two-day on-site curriculum review includes an evaluation of progress toward

meeting or achieving the specific actions from previous curriculum reviews and a discussion of future sponsor needs and requirements, which may result in changes to the ESRs and (or) the curriculum. The curriculum review additionally examines a department’s foundation for providing a quality program, including issues related to faculty, research programs, and resources. This examination includes confidential interviews of current students, graduates, and employers of our graduates. The resulting report from the curriculum review explicitly lists areas in need of improvement or change, if any; any actions resulting from the review are formally documented in a letter signed by the curriculum sponsor and the NPS president (among others).

A significant benefit of our curriculum review is that it ensures the department is aware of our industry’s needs and requirements. Some in academia may wonder whether this process could have the unintended effect of putting too much emphasis on the practical needs of industry at the expense of curriculum academic rigor. We have found that, properly conducted, the process results in a healthy dialog in which faculty interests in academic rigor and sponsor interests in practical skills are balanced appropriately.

Most importantly, the curriculum review helps ensure that we enjoy a special relationship with our sponsors, which may be unique in graduate education. Conducting biennial reviews, and otherwise maintaining this relationship takes time and effort; however, it provides an invaluable connection to ensure our graduates are appropriately prepared to become practitioners. As we discuss in the *Conclusions* section, we believe other academic institutions could benefit from instituting a process similar to our curriculum review.

The NPS OR Department and Focus on OR Practice

The NPS OR department has a three-fold mission:

1. Educate analysts who are fully capable of conducting independent analytical studies of military problems, and provide an educational basis for continued learning and development;
2. Develop and maintain a world-class research program in OR and related areas; and

3. Provide OR and general analysis support to DoD.

The NPS OR department is one of the largest in the United States, with about 50 faculty members, including three members of the National Academy of Engineering and many fellows of INFORMS and other professional societies. Three-quarters of the faculty hold PhDs in OR or a related discipline (e.g., mathematics, statistics, computer science); most of the faculty members without a PhD are military faculty who have deep military operations and applied OR experience.

Although all NPS OR faculty members have familiarity with and competence in OR practice, one of the strengths of our faculty is the background in practical OR application it brings to the classroom. We currently have eight active-duty military faculty (five Navy, two Army, and a Marine) with diverse educational and operational experience. Three members of the military faculty have PhDs earned in OR-related disciplines. The rest have MSOR degrees earned from NPS, and return to NPS only after serving at least one tour as a practicing military analyst. Each military faculty member typically spends three to six years on our faculty. The wealth of firsthand information they bring regarding the relevancy and value of our curricula, combined with the real-world challenges DoD is currently facing, is extremely valuable in associating the material we teach with how to apply it to the requirements.

In fiscal year 2013, the OR faculty brought in more than \$10 million in research funding (a sum that is all the more significant given that none of our students need support), all focused on the development, implementation, or practice of OR. A typical faculty member brings in at least one-quarter of external research support (i.e., total compensation) each year, and on average two. Some faculty members are fully supported by their research funding. About half of this funding comes from Navy organizations other than NPS, more than one-third comes from the Army, and the remainder is from other DoD organizations. This research funding includes both applied research that directly assists a DoD organization and pure research. Sponsors include the Air Force Office of Scientific Research, Army Research Office, and Office

of Naval Research. This funding is critical for keeping OR faculty focused on the issues that our DoD sponsors want addressed. The faculty also publishes widely in the open literature (e.g., *Science, Operations Research, Interfaces, Military Operations Research*, and *Naval Research Logistics*) and technical reports, including a significant volume of classified work. Some of these publications have become seminal references in OR worldwide. Others appear “in every wardroom” (commissioned officers’ mess, that is, dining room and meeting room aboard a warship) because of their military value.

Since 1996, *Interfaces* has published 10 rankings of universities that contribute to the INFORMS practice literature. These rankings are now referred to as the Rothkopf rankings in honor of the late Mike Rothkopf, their originator. In the 10th set of Rothkopf rankings (Fricker 2013), NPS was ranked first among all U.S. universities based on the number of papers published (i.e., the “yield” metric). NPS ranked first among all universities worldwide in a combined ranking of universities within and outside of the United States for yield. In addition to the most recent ranking, NPS has been a consistent leader in its contributions to the practice literature: “among all U.S. universities, only the Naval Postgraduate School has ranked in the top six for all the rankings since 2002” (Fricker 2011, p. 593). From the fifth rankings: “Over the five rankings, some schools have been consistent performers. Four schools have always been in the top 10: MIT, the Naval Postgraduate School, Stanford University, and Temple University” (Rothkopf 2004, p. 137).

Improving the Effectiveness and Efficiency of DoD Operations

Next, we include examples of faculty and student research that have resulted in far-reaching positive impact on both the effectiveness and efficiency of DoD operations. These research efforts are supported by extensive student involvement, especially through thesis research. A video presentation of some of these and other research projects is available at http://www.youtube.com/watch?v=V-icP_8QIH4&feature=plcp. This video was produced for the October 2012 INFORMS Annual Meeting in Phoenix, Arizona.

Steaming on Convex Hulls

NPS faculty has developed and patented, and NPS students have improved and used, a method to save fuel on Navy ships that have alternate propulsion plant configurations (Brown et al. 2007, 2011). One such ship is the new USS *Freedom* (LCS-1), first in a littoral combat ship class. She has both a pair of fuel-efficient diesel engines for slow speeds and a pair of fuel-thirsty gas turbines for fast speeds. She can operate on any one engine, or any combination of all engines. To achieve an average speed for a given transit distance and time, she may save fuel by using one fast configuration for some fraction of time, and another slower one for the remaining time. The fuel savings, which can be significant, can be used to either reduce operating costs or extend mission endurance. The optimal configurations and throttle settings can be posted on a small placard on the bridge and in the engine spaces. Recently, students have generalized these results to include considerations of current direction and speed, wind direction and speed, and sea state.

Replenishment at Sea Planner

The U.S. Navy will consume more than 600 million gallons of fuel this year, operating its ships around the world. It supplies these ships while they are underway at sea to maximize presence and mission effectiveness. A small fleet of supply ships in the combat logistics force loads fuel and commodities in any port with which the U.S. Navy has such arrangements, and deploys to meet customer combatant ships operating at sea. The distances are very long and the ships are relatively slow. This is a multiple traveling salesman problem with moving customers, where the Navy may consume a gallon of fuel to deliver one. The sole degree of freedom for responding to any schedule mistake or surprise is to speed up, and fuel consumption rises dramatically (super-linearly) with ship speed. A human planner cannot be expected to manually solve this problem with time fidelity of a watch (four hours) over a planning horizon that may span weeks ahead.

NPS faculty and thesis students have developed the Replenishment at Sea Planner (RASP), an optimization-based decision support system consisting of an Excel graphical user interface, embedded optimization model, and visualization tools

that include animations on Google Earth displays. The system, which has been deployed to 5th Fleet, Bahrain, and 7th fleet, Singapore, saves a significant amount of money. Analysis shows that the key seems to be that RASP recognizes customer needs and locations that are far into the future and adjusts its near-term schedule in anticipation. The system will be deployed to 6th Fleet, Naples, and to all the other numbered fleets, with NPS providing reach-back support. Student involvement includes more than 15 student theses that started at the beginning with the precursor combat logistics force planner (Brown and Carlyle 2008), which has evolved into RASP.

One unanticipated product of this research is a new algorithm to quickly determine the shortest great-circle path from any navigable point on the planet to any other, while avoiding obstacles. This has been installed on all Navy combatants as a stand-alone planning tool, and a U.S. patent is pending.

Theater Ballistic Missile Defense: Joint Defender

To counter increasing theater ballistic missile threats from a number of adversaries, the United States has developed missile defenses including: Navy AEGIS, originally a shipboard system with an extremely powerful phased-array radar capable of detecting and tracking attacking missiles at very long ranges, and a variety of mid-course anti-missile interceptors, such as the SM-3; Army patriot batteries with terminal defense interceptors; Army terminal high-altitude area defense (THAAD) batteries with extended-range terminal defense interceptors; and a number of other test systems. The first three systems are fielded (i.e., in possession, training, and use by our military forces) and work well.

Joint defender (JDEF) advises how these disparate sea- and land-based systems can, or could, be employed in a unified defense of a set of high-value defended assets (i.e., targets such as population centers or military installations). JDEF has been enhanced by a score of NPS students, who have added increased fidelity, deployed to advise theater commanders on defensive tactics, and evaluated suggested improvements in our defensive hardware and its employment (Brown et al. 2005).

Planning Intratheater Military Airlift in Iraq and Afghanistan

The air tasking and efficiency model (ATEM) has been used since 2006 to plan and evaluate intratheater airlift of passengers and palletized freight for Operation Iraqi Freedom in Iraq and Operation Enduring Freedom in Afghanistan. ATEM plans routes and route configurations (i.e., capacity of passenger seats and pallet positions) for a heterogeneous fleet of aircraft flying between multiple airfields. ATEM respects limits on crew duty periods, times and abilities of each airfield to handle and fuel each aircraft type, and aircraft speed and carrying capacity. Initially, ATEM advised improving daily and weekly route ensembles, conveying more passengers and pallets, and using fewer aircraft than prior manually generated solutions recommended. Later, ATEM advised where to advantageously move aircraft to new home airfields, how to shift aircraft between theaters, and when to bring aircraft home from war. Although the use of ATEM has saved money, improved aircraft utilization has reduced the required number of ground convoys, reducing their exposure to improvised explosive devices, thus saving lives.

This project was initiated by a NPS MSOR graduate reaching back to NPS, and required civilian faculty to fly into the war zone. Student thesis work later produced another planning system for helicopters, an even more complex problem (Brown et al. 2013, Wray 2009).

NPS Optimized Watchstanding Schedule

According to the Naval Safety Center, sleep deprivation and fatigue are major causal factors in many Navy mishaps. In addition to sleep deprivation, fatigue can also result from inadequately staffed vessels. Reduced staffing levels increase sailors' daily workload because they must work longer hours to compensate for absent shipmates. These longer work hours come at the expense of sailors' daily scheduled activities, including sleep and training, both critical determinants of safe and productive operations.

At NPS, a series of studies aboard U.S. Navy surface combatants has explored sailors' work and rest patterns and alertness levels. The results of these studies have been used to design alternative watchstanding schedules (i.e., personnel schedules to continuously provide command guidance, and operate a

ship's maneuver, sensing, propulsion, and weapons systems around the clock) that are being tested on multiple Navy ships. These alternative watchstanding schedules have received consistently high marks from sailors. The program of research informs the U.S. Navy senior leadership about the usefulness of alternative watchstanding schedules and improved shipboard staffing strategies, and is expected to result in improved morale, enhanced safety, and more effective systems. This continuing research effort has included the work of 28 MS students, a PhD student, two postdoctoral fellows, and faculty (Miller et al. 2012), and is another example of NPS OR faculty deploying into combat areas to conduct research.

Center for Infrastructure Defense (CID)

The principal activity of the Center for Infrastructure Defense (CID) is to develop new theoretical and applied analysis techniques to understand how regional and national infrastructure systems respond in the face of major disruptions, whether deliberate or nondeliberate events. It focuses on the "continued operation of critical military and civilian infrastructure in the presence of accident, failure, or attack" (Naval Postgraduate School 2013). CID addresses both long-term and emergent issues related to national and international infrastructure systems to make these systems resilient to such disruptions. CID has completed 150 red team case studies (many are student theses) on infrastructure by viewing domestic critical infrastructure through the eyes of intelligent adversaries. (A red team is a group that independently investigates facts at hand, and may challenge existing decision protocols or suggest alternatives to standard courses of action; red teams are often specifically charged with assessing a problem or determining courses of action from an adversary's perspective.) This research has resulted in identifying the fragility of systems and making recommendations on where to mount effective hardening and defensive efforts.

Simulation, Experimentation, and Efficient Designs (SEED) Center for Data Farming

The SEED Center for Data Farming (<http://harvest.nps.edu/>) was created to address the high dimensionality inherent in models of real-world phenomena

by developing, advancing, and disseminating experimental designs that facilitate the exploration of complex simulation models. The center provides unique research and support for faculty and students, U.S. Armed Forces, and our allies. In addition, it leverages strong ties with international military and civilian simulation communities. Recent research initiatives include a series of international workshops; in addition, more than 50 students successfully completed their thesis research in the past three years.

Sanchez et al. (2012), a paper by researchers from the SEED Center, received the 2013 INFORMS Koopman Prize (awarded for the outstanding publication in military operations research during the previous year). The paper describes state-of-the-art design of experiments for simulation models using an unmanned aerial vehicle (UAV) case study; it includes the following quote by Michael F. Bauman, director of the U.S. Army Training and Doctrine Command Analysis Center, attesting to the impact: “The UAV modeling...harvested \$6 billion in savings and 6,000 to 10,000 billets, that’s a brigade’s worth of soldiers. Over 20 years that allowed us to avoid a cost of \$20 billion” (Sanchez et al. 2012, p. 437).

Influencing Policy via Operations Research

The NPS OR department practices OR to constructively influence not just tactics, operations, or strategy, but high-level policy. We know we have succeeded because of feedback from our students who have become general or flag-level officers. Scott Redd, (http://en.wikipedia.org/wiki/John_Scott_Redd), who graduated from the NPS-MSOR program in 1983, is a good example. While in uniform, he held many senior policy positions, persuaded Navy leadership to create our 5th Fleet in the Middle East, headquartered in Bahrain, and was appointed by President Bush after 9/11/2001 to create the National Counter Terrorism Center. He advises:

“Donna and I spent two years here at the Postgraduate School and, as it turned out, this was our last family-friendly tour before the 20-year sprint to Navy retirement. They were two of the best years of our lives... Remember that platitude we all espouse about the value of education? That the real value of education is not in the specific skills we learn but in the

mental disciplines we develop? Well it’s true. And not only that, I would submit to you that some of the best policy people I know come out of a quantitative discipline....

ORSA has a key role to play... In fact, in today’s world of sound bites and short news cycles, your role is even more important. There are lots of reasons for that, but the primary one is this. At the end of the day, in the real world, function triumphs over form, and substance triumphs over style.

And ultimately that’s true, even inside the beltway!” (Redd 2011)

Admiral Mike Mullen, former chairman of the Joint Chiefs of Staff, has been quoted several times on the value of his OR education. One such quote is as follows.

“I think the operations research curriculum I went through is one that’s very relevant to what we do in the Navy. ... I’ve used it in three significant tours in the Pentagon. I’ve also used it at sea and war fighting. What the curriculum taught me to do was to properly frame a problem, ask the right questions, to assess risk and to move on from there.” (Mullen 2014)

In addition, see Horner and List (2010) for an interview with Mullen describing the benefits of his OR education.

Conclusions

Returning to the purpose of the Smith Prize—to motivate programs to share their successful practices and document these practices in the open literature, readers of this paper may be wondering how they can apply unique aspects of our military-specific program to civilian academic programs. Once the specific defense-related terminology and other aspects are stripped away, much of our program structure has potential applicability and relevance for programs seeking to improve their “effective and innovative preparation of students to be good practitioners of operations research, management science, or analytics.” Here, we discuss some examples.

- Program evaluations: Biannual program evaluations by our sponsors is a requirement for us. They can sometimes present us with challenges, such as having to negotiate accommodating sponsor needs within our academic requirements; however, they are very useful overall because they ensure that we stay in touch with our industry’s requirements and

desires. Although a civilian academic program is unlikely to have an industry-sponsor arrangement similar to ours, it may benefit if administrators of such civilian programs periodically invite representatives from key industries (e.g., those industries in which many of the institution's students will be placed) to campus to meet and discuss industry needs and requirements. In so doing, the department would be armed with better information about how well its program is serving the needs of industry and could adjust as desired.

- **Military faculty:** Because we are literally a part of the organization we serve, we have access to OR practitioners within the organization and have the ability to bring some of those practitioners directly into our faculty. What makes these military faculty members unique from, for example, adjunct faculty, is that they are full-time members of the department while in residence and have expertise in the day-to-day practice of OR within DoD. Thus, their status as active-duty military is only relevant because that is the industry we serve. For civilian programs, the equivalent would be bringing practitioners from the industries served onto the faculty for a few years, perhaps under an extended sabbatical or fellow program for qualified industry employees. The immediate outcome of such an arrangement is a natural increase in the connections of the faculty to the industry from which research problems and other benefits are likely to follow.

- **Faculty research:** One of the reasons for our large faculty is that we expect the faculty to both teach and conduct research, including practicing OR within the DoD, in roughly equal measure. That is, for pay purposes, we expect our faculty members to teach roughly half of the time and conduct relevant OR research the other half. Given that we hold classes year-round, this translates into two quarters in the classroom and two quarters doing research. The purpose of the research is to ensure that the faculty stays at the forefront of DoD issues, problems, and practices, and brings that research back into the classroom to enhance the relevance of the material we teach. Although this can be applied directly to civilian programs, we should consider a few important points. First, much of the research must relate back to the

relevant industry or industries, both in terms of substance and practice. This will require establishing and maintaining close ties to those industries. Second, the scale of the research exceeds the usual month or two of summer research funding typical of many civilian institutions. This, then, requires a larger faculty and additional funding; however, as a research program expands, both follow naturally.

- **Student theses:** As we discuss previously, we require each MSOR student to complete an individual thesis. This places a significant burden on the faculty, but that is mitigated by having a larger faculty and because many students work directly on faculty research projects. When the latter occurs, it provides a triple benefit: the effort that the faculty members put into thesis supervision directly benefits their research, the students often bring critical industry-specific knowledge to the research effort, and the students have direct access to DoD-relevant research problems. That is, the requirement for faculty to maintain large, active, industry-relevant research portfolios naturally results in many student-thesis opportunities. Because the students do superior work, the resulting theses generally help satisfy the faculty's research requirements and deliverables.

In closing, we wish to express our gratitude to INFORMS and the 2013 UPS George D. Smith Prize committee for selecting the NPS OR department for this prestigious prize. We hope this paper provides other programs with useful practices, developed over more than 60 years, which we have found to be effective for preparing students to be good practitioners of OR.

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Editor's Note

In 2012, INFORMS established the UPS George D. Smith Prize to strengthen ties between industry

and higher education. The prize is awarded annually to an academic department or program for effective and innovative preparation of students to be good practitioners of operations research, management science, or analytics. The prize is named in honor of George D. Smith, the late UPS Chief Executive Officer, who was a champion of operations researchers. UPS has generously underwritten the award in his memory. Part of the motivation for the prize is to encourage the sharing of best practices among academic programs, particularly those practices that increase and improve the connections between academia and industry, and to document these practices in the open literature.

References

- Assad A, Gass S (2011) *Profiles in Operations Research: Pioneers and Innovators* (Springer, New York).
- Brown G, Carlyle WM (2008) Optimizing the U.S. Navy's combat logistics force. *Naval Res. Logist.* 55(8):800–810.
- Brown G, Carlyle WM, Dell RF, Brau JW (2013) Optimizing intratheater military airlift in Iraq and Afghanistan. *Military Oper. Res.* 18(3):35–52.
- Brown GG, Kline JE, Rosenthal RE, Washburn AR (2007) Steaming on convex hulls. *Interfaces* 37(4):342–352.
- Brown G, Carlyle M, Diehl D, Kline J, Wood K (2005) A two-sided optimization for theater ballistic missile defense. *Oper. Res.* 53(5):745–763.
- Brown GG, Kline JE, Rosenthal RE, Menconi P, Washburn AR (2011) Mixed mode fuel minimization. U.S. Patent 8,050,849 B1, filed February 10, 2009, issued November 1, 2011.
- Fricker RD (2008) Looking for a few good statisticians: Being a government statistician at the Naval Postgraduate School. *Amstat News* 374(August):31–32.
- Fricker RD Jr (2011) Editorial: The ninth Rothkopf rankings of universities' contributions to the INFORMS practice literature. *Interfaces* 41(6):590–598.
- Fricker RD Jr (2013) Editorial: The 10th Rothkopf rankings of universities' contributions to the INFORMS practice literature. *Interfaces* 43(6):572–577.
- Horner P, List B (2010) Armed with O.R. *OR/MS Today*. Accessed January 8, 2015, <http://www.lionhrtpub.com/orms/orms-8-10/frqanda.html>.
- Kline J (2012) Innovative education: Shaping tomorrow's problem solvers. *OR/MS Today* 39(4):26–29.
- Lowe JK, Armacost AP (2012) Editorial—Introduction to the special issue: Student projects with industry. *INFORMS Trans. Ed.* 13(1):1.
- Lowe JK, Armacost AP (2013) Editorial—Introduction to part 2 of the special issue: Student projects with industry *INFORMS Trans. Ed.* 13(2):67.
- Miller N, Matsangas P, Kenney A (2012) The role of sleep in the military: Implications for training and operational effectiveness. Laurence J, Matthews MD, eds. *The Oxford Handbook of Military Psychology* (Oxford University Press, New York), 37–52.
- Mullen MG (2014) Quote. Accessed January 8, 2015, <http://www.nps.edu/Academics/Schools/GSOIS/Departments/OR/index.html>.
- Naval Postgraduate School (2013) Center for infrastructure defense. Accessed October 5, 2014, <http://www.nps.edu/cid/>.
- Redd S (2011) Plenary speech at the 79th MORS symposium. *Phalanx* 44(3):11–15.
- Rosenthal R (2007) It's more than a job or an adventure. *OR/MS Today* 34(4):22–28.
- Rothkopf MH (2004) Editorial: The fifth *Interfaces* ranking of universities' contributions to the practice literature. *Interfaces* 34(2):135–138.
- Sanchez SM, Lucas TW, Sanchez PJ, Nannini CJ, Wan H (2012) Designs for large-scale simulation experiments, with applications to defense and homeland security. Hinkelmann K, ed. *Design and Analysis of Experiments, Vol. 3: Special Designs and Applications* (Wiley, Hoboken, NJ), 413–442.
- Schradly D (2001) Golden anniversary: Fifty years of graduate education in operations research at NPS produces 3,300 alumni worldwide. *OR/MS Today* 28(1):38–41.
- Washburn A (1996) The teachers' forum: The operations analysis curriculum at the Naval Postgraduate School. *Interfaces* 26(5):71–80.
- Wray JD (2009) Optimizing helicopter assault support in a high-demand environment. Master's thesis, Naval Postgraduate School, Monterey, CA.

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