The Teachers' Forum: The Operations Analysis Curriculum at the Naval Postgraduate School

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Now in its fifth decade, the operations analysis curriculum at the Naval Postgraduate School is one of the oldest and most respected masters programs in OR/MS in the United States. In this article, Alan Washburn describes the origins and evolution of the program and compares it to the ORSA/TIMS "model" curriculum [Dyer et al. 1993].

The operations analysis program at NPS is unlike most other masters programs in its exclusive connection with the military. However, what is most interesting about this program to an outsider is its "intimate relationship with a customer who pays close attention to the fate of graduates." The scrutiny and feedback this program receives from the employers of its graduates must be a major factor behind its long-term success. Those of us who teach in nonmilitary programs typically have more distant relationships with our "customers": employers and other faculty who rely on us to teach quantitative skills. While we can envy the close customer contact at NPS, perhaps we can also emulate it through closer contacts with our various customers.

—*Stephen G. Powell*

The operations analysis curriculum at the Naval Postgraduate School has responded to a variety of pressures for change in the 45 years since its founding, and its managers have continually wrestled with the theory-versus-practice question that has recently preoccupied ORSA/TIMS and INFORMS. Even though NPS is almost unique among graduate schools on account of its navy sponsorship, our experiences may still be of interest to others.

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The Naval Postgraduate School (NPS) can trace its history back to 1897, when the Naval Academy initiated a course in naval construction in response to the British Board of the Admiralty's decision to exclude foreigners from its Naval College [Rilling 1972]. NPS still maintains a successor curriculum called naval/mechanical engineering, but by now it has been joined by 38 other curricula in a wide variety of scientific fields, one of which is the operations analysis (OA) curriculum. Most students are US Navy officers, but significant numbers are from other services and other countries (Figure 1). The international group includes students from over 30 countries (including Great Britain!).

Curricula range in length from 18 to 36 months, with OA having the median length of 24 months. Completion of his (or her—nine percent of NPS students are female) assigned curriculum qualifies a navy officer in a *subspecialty*. Formally, this subspecialty qualification—not the award of a master's degree that usually occurs simultaneously—is the justification for graduate education. However, all navy officers attending NPS do so voluntarily, since each must commit to remaining in the navy for a certain period of time after graduation, and the award of a degree plays a strong motivational role because of its importance in the civilian world that every officer must contemplate reentering some day.

The typical navy officer-student spends about five years on active duty after obtaining a bachelor's degree and before entering NPS. The bad news about these five years is that the first six months of most curricula must be devoted to essentially undergraduate material so that students can refresh or update what has atrophied or become out of date in the meantime. The good news is that the five years bring a maturity of judgment and an awareness of potential application areas that are of great value when it comes time to write a thesis, as nearly all curricula require. Students are paid at the customary rate for their rank throughout their tenure at NPS, so most of the cost to

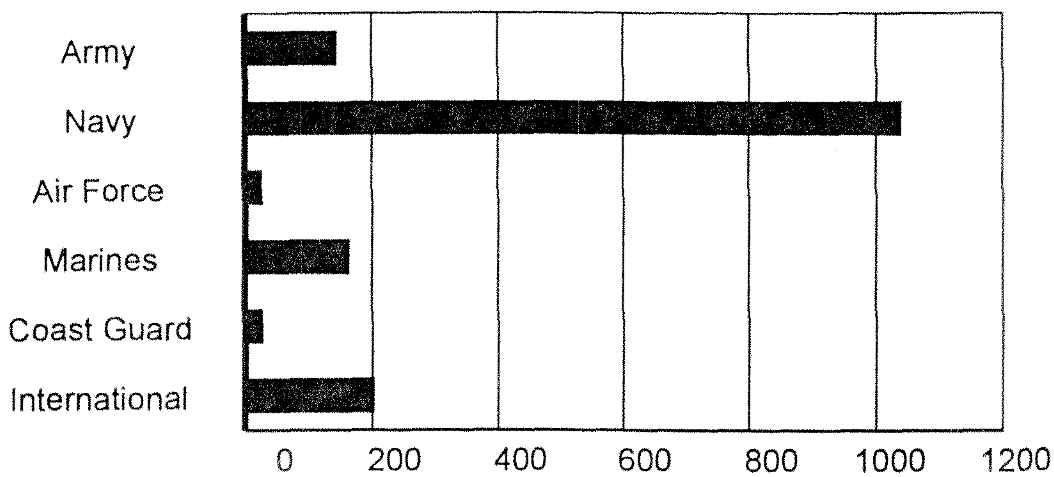

Figure 1: The 1,600 students currently enrolled at NPS are partitioned into six groups.

the services of graduate education for their officers is actually in student salaries. Students are in school during all four of NPS' yearly quarters, lest this cost be even larger. A *quarter* is 12 weeks long, leaving four weeks per year for breaks.

Most of the 400 faculty members at NPS are civilians, and it is the faculty who manage NPS curricula in the short term. The Navy interacts only a little with the faculty

A letter from a high-ranking officer that one's work has made a difference can be very influential.

on a daily basis, but still maintains quality control of curricula through a series of biannual reviews conducted by each curriculum's *sponsor,* a Navy officer charged with ensuring the well-being of the associated subspecialty. If the sponsor determines that graduates lack some capability or that some other capability turns out not to be useful, then he will describe the problem and expect a correction. This intimate relationship with a customer who pays close attention to the fate of graduates is one of the things that distinguishes NPS from other graduate schools; the customer has a formal feedback mechanism and, if necessary, ultimate power over the curriculum. The relationship between the faculty and the sponsor is perhaps similar to the relationship between the management and board of directors in a corporation, except that the sponsor replaces profitability with "suitability of graduates for the subspecialty jobs we have identified for them."

Partly because NPS wishes to remain an attractive destination for new faculty, it structures academic life to be similar to that at other graduate schools. Faculty are organized into 11 departments, such as mechanical engineering and OR. Faculty members are expected to do research, and they must seek research sponsors and publish the results. In fact, Woolsey and Maurer [1995] link us (the OR department, that is) with Stanford, Berkeley, University of Southern California, UCLA, and MIT as schools interested in "pushing back the frontiers of theory in OR." They are correct. The tendency of OR graduate curricula to be overly theoretical is sometimes blamed [Geoffrion 1992] on requirements for faculty to publish. We claim that our curricula are more on the practical side, but this practical bent does not stem from lack of a desire to push back frontiers.

Another reason sometimes given [White 1991] for overly theoretical OR curricula is that terminal master's students must usually share classes with students for whom the master's degree is just a stepping stone to a PhD. NPS does offer a PhD in OR, but the number of PhD students is so small (one or two in residence) that that kind of influence is unlikely.

The promotion-and-tenure process at NPS is conventional in the sense that proposals originate in the individual's department and propagate upwards through multiple administrative levels. NPS criteria (in all fields) have shifted over the last decade to provide more weight to applied work—a letter from a high-ranking military officer to the effect that one's work has actually made a difference can be very influential. NPS has a well-organized system for collecting student feedback about teaching.

Summaries of this feedback play an important role in promotion and tenure decisions, as is natural given the maturity of the students.

History and Current Status of the OA Curriculum

In 1951, at its founding, the OA curriculum was supported mainly by the physics and mathematics departments—there was no OR department then. The original two-year curriculum included six months devoted to practical work that was expected to lead to a thesis. It also included 11 semester-length courses in physics. The physics courses have since been gradually displaced by an experience tour and by additional courses in probability and statistics, computer programming, optimization, human factors, and economics, a process that accelerated when the OR department was created in 1961. The last physics course disappeared in 1993. This displacement of physics was also occurring elsewhere within the OR profession at about the same time [Larson 1992]. It is the biggest qualitative change in the curriculum since its founding, but there have also been others.

The student population increased about five-fold in the 1960s ("the McNamara years"), and the sponsor began to emphasize systems analysis in defining the subspecialty. The curriculum was renamed the operations research systems analysis (OR/SA) curriculum in 1965, and the course mix changed correspondingly. A decade later, part of the navy became concerned that tactical development was languishing. It was suggested that a new curriculum was needed, and there was a debate about what to do. In the end, it was decided to increase the OR/SA tactical content and change the name of the curriculum back to the more neutral operations analysis (OA). A similar concern with logistical planning led in 1986 to the creation of a new operational logistics (OL) curriculum, with a separate sponsor, rather than a modification of the OA curriculum. OL graduates take many of the same courses as OA graduates and get the same OR master's degree, but they qualify for a different subspecialty and therefore for different jobs. Currently about 15 officers per year graduate from OL, compared to about 60 per year from OA.

The OA curriculum permits a small amount of flexibility in the form of "options," all of which lead to the same subspecialty and the same degree. For example, the land combat option was developed when army students were accepted in 1965. The joint and naval warfare option (Table 1) is taken by most army and navy officers, and is therefore the most popular. The presence of the cost estimation course testifies to the influence of the sponsor: the course is not new, but it has not always been required. Attendance at a series of application-oriented seminars on topical subjects is also required.

The OA curriculum is serviced by several departments, but most of the teaching (all of the OA courses in Table 1) is done by faculty in the OR department. The OR department includes 40 faculty members, most of whom hold PhD degrees, plus three chairs in applied systems analysis, tactical analysis, and joint warfare. Nine of the 40 faculty are military—seven navy and two army. The navy instructors occupy seven of the 167 jobs in the navy's OA subspecialty. The civilian faculty can be roughly divided into stochastic types, op-

1	OA2200 (4-0) Computational Methods I	MA1118 (5-2) Multivariable Calculus	MA3402 (4-0) Linear Algebra	OA3101 (4-1) Probability
2	OA3200 (4-0) Computational Methods II	AS3610 (4-0) Micro Economics	MA3110 (4-0) Intermediate Analysis	OA3102 (4-1) Probability and Statistics
3	OA3201 (4-1) Linear Programming	OA3401 (4-0) Human Performance Measures	OA3301 (4-0) Stochastic Models I	OA3103 (4-1) Statistics
4	OA4202 (4-0) Network Flows and Graphs	OA3602 (4-0) Search Theory and Detection	OA3302 (4-0) OA Systems Simulation	OA3104 (4-1) Data Analysis
5	OA4301 (4-0) Nonlinear Programming		OA4655 (4-0) Air-Land-Sea Analysis	
	Experience Tour			
6	OA4301 (3-2) Stochastic Models II	OA4654 (4-0) Air-Land Models	OA4604 (4-0) Wargaming Analysis	Thesis Research
7	Elective	OA4602 (4-0) Joint Campaign Analysis	OA4603 (3-2) Test and Evaluation	Thesis Research
8	OA4702 (4-0) Cost Estimation	NS3252 (4-0) Joint and Maritime Strategy	Elective	Thesis Research

Table 1: Each row corresponds to one of the eight quarters of the joint and naval warfare option of the OA curriculum, with four columns because students take four courses in each quarter. The two courses in the fifth quarter are intense and short to make room for the six-week experience tour. OA courses are taught by OR faculty, others are not. The (M-N) notation means that there are M hours of lecture and N hours of lab per week.

timizers, and a third group that will admit to no label other than OR. The inevitable rivalry among these groups is usually good natured. We undertake a variety of research projects, both theoretical and applied, with the applications being mostly to problems within the Department of Defense. As a sampling of publications, the last five open literature publications in 1995 are listed below. The first names of OR faculty members are spelled out to distinguish them from non-NPS coauthors:

—Almeida, R.; Gaver, Donald; and Jacobs, Patricia., "Simple probability models for as-

sessing the value of information in defense against missile attack," *Naval Research Logistics*, Vol. 42, No. 4, pp. 535–548.
—Buss, Arnold and Lawrence, S., "Economic analysis of production bottlenecks," *Mathematical Problems in Engineering*, Vol. 1, No. 2, pp. 341–363.
—Kemple, William.; Sadler, P.; and Strauss, D., "Extending graphic correlation to many dimensions: Stratigraphic correlation as constrained optimization," *Graphic Correlation*, Keith Mann and H. Richard Lane, eds., Society for Sedimentary Geology, Tulsa, Oklahoma, pp. 65–82.
—Read, Robert., "The evolution of a selection system," *Naval Research Logistics*, Vol. 42, No. 7, pp. 1099–1114.
—Washburn, Alan., "Finite method for a nonlinear allocation problem," *Journal of Optimization Theory and Applications*, Vol. 85, No. 3, pp. 705–726.
The first paper is a military application (coauthor Almeida is a former OA student from Portugal's navy), the next two are nonmilitary applications, the fourth is a study of statistical questions arising in selecting the annual teacher of the year at NPS, and the last is a methodological paper motivated by a military application.

Operational Curricula

The OR department does nearly half of its teaching to students who do not receive the master's degree in OR. Much of this is service courses in probability and statistics—the relevant faculty were moved to the OR department shortly after it was formed. There are also service courses titled "Introduction to OR for xxxx," with xxxx including "management" and "naval intelligence." Each of these is a single quarter survey usually founded on a software package combining a variety of OR techniques, with applications tailored to the xxxx group of students. Most of these service courses would be familiar to any OR academic.

In some cases, the department's service is deeper than just a course or two. Beginning in 1972, NPS established several "operational" curricula, the first of which was the undersea warfare (UW) curriculum. UW students spend much of their time learning about sound propagation, signal processing, and oceanography, the technology of the UW world. Since the intent of the curriculum is to turn out warfighters rather than engineers, however, UW students also need to study the development and evaluation of tactics, software, and equipment. Consequently the UW curriculum includes several courses taught by the OR department (Applied Probability, Computer Simulation, Tactical Decision Aids, and others), and the overseeing committee includes OR faculty. The OR department plays a similar role in the information warfare; space systems operations; and joint command, control and communications curricula.

Roughly speaking, one could obtain one of the current operational curricula by starting with the 1951 OA curriculum and modernizing or specializing its physics courses. The coexistence of the current OA curriculum and the four operational curricula at NPS, each of which might trace its heritage to the 1951 OA curriculum, is evidence that there is no correct design for an OR master's program—a wide-ranging field such as ours has room for a variety of useful solutions.

Practice

NPS requires a thesis for the OR master's degree, which puts us in the minority according to INFORMS [1995]. Nearly all these describe applications, so the thesis requirement should be regarded as an enduring part of the OA curriculum's emphasis on practical work. Practical or not, the thesis is also the student's most important exercise in written communications. Here is a selection of thesis titles and authors for Fall/95 OA graduates:

—"Optimal airfield capacity expansion," Lieutenant David Chapates, US Navy;
—"Shallow water tactics for the Mark 50 Torpedo directed search pattern," Lieutenant Kyle Kliewer, US Navy;
—"Route optimization model for strike aircraft," Captain Steve Lee, Singapore Airforce;
—"A waste management plan for US Navy ships," Lieutenant Nancy Paulsen, US Navy; and
—"Optimizing strategic sealift," Captain Gust Pagonis, US Army.

Most students start working on their theses in the fifth quarter during the experience tour, a six-week period during which the student leaves NPS and examines OR problems from the viewpoint of a host organization. The student typically does not select his thesis advisor until after returning from the tour, but may still contact faculty during the tour to discuss models, data sources, and so forth. Experience tours are expensive in terms of time and money, but there is a lot to be said for getting away from the academics and dealing with people who think they have a real problem, rather than just an "exercise".

While the thesis and tour are the centerpiece of practice, the OA curriculum also includes the aforementioned seminar program, plus practical material within formal courses. There are two schools of thought with regard to incorporating practical material in courses. One is that early courses should be primarily theoretical, with practical experience coming in later courses that have "applied" in their titles, or perhaps even in capstone courses designed to "put it all together." There is something to be said for this approach—clearly one can't apply something until one has learned it—but we have found it hard to carry out. In practice, capstone courses end up considering problems where some techniques are heavily used and others are omitted entirely. There is nothing wrong with this, since it mirrors real life, but still the usefulness of all material ought to be demonstrated. This leads to the other school of thought, which is that every course ought to include applications. The OA curriculum has been influenced by both schools of thought. It is probably evident in inspecting the naval warfare option (Table 1) that Joint Campaign Analysis is a capstone course, as are such unshown electives as Problems of Naval Warfare. Many of the earlier courses also include application projects.

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Willemain [1994] and Powell [1995] report favorable experience with teaching nontraditional courses on the modeling process itself, courses that emphasize creativity, context, and the unimportance of "correctness" in dealing with real problems. The OA curriculum does not currently require such a course, although many OA students do take an elective that is devoted to the modeling process, rather than to any particular technique. Nor does the OA curriculum include formal material in other important practical areas such as the history of OR or communication skills. There simply isn't enough time, or, put another way, the OR faculty feel that the material that is in the curriculum is more important. Like all OR curricula, the OA curriculum is a compromise that is very much influenced by the presence of a constraint on its length.

Communication Skills

At a retreat in 1984, the OR faculty identified written communications skills as the characteristic of our graduates most in need of improvement. It has even been suggested that a formal course in technical writing should be inserted into the OA curriculum, although this is not likely to happen because the 11 departments at NPS do not include an English department. The experience of writing a thesis helps, of course, but for some students, particularly but not exclusively foreign students, the experience is an exercise in applying something that hasn't yet been taught.

Verbal communications, especially short talks called briefings, are particularly important for military officers. Army officers arrive at NPS with some training in the area. While the OA curriculum provides no additional training, it does provide opportunities for practice and criticism. Students often brief the rest of the class on their course projects, for example. At times the curricular officer has required that all theses be briefed, but the students object because every student is required to attend every briefing, a large time commitment at a point in the eighth quarter when many theses aren't really finished. At the moment, only theses in competition for the Military Operations Research Society/Tisdale Award are briefed.

Briefings have improved in recent years with the advent of software for generating presentation materials. It is a tribute to the user-friendliness of modern software packages that computer-literate students can learn to use them without formal instruction.

Computers

The OA curriculum included a course in FORTRAN programming from the time of the department's founding until 1992. FORTRAN still has its devotees, but it was replaced as a general purpose language in 1993 by Pascal, at the same time that instruction switched from the mainframe to a network of PCs. In the early decades no language other than FORTRAN was employed—the set-up cost of learning to use other languages was simply too high, so all programs were written in one general purpose language. As special purpose languages became easier to learn and use, instructors sometimes found it worthwhile to teach students how to use them, even when the students already knew FORTRAN. The use of special purpose languages has accelerated within the last decade. Today's OA graduates are familiar with Pascal, MODSIM, LINDO, GAMS, S+, APL, MAPLE, MATLAB, and various word/presentation processors by the time they leave. Service courses to other curricula may employ STORM, GPSS, FAST-QM, or MINITAB. This ease of learning and using new, special purpose languages is revolutionary in permitting us to teach important ideas in the context of realistic problems. Graphical capabilities are especially useful. The two Computational Methods courses (Table 1) teach Visual Basic and Java; all of the other languages are taught within the courses in which they are used.

Comparison with the Model Curriculum

The ORSA/TIMS Committee for Review of the OR/MS Master's Degree Curriculum proposes [Dyer et al. 1993] a model curriculum for a terminal master's degree. It suggests a curriculum that is one year long, including time devoted to a "project/thesis," but acknowledges that a second year would permit the inclusion of an internship and additional desirable material. By comparison, the OA curriculum includes a second year because of the need for early undergraduate work and the thesis and tour requirement, and because the curriculum must meet subspecialty requirements as well as degree requirements. There is a rough but good correspondence in terms of academic content and length between the OA curriculum and the one proposed by Dyer et al. Each has heavy emphasis on probability and statistics, less heavy emphasis on other traditional OR areas, and a liberal admixture of specialization courses and projects.

Dyer et al. conducted a survey in which practitioners ranked "computer use skills" above all others in importance, including probability and statistics, and Geoffrion [1992] identifies the microcomputer and communications revolutions as two of the four major forces acting on OR/MS. The importance of these forces has surely increased with advances in networking over the last few years. The widely acknowledged importance of computers to OR, the rapid improvements in hardware and software, and most particularly the advent of computer networks have caused a continual ferment about how the subject is treated within OR/MS curricula. The OA curriculum and the model curriculum have reacted differently to this pressure. The OA curriculum devotes two courses to formal instruction in computing, using Visual Basic and Java as general purpose programming languages within which such concepts as objects, structures, and complexity can be explored. OA graduates should be able to write, debug, and criticize complicated computer programs and often do so in the course of writing a thesis. The model curriculum, on the other hand, simply makes knowledge of "an algorithmic language such as C" a prerequisite, using the time saved to introduce material on networking and telecommunications. This should produce graduates with an understanding of the architecture and limitations of the computer systems they will have to deal with, a capability that cannot be claimed for OA graduates. Thus the two curricula definitely differ about what should be taught about computers and their uses. On the other hand, both curricula make liberal use of special purpose software packages.

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The model curriculum contains several specialization courses that permit considerable variety among graduates with the same degree. This is accomplished by options within the OA curriculum, but options permit less freedom than Dyer et al. apparently have in mind. NPS is quick to distinguish between graduates of different curricula. OL graduates get the same operations research degree as OA graduates, but (just as important to a military officer) different subspecialty codes. Graduates of operational curricula, such as UW, get a different degree and a different subspecialty code. Thus, while NPS permits relatively little flexibility within the OA curriculum, other closely related curricula are available.

Dyer et al. emphasize the importance of communications skills to OR, going so far as to suggest modifying admission procedures in favor of applicants with those skills. We agree that communication skills are important, but modifying the admission procedure is not an option. We feel that our students' verbal skills are good in spite of our lack of instruction. We continue to agonize about written skills.

In terms of basic philosophy, the OA curriculum and the model curriculum are in complete agreement. Put simply, the object is to produce graduates capable of recognizing, formulating, and solving real-world operational problems.

Summary

The OA curriculum at NPS is alive and well and can be expected to remain that way as long as its graduates continue to be effective analysts. It strongly resembles the model curriculum of Dyer et al. in both content and philosophy, although there are differences. At about the time when the OA curriculum was founded, Morse and Kimball [1951, p. 1] stated that

> Operations research is a scientific method of providing executive departments with a quantitative basis for decisions regarding the operations under their control.

We still like that definition, even though the scientific method that we teach today at NPS would hardly have been recognizable to Morse and Kimball in 1951. Stated very simply, our goal is to produce graduates who can do that.

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