# Military Operations Research Society (MORS) Oral History Project Interview of Dr. Gerald G. Brown

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MILITARY OPS RESEARCH HERITAGE ARTICLE

## INTRODUCTION

*Oral Histories represent the recollections and opinions of the person interviewed, and not the official position of MORS. Omissions and errors in fact are corrected when possible, but every effort is made to present the interviewee's own words.*

Dr. Gerald G. "Jerry" Brown is currently a Distinguished Professor of Operations Research and Executive Director of the Center for Infrastructure Defense at the Naval Postgraduate School (NPS), Monterey, California. In 1976 NPS students elected him best teacher; in 1982 NPS faculty elected him best researcher; in 2005 he was elected an Institute for Operations Research and the Management Sciences (INFORMS) Fellow; in 2008 he was elected to the National Academy of Engineering (the first NPS faculty member to receive this honor); and in 2009 the Secretary of the Navy awarded him the Navy Distinguished Civilian Service Medal. Dr. Brown also won the INFORMS Military Applications Society's Koopman Prize in 1990, the MORS Barchi Prize in 2007, and the MORS Clayton Thomas Award in 2010. This interview was conducted in Jerry's office at NPS on June 20, 2011. Notes at the end identify Jerry's citations, most of which can be downloaded from his NPS homepage http://faculty.nps.edu/gbrown/.

## MORS ORAL HISTORY

Interview with Dr. Gerald G. Brown
June 20, 2011
Naval Postgraduate School (NPS), Monterey
Dr. Kirk Yost and Dr. Bob Sheldon, FS, Interviewers

*Bob Sheldon:* Jerry, let me first ask you to give us your parents' names.

*Jerry Brown:* My dad's name is Gerald Brown. I'm the second. And my mother's name was Ruth.

*Bob Sheldon:* Tell us about your parents and how they might have influenced you. What did your dad do for a living?

*Jerry Brown:* My dad worked at North American Aviation. He was one of the developers of the F-86, F-100, A-5, XB-70, X-15, and the original B-1. Early on, I lived in El Segundo, California, in a house on the beach that later was razed to make way for Los Angeles International Airport (LAX) runway 25. I've been involved with our military all my life.

I lived in Southern California for a while, but then I was moved around quite a bit because of family disruptions and so forth. I spent time in Idaho on a ranch, in Ohio on a farm, and at Fort Knox, Kentucky.

I went to high school for four years in Vicenza, Italy, and received what I later appreciated to be a very, very excellent education at the Vicenza American High School, preparing me for university.

*Bob Sheldon:* Did you get to travel around Italy while you were there?

*Jerry Brown:* I traveled all over Europe.

*Bob Sheldon:* You said you had some really good teachers; were any of those in math or science?

*Jerry Brown:* They were. I had excellent teachers in mathematics and science, and in English exposition. I was really blessed.

*Kirk Yost:* Despite growing up in so many places, you decided to return to California?

*Jerry Brown:* I decided to come back and I'm currently living in Pebble Beach, about as far from the ocean as I've ever lived in California.

I should admit about my California education that I failed kindergarten in El Segundo, California, and I assume I'm still recorded in El Segundo as being "mentally challenged" or whatever the currently acceptable euphemism is.

This had to do with a congenital problem called trigger thumbs that physically interfered with my speed manipulation of blocks on an IQ test. This was diagnosed and surgically corrected. But, in California, I'm still officially "mentally challenged"—just ask my spouse.

*Kirk Yost:* How did you decide where to go to college from Vicenza?

*Jerry Brown:* I came back from Vicenza during my senior year so I could get a high school diploma from a California school and not have to explain to colleges what was going on.

I graduated from Fullerton Union High School in Southern California and had had such a good preparation in Vicenza that I was allowed to enroll in the junior college even though I was still in high school. And I applied to, I think, about six universities.

I was accepted to a number of schools, and I ended up going to the University of California at Berkeley. But that was not a good time to be in Berkeley, with the Free

Speech Movement and the riots and tear gas and so forth. And not having a scholarship, I had to work for a living.

Between the demonstrations and working at night I had had enough of that in about three quarters and transferred. I ended up getting two college degrees from California State University Fullerton, and then I went to UCLA for my PhD.

*Kirk Yost:* Both your bachelor's and master's degrees are from Cal State Fullerton?

*Jerry Brown:* They are. And are you ready for this? My bachelor's degree is in business marketing (quantitative methods), my master's degree is an MBA (quantitative methods), and my PhD is in management.

*Bob Sheldon:* I want to ask a question about perception. There's often a perception of two-way snobbery between engineering schools and business schools. Many folks in the engineering schools assume that if somebody's too weak in their mathematical rigor to survive the engineering school, they go to the business school. And in the business schools, there's a perception that if a person's too weak in their personality skills to survive in the business environment, they go to the engineering school. Given that you survived quite well, you excelled in business school and you are quite rigorous mathematically, what's your comment on that?

*Jerry Brown:* It depends on the business school and on the engineering school. My recollection is that if you could understand the Black-Scholes equation you were no slouch mathematically. If you talk to a mathematical economist or to someone mathematical in finance and so forth, they don't have much to apologize for in terms of mathematical rigor. You need to establish foundations in mathematics and English exposition. Equipped with these skills, you can do about anything you want. The engineering and business options you mention just emphasize one or the other, but cannot (or should not) be attempted with serious deficiencies in either area.

I'm not a keen fan of undergraduate business programs. I prefer to see MBA students who have completed undergraduate studies in some conventional academic area.

I don't think there's any particular weakness on either side here. If you choose a good university, a good curriculum, and if you seek rigor and follow accomplished scholars, you'll find it.

*Kirk Yost:* Although all of your degrees are in management or business administration, your early publications are on statistics. Did you think you were going to be a statistician? And how did you eventually turn to optimization?

*Jerry Brown:* One of my early mentors was Herb Rutemiller, and you'll see his name as a co-author in some of those papers. He was very influential, and showed me how to do research and how to publish. He was a very accomplished statistician. I followed his lead and got exposed to the literature of operations research (OR). But I don't regret the business degrees because I can read operating statements and speak the language, and that's been useful in consulting. I had worked for some time at North American Aviation, Beckman Instruments, and Hughes Satellites on computers, and so I was lucky to be an early computer guy when such were still rare.

I was at that time hired out as a general-purpose, mathematical, and scientific digital programmer. This was when there weren't that many large-scale machines and before the advent of the current numerical recipes and such. On my bookshelf here I've still got basic references like Abramowitz and Stegun with tables of Bessel functions and the like. It was computer experience that opened up early research to me, paid my bills, and also got me working on some defense problems.

I became interested in optimization while working with Rutemiller, but also while working at UCLA with Art Geoffrion, Glenn Graves, and company. And they're the ones who really persuaded me to move from descriptive statistics to prescriptive optimization.

I became besotted with the leverage that this sort of modeling gave us and I was fortunate to be involved in some early practical applications at large scale, including one at RAND Corporation you may remember, Kirk, that helped the Air Force decide what bombs to buy every year for two decades (Brown et al. 1994).

*Kirk Yost:* Can you outline how you went from Cal State to UCLA and subsequently into the Navy?

*Jerry Brown:* When I got my master's degree and was accepted into UCLA, I was hired at Cal State Fullerton as an assistant professor of quantitative methods.

*Bob Sheldon:* What year was that?

*Jerry Brown:* 1969. I taught basic OR and computer classes, and the computer classes were attended by various people from the engineering school and the sciences because we owned the biggest, baddest machine on campus (an IBM 1620 with 20,000 decimal digits of memory). I noticed a couple of excellent students with real short haircuts compared to the fashion at the time.

I eventually learned that they came from an organization called the Naval Security Group (NSG). They were taking my computer classes because I was teaching one of the few sequences that actually taught programming on a large-scale computer while also showing how to integrate mathematics to design and implement useful systems.

And a quarter after that, there were about six guys with nice haircuts. In parallel to that, I was having exchanges with my draft board, and I was single. My draft board was harassing me, as was their due, and one evening in my class, one of my short-haired students came up and introduced himself as a Navy Commander, and said, ''Do you think you could pass the aptitude test for the Navy?''

I guess I did okay on the aptitude test because I ended up in basic training at San Diego, California, to be issued as a freshly minted Seaman Recruit E1 with a master's degree. This was not too unusual because NSG was pretty fast company, and the typical commissioned officers and petty officers had advanced degrees, some of them with very impressive backgrounds.

In 1969 I got my first top secret clearance (something I find amusing when I fill out my forms today because there can't be anything they don't know about me by now) and started serving with a reserve unit of the NSG.

Then, I contacted my Navy detailer and said, ''Here's the deal. I've been accepted to UCLA for their doctoral program. There's no guarantee of success, but if you give me the time to try to earn my doctorate there—I don't want you to pay for it, and I'll go on inactive duty with no pay—when I finish the degree, I might be of more value to the Navy and at that time I'll come back on active duty.''

Some lieutenant commander in the Pentagon concluded this was a good deal, and made it happen. On graduation, I was supposed to get a direct commission as a Lieutenant. One thing led to another, and the Navy got impatient filling their quotas, and said ''Come join us now, you're going to like Newport, Rhode Island, and you're going to like Officer Candidate School (OCS).''

In fact, I did like both. For me it was a vacation. I was the oldest guy there at OCS. And in June, 1973, I was commissioned as an Ensign in the (regular) United States Navy. I was expecting to ship out to Vietnam because of some other background I had with French and earlier work as a diver doing insurance and salvage work, and diving for abalone. This meant I could read navigation charts printed in French. And so my orders were essentially for the job you saw in the movie *Apocalypse Now.*

*Kirk Yost:* You were going to be a swift boat commander?

*Jerry Brown:* Yes, of a Vietnamese river boat detachment. My detailer really played this up as ''a Lieutenant's billet.''

I put my modest affairs in order. Then I got a call from a guy named Jack Borsting at NPS, and he said ''According to this IBM card, you've got advanced graduate education. Tell me about yourself.'' I explained to him what I had done and what I was interested in, and he said, ''Would you like to come to Monterey and be a military instructor?'' I said, ''Well, let me think that over.'' And, as you know, you have to find somebody else to take your orders in a situation like this. Otherwise you just can't step back.

But it turned out there were 30 guys eager to go over and be heroes, so they had no trouble filling my billet, and I ended up back in my California, and in Monterey.

*Kirk Yost:* Were you done with your PhD at that time or were you still working with the people at UCLA?

*Jerry Brown:* I was still working at UCLA.

*Kirk Yost:* You ended up going to Monterey as a professor not having finished yet at UCLA? How did that work?

*Jerry Brown:* I arrived here as a newly commissioned Ensign, and I was made a military instructor, but because of my publications and other activities, they gave me an academic appointment as an assistant professor. They desperately needed my computer skills, and so

I was dual-appointed to computer science and OR and given a double teaching load—a full-time load in each department.

I had a pilot's license. That put me within two hours of UCLA, so I commuted down to UCLA on Friday and came back Sunday night. After a year of this, people realized the sorts of research I was doing were of interest to the Navy, and they actually cut me some slack and gave me—which they were supposed to do anyway—a quarter off. I was able to finish up the degree.

*Bob Sheldon:* What was your dissertation on?

*Jerry Brown:* My dissertation was on nonlinear programming used to find maximum likelihood estimates for very difficult distributions such as the three-parameter Weibull. The motivation was exigent statistical problems, but the base was developing some rather abstruse nonlinear programming theory.

*Kirk Yost:* How long were you in uniform at NPS?

*Jerry Brown:* Three years. During those years, I was promoted to associate professor as an Ensign, then to Lieutenant, Junior Grade (LTJG).

*Kirk Yost:* Were you the only Ensign to ever be an academic associate professor at NPS?

*Jerry Brown:* I think so. My computer science colleague Gary Kildall was a full Lieutenant. I was also dead last on the NPS accession list for 36 months. In other words, for me to have assumed command here, everyone else would've had to be gone.

*Bob Sheldon:* Let's back up to your PhD program. Any other notable professors that you recall from your academic studies?

*Jerry Brown:* Too many to name. These were heady times at UCLA in my departments of mathematics, computer science, and my home school of management. I also met some very impressive and famous (just ask them) medical researchers. One of the ways I paid my bills was consulting with the medical school. A medical school, as you can imagine, has a number of small-sample statistical puzzles, and their researchers would show up and put a small sample on my desk and say ''I need to write a paper about this. What can you prove from this data?''

Instead of trying to school them on statistical propriety, I scoured the literature and developed a library of the best small-sample tools I could conjure. This was quite remunerative; it was good pay for not too much work.

I recall a case where I had to tell a physician researcher, ''This is just too small a sample size.'' And he replied, ''Oh, I'll go get more data.'' When he came back later, I finally thought to ask this guy, ''What's this data about? What are you measuring?''

He described a painful procedure that was being inflicted on unknowing undergraduate controls who were patients at the UCLA medical facility. I immediately declared, ''We've got plenty of data. What do you want to prove?''

I guess the most impressive guy who tolerated me at UCLA was Jacob Marschak. He was a Russian polymath. He was just brilliant. He wasn't an optimizer, but he was just so doggone smart that you'd spend half an hour with him over a cup of coffee, and he'd end by asking some question. You'd think that over and it would occur to you about a week later what he meant. Sometimes it would take you a month to prepare for the next cup of coffee, but you didn't want to go back into his office again and be ignorant of what his direction had been.

I am very grateful for having had his acquaintance and it was a great honor a couple of years ago when I was invited back to UCLA to give the recurring ''Jacob Marschak Interdisciplinary Colloquium on Mathematics in the Behavior Sciences'' (http://www.anderson.ucla.edu/x1094.xml) with an audience coming from all over Southern California.

*Bob Sheldon:* Could you comment a bit more about your early work in statistics?

*Jerry Brown:* The initial work we did was in fixed sample acceptance testing (Brown and Rutemiller 1971) and in reliability testing that was required by the U.S. military to monitor procurement quality (Brown and Rutemiller 1973, 1974, 1975). Civilian entities also use these military quality controls. There are military specifications for acceptance tests where you have a lot of a given number of items, and you sample from the lot and subject that sample to testing, and based on the number of successes and failures, either accept the entire lot or not.

My colleagues and I agreed these were adequate tests statistically. (I believe Jerry Lieberman at Stanford at the time was one of the most influential proponents.) But, we felt the tests

could be unnecessarily expensive in the following sense.

If you take a sample, and you begin testing it, and your results are inordinately successful, your instincts tell you that you could probably stop testing, save a lot of money, and make an early conclusion that things are all right. Conversely, if you have early results that are very, very bad, it might be cheaper to just stop and back up to try to find the cause.

We did some early work in revising these military specifications to do sequential sampling so that we could get better decisions earlier at less cost. That was my early involvement in statistics.

*Kirk Yost:* Where did your extraordinarily high level of entrepreneurialism come from?

*Jerry Brown:* I don't like being hungry. And it's part of my background with my family who were products of the Depression that I've never accepted money from anyone for anything. I never took a dime in scholarship or support of any type, never had a fellowship, and never accepted any tuition assistance from the Navy. And I graduated debt-free with each of my degrees. I worked in parallel and paid my bills as they came up.

*Bob Sheldon:* What were the first courses they assigned you to teach here at NPS?

*Jerry Brown:* Basic computer programming for the masses. Lots of that. Databases, and digital simulation.

*Bob Sheldon:* Was that in Fortran?

*Jerry Brown:* Yes, some of it was in Fortran. We had a couple of other teaching languages, and special languages for artificial intelligence, APL, graphics, list processing, simulation, and so on, but Fortran was in widest use. It was on punch cards. We had civil service civilians who typically had master's degrees in mathematics as daytime duty consultants in our computer center. But, at that time, with punch cards and batch processing, the only way you could get your work done was to come in at night. The students would go home for dinner and then come back and spend the better part of the night here, and if you were their instructor, it was a good idea to do the same.

I ended up spending virtually every night here with students. Of course, if students know you're here and they know you know how things work, then they come by and ask you questions even if they're not your students. I ended up working on a lot of things like orbital dynamics and engineering acoustics and learned a great deal along the way.

Scott Redd recently reminisced as our NPS graduation speaker about these night shifts with me, and we laughed with the recollection that I was neither his advisor (Al Washburn was), nor second reader; I was just there. And I learned from working with Scott, and still learn working with Al.

*Kirk Yost:* One of your first breakthroughs in the OR community was the network optimization paper you wrote with Gordon Bradley and Glenn Graves. What led you into that area?

*Jerry Brown:* That actually started on the high side for me. I consulted for the Joint Strategic Targeting Planning Staff, Omaha. My early classified work was on planning the Strategic Integrated Operations Plan, the SIOP, replacing pins and strings with optimization. You can see how that leads to the necessity for large-scale network optimization given the large number of weapons we had at the time. I worked with another agency in the Pentagon reckoning the Red SIOP, or RISOP.

On the unclassified civilian side, Glenn Graves had a consulting contract with General Motors to determine how to distribute automobiles to dealerships and customers. And the combination of those two challenges, plus the interesting nature of the problem, led Gordon Bradley and me to spend quite a bit of time and eventually publish (Bradley et al 1977). We were offended as scholars that a competing network solver being published at that time in our open literature was being sold as a proprietary product by the authors. We gave away our superior product for free and undermined the market.

*Kirk Yost:* Putting the GNET© code in the public domain eliminated most of the competition?

*Jerry Brown:* No, not eliminated. We weren't fielding salesmen. We changed the market. These competitors were using our open scholarly literature as commercial advertising. And the sweet part here was our algorithm is actually much more efficient. To this day, despite a lot of advances in network optimization, and even though our network solver is a network simplex algorithm with a bad theoretical worst-case

runtime, in live benchmarks against live data, it's still the fastest code.

*Kirk Yost:* Was Gordon Bradley at NPS when you arrived, and was he already working in the networks area?

*Jerry Brown:* Gordon and I arrived on the same day in 1973. He had been a tenured associate professor at Yale. He had taught optimization, doubtless including networks, but I think the two of us launched off on our network initiative at the same time.

*Kirk Yost:* Although from radically different backgrounds, I would suspect.

*Jerry Brown:* That's true, and the good fortune for me was that Gordon had done a postdoctoral fellowship at Stanford with George Dantzig, and that opened up another set of doors for me. Gordon was very gracious to introduce me to George and Phil Wolfe and other people he knew and who I had not encountered during my odd career.

*Kirk Yost:* Up until the 1970s the optimization community seemed to be divided between theoreticians and implementers. You and Gordon seemed to be at the forefront of people who worked on both the theory and the coding aspects of these problems. Can you comment on that?

*Jerry Brown:* Going back to that era and looking at the literature, you wouldn't see much that you would recognize today as an algorithm. Procedures were described in a rather hand-waving, imprecise way because we just hadn't developed our way of thinking about such things. Theorems were well-defined, but algorithms not so much. However, those early literature articles are beautiful to read. If you go back to the earliest issues of *Operations Research* and *Management Science*, you will find some lovely military OR, really well thought out and eloquently expressed.

In that era there were a lot of professors who were well-trained mathematically (recall that our OR discipline is a descendant of mathematicians and physicists in World War II) who looked down on those of us who dirtied our hands doing real computer implementation. But, we also had a parallel discipline in computer science that was just sorting out things like data structures and algorithms. The academics who kept to mathematics vigorously defended their theoretical journals from mere applications. Inevitably, those of us fortunate enough to have a foot in OR, computer science, and experience with cutting-edge applications, developed new theory.

One of the offshoots of this for Gordon and me was that we were two of the three founders of what is today the INFORMS Computing Society (ICS). We founded the Computer Science Special Interest Group, and Gordon and I served as two of the three first presidents. The early attendance of our fledgling interest group meetings was helped by me smuggling in cheese, crackers, and wine. I was told by the poobahs at the Operations Research Society of America and the Institute for Management Science at the time, ''You can't do that!'' This evidently violates contracts with meeting hotels and their unions. Well, I did it anyway, and guess whose meetings were standing room only? To this day, one of the traditions of ICS, and now of other INFORMS special interests groups, is an informal cheese, crackers, and wine meeting.

*Kirk Yost:* Can you talk about one of your major philosophies, the notion of elastic programming? It's central to much of your work, but rarely addressed in the mainstream optimization literature.

*Jerry Brown:* Some contemporary textbooks now mention elastic programming. I credit the original idea to Glenn Graves. I was just quick to grasp its charm. We were building a large-scale optimization system from the ground up at the time, and we developed theory and algorithms with the elastic feature intrinsic. We were dissatisfied with the commercial products then and thought we had some better ideas. One of the difficulties we had was with some standard benchmark problems, rogue problems that had been developed precisely because they're so pernicious. We were trying to find ways of solving them much faster than the competition. And it turns out that if you can relax constraints you don't like, at least temporarily, this is a good thing to do.

One thing led to another and we began to think, ''You know, this elastic business with linear penalties is equivalent to bounding the dual variables, so that more fully defines the model. You state the model, you specify the constraints on your courses of action, and along with each constraint, you specify exactly how important this constraint is to you. You specify how much, at most, you're willing to spend to satisfy this constraint. That had a rather compelling ring to

it, and when we looked further, it turns out that if you implement an algorithm that incorporates elasticity as a fundamental intrinsic function, you get some very elegant results, and a very efficient algorithm.

*Kirk Yost:* Are you the only practitioner that has written a code that incorporates those methods?

*Jerry Brown:* I don't know for sure, but I suspect the root node integer enumeration rounding in CPLEX uses crude penalties. And certainly many people write elastic models, but they're solving them with traditional codes that treat the elastic variables as explicit logicals—slacks, artificial, and surpluses—and this is not as efficient as it could be.

*Kirk Yost:* You're the only professor I've heard who not only talked about the notion of elasticity, but talked about it as a fundamental part of an optimization problem.

*Jerry Brown:* It's absolutely fundamental. I was told by academics early on that elastic constraints ''cheat.'' But, a manager, policy maker, or a general officer understands immediately what elastic constraints mean. They can control what's going on in a way they understand.

If you like, you can use conventional modeling and declare ''all my constraints are immutable, and infinitely important.'' Good luck with that in the real world, and especially in the Department of Defense (DoD), where objectives and constraints are rather fungible, and where mere whims by senior policy types become hard constraints for junior analysts.

*Kirk Yost:* Another central idea you've introduced is the notion of persistence in optimization. Do you feel that you've made headway in the community with those ideas?

*Jerry Brown:* I think in most cases such features arise because if a model without any persistence feature gets used repeatedly, say over time, it's pretty hard to brief a solution that has amplified some inconsequential data change into a wholesale revision of plan, some of which may have already been promulgated (Brown et al. 1996). When I find persistence features in a model, this is a telltale that the model has actually been used and is not merely some mathematical confection.

As you know, Kirk, any model ignorant of its own past advice is really an ignorant model. And you're not going to be able to use an optimization model very long in reality if the model has no feature to recall and heed decisions that have already been advised and advertised. That idea is not yet in textbooks, and that's too bad (Brown et al. 1997).

*Kirk Yost:* Can you talk about your involvement with the Karmarkar algorithm for linear programming? Its introduction, and the subsequent efforts to control it as a proprietary method, were very controversial.

*Jerry Brown:* When we first saw Khachian's algorithm, Al Washburn and I took a look at it computationally and found it to be interesting, but not very efficient (Brown and Washburn 1980). Certainly the theoretical result—the polynomial worst-case bound on the number of iterations to solve a linear program—was valid, but not efficiently implementable. Karmarkar's algorithm was potentially more efficient, although there are a couple of missing steps in terms of transitions from the interior points to what we call basic solutions.

My initial concerns with the Karmarkar results were twofold.

One was that our open academic literature was being used (here we go again) to promote and sell a commercial product and presuming to publish papers about algorithms that were patented trade secrets. That is, they successfully published results without showing how the results were obtained. This is not science. They also created a custom-design supercomputer to run this algorithm and were trying to sell it to major companies in the United States to solve planning problems. I believe Delta Airlines bought one.

We were at the same time solving the same crew scheduling problems for another, larger U.S. airline, with our own algorithm. These problems are not linear programs, but rather integer linear ones. Lacking an integer feature, somehow you have to deal with fractional crew assignments. You can't assign half a pilot here and a third of a flight attendant there; you've got to assign whole people. The Karmarkar implementation had no integer procedure at all, so I was at the time wondering what Delta Airlines was doing.

I believe this was a commercial disaster for the proponents. I don't think they sold more than a handful of these, and they only sold those to people who were rather innocent of what was

being inflicted on them. Another thing that disturbed me was a presentation by Karmarkar at Stanford hosted by George Dantzig. A bunch of numerical results were displayed purporting to compare the new algorithm against IBM's MPS 360, at that time a well-regarded commercial-quality optimizer. Apparently no one else in the audience knew MPS 360 had a limit on the number of model constraints. The reported results far exceeded that limit, and therefore were concocted.

*Kirk Yost:* Did that eventually get exposed?

*Jerry Brown:* I exposed it only by asking a question from the audience, but I don't recall that anybody ever retracted a paper or published a correction or explanation. It's too bad these interior point methods got off to such a poor start. Others have independently developed the theory and implementations since, and mated these with conventional simplicial optimization. For some problems, this works well.

*Kirk Yost:* Was there any substantive change in the community with respect to dividing scientific discovery and marketing products?

*Jerry Brown:* A few journal editors stepped up, but generally the Operations Research Society of America and The Institute of Management Sciences, today merged as INFORMS, are pretty passive in that regard. Despite a case I made as a plenary address before an annual meeting of INFORMS, and another plenary address by Seth Bonder with the same subject, INFORMS still hasn't even defined what OR is as a profession. There are no standards. Anybody can hang out a shingle. And so they've been rather passive and ineffectual at fencing off behaviors that you would consider unprofessional. We haven't defined what the profession is.

By contrast, the uniformed military services do have educational skill, degree, and experience requirements for OR billets—we should be proud of this.

*Kirk Yost:* On a different subject, can you talk about why you chose to stay at NPS as a professor once you left the active-duty Navy?

*Jerry Brown:* I thought you'd never ask. I've delivered seminars at many universities, worked with their students, and remotely advised theses and dissertations. There's nothing like teaching at NPS.

For starters, our students are paid full salaries, with their sole duty to be our students and to graduate. During tenure here, students get to catch their breath during a military career. Nothing the student does here will appear in a service record or on a fitness report, other than ''attended, and graduated.'' Imagine that. Many students who were lackluster undergraduates return to our graduate program after some time and experience in uniform, having learned how to allocate time, effort, and attention, and absolutely bloom as analysts.

I walk into classes on Tuesday, which is uniform day here, and the one day a week that the students don't wear just business casual attire. I admire their decorations and qualification insignia, and ask myself, ''Where do we find people like this? Where do we find people who do the things these young people do so willingly, ably, and even heroically?''

It's humbling. My students may not have ever noticed, but out of respect my uniform on Tuesday includes a tie, and I always begin by complimenting them on their sharp appearance, and thanking them for their service and for making me proud.

I think of my thesis student CPT Tom White, then already having earned two Silver Stars, whose thesis led to the redesign of our main battle tank; CDR Mike Mullen [later Admiral and Chairman of the Joint Chiefs of Staff] (who still calls me ''Ensign Jerry''), a section leader, whose thesis under the Navy's preeminent tactician Wayne Hughes presaged the employment of AEGIS combatant ships with new-generation phased array radar and interceptor missiles; LCDR Steve Tisdale, who completed two completely independent degrees in OR and space systems, and developed a space junk tracking algorithm still in use today; and Scott Redd, who retired as Vice Admiral, and then directed the formation of our National Counterterrorism Center. The list goes on and on, and there are echelons of more junior officers rising. I have been pleased and proud to see their accomplishments, both in uniform and after.

I also have to express my admiration for our international students. Although we try our best to be good hosts, I can't imagine how hard it is to move a family to Monterey, get established and culturally aligned, while at once engaged in a graduate study program that assumes the student is available full-time, without qualification.

My spouse volunteers teaching English to international student spouses and family members as part of a very important program supported by NPS and our local school district. This course involves daily mixing of all internationals with a master teacher and qualified volunteers. This cultural exchange, in the long term, may prove as valuable as the academic achievements of the international students. Our international students come from professional upper classes of their home countries, and the spouses include very accomplished professionals—doctors, lawyers, architects, engineers, and so on—who are not allowed to practice their professions in the United States while their spouses attend NPS. (This is, by the way, a nutty U.S. policy.)

We're spoiled by the fact that when we give homework to our students, it's considered orders. And they respond in kind. You have to be very careful. If you give a bogus homework assignment at the end of a week, you may find out later the students spent all weekend trying to complete it.

So NPS is a great place to be. There's nothing like it anywhere else. I wouldn't trade my master's students for PhD students at any university anywhere.

The pay is better elsewhere, but we've got all the computers and all the toys you can imagine, and if we come up with some idea involving blowing something up, firing some rounds, shooting a missile, dropping some bombs, or something less kinetic but no less interesting, we have the means to get such experiments accomplished.

*Kirk Yost:* Have you ever been tempted to leave and assume another position?

*Jerry Brown:* There have been a number of occasions, including recently, when I've received unsolicited offers significant enough that I had to take them up with my spouse. To her credit, she has advised ''You're happy at NPS. Don't worry about it.''

*Kirk Yost:* Can you talk about the commercial consulting you do, and how that compliments your duties at NPS?

*Jerry Brown:* NPS is a military school, but administered by scholars. The distinction here is key. NPS wants me to know everything I need to know within DoD, at all levels of classification, and NPS also wants me to know what's going on in civilian industry. They want me to know what's going on in the United States and internationally. They want me to be ready when called to be able to advise on, and with, the global state-of-the-art.

NPS encourages us to do commercial consulting on a not-to-interfere basis. We have to file paperwork with the Judge Advocate General, and the work can't involve any client who does any business with the federal government, which rules out a lot of organizations, but it has been a way for us to find out in the private sector what's going on with a good portion of the Fortune 50, if not the Fortune 500.

*Kirk Yost:* Many senior people in DoD believe that the commercial sector has better ideas, and the DoD should be employing them. Given your significant experience in that world, what is your opinion?

*Jerry Brown:* I think the analysts and professionals I deal with in DoD, including the decision makers those analysts support, are equal to anything that you would expect to find in the private sector, if not better. I've never found a more admirable or harder-working cohort of professionals.

Of course, there are exceptions in all organizations.

I have to refer to Carl Builders' great book, *The Army in the Strategic Planning Process: Who Shall Bell the Cat*? Builder hilariously advises, with deadly accuracy, that when it comes to OR, ''God created the Navy and all else follows.'' Our Air Force (Brown et al. 2003), Army (Brown et al. 1991), and Marines (Bausch et al. 1991) embrace OR and use it well, but I admit my Navy is, well, not as willing a client as I would wish.

We have had some successes, but the Navy ratio of success per attempt is not as high as we wish. Much Navy OR emphasis is on program planning, because our OR degree sponsor is OPNAV N81 Assessment Division. However, even though I always advise following the money, military OR is about a lot more than just program planning (Brown et al. 2004, 2005, 2007; Brown and Carlyle 2008; Newman et al. 2011).

NPS is a joint institution, and this is a good thing for NPS OR, for DoD OR, and for DoD.

*Kirk Yost:* Do you think that there are effective commercial OR methods that DoD isn't using?

*Jerry Brown:* No I don't. In fact, there are some fashionable things in industry I'm glad DoD is not using, for instance, Enterprise Resource Planning (Brown 2003). ERP has made some modest inroads into DoD, but the cost of these systems is just enormous and for a couple of applications I have seen that will remain nameless, the legacy software was better than the ERP that replaced it. This is a situation where senior officers and senior executives make decisions too expensive to fail, and they're not around when the implications follow.

*Kirk Yost:* You don't think it's true that private industry is quantitatively much smarter than the DoD?

*Jerry Brown:* No, I don't. No private enterprise is planning at anywhere near the scale, the potential consequences, the long planning horizon, or the myriad exigent scenarios we are duty-bound to deal with in DoD. Even our limited NPS OR contributions have been flattered by an external review that assessed our advice to have influenced more than a trillion dollars of defense investment.

Whether or not we always have the influence we seek at the right levels of policy within DoD, it is structured and organized, and we understand which levers to pull. So, if people ask the right questions, and we come up with the answers, we can at least make a pitch.

I have always felt, even as an Ensign, that I have had advantaged access and audience anywhere in DoD. I have on occasion exercised that leverage, and gotten myself invited to talk to people when I thought there were emergent problems worthy of our analysis, and to which we could contribute. I've always been granted an audience. Every time. Sometimes it's been influential, and sometimes not.

Unlike civilian corporate bureaucracies, DoD is much more deeply layered with levels of authority. But, setting aside whether this organization depth is necessary, I only care if it is effective. In my experience, it is.

When you know you're right, never give up.

*Bob Sheldon:* Jack Borsting recruited you here and I've done an oral history interview with him. He's noted for being one of the founders of the modern OR curriculum at NPS. Do you have any comments on the formative years of the OR curriculum here?

*Jerry Brown:* I was a latecomer. Current Professors Washburn, Gaver, and Schrady predate me. Jack Borsting, at that time, built a large organization that was the combined OR and Administrative Sciences Department. Think of this as a combined military business school and OR organization. I forget how many mailboxes there were, but it was a lot of people.

Jack's a remarkable guy in the sense that our organization chart was completely flat. We had the entire faculty—and we had Jack. Jack was (and still is) very good at making you feel like you have a valued opinion, but as he always advised, ''You all get to vote. But, I get to count the votes.''

I would credit Jack with the formation of the department. He cultivated the connections he needed. He served in executive positions professionally, had a good nose for talent, and worked the phone tirelessly. If he could find some obscure Ensign in Newport, Rhode Island, he could ferret out talent at Johns Hopkins or Georgia Tech. He was really remarkable in that respect. Since Jack, I've worked for other chairmen, I guess a total of eight, and we've been fortunate to have a deep bench and really good leadership here through some tough times.

The key thing about working here is that I'm absolutely shielded from the normal politics that is a preoccupation and distraction at other universities. I can stay in my office, do my work, work with my students, work on their theses, work on research projects, and I don't have to worry about any politics at all. Well, except occasionally when we are threatened with a Base Realignment and Closure action and are asked ''What have you done for us lately?'' That's an easy question to answer, but you never know if your answer carries any weight in the political milieu of that epoch.

*Bob Sheldon:* In your career, you've avoided positions such as department head, dean, and so on. Yet, you have given considerable support to professional societies. Can you talk about that?

*Jerry Brown:* My career is distinguished in that I have never had a major administrative position of any kind, and I hope to complete my career that way. With INFORMS (then the Operations Research Society of America), my only contribution work was helping set up the computer science interest group, and an early

publication that started as a newsletter and is now one of their flagship journals.

I've done a fair amount of editorial work for INFORMS, *Risk Analysis*, and the *Military Operations Research* (MOR) journal. I've served on a number of committees. For instance, I recently chaired a committee to choose a new editor for the journal *Management Science*. I've served for a three-year cycle and chair for a year of the INFORMS Fellows selection committee. I serve on the editorial board for the *MOR* journal. I lack administrative ambition. I did chair the OR PhD committee here for 20 years, and have been our associate chair for research. I can't think of much else I've done besides mentor junior faculty, advise students, and do research. I could let the National Academy of Engineering (NAE) become another unpaid full-time job. Unfortunately, NPS doesn't have endowed chairs like other major universities, so NAE work is ''additional duty.''

I'm currently serving on a National Research Council (NRC) Army board on explosives and survivability, and I'm on the NRC Board of Mathematical Sciences and their Applications (BMSA) that sets the agenda in these fields on what studies will be conducted. I review reports for the academies, and have the advantage of facilities to review classified reports without having to travel to Washington.

The payback is access via the academies' legislative affairs office to policymakers. This is two-way access, and we get calls from them, for example, the Government Accounting Office and congressional staffers, with technical questions.

*Kirk Yost:* Does your future include writing a textbook, or at least collaborating on one?

*Jerry Brown:* I don't think so. I'm having too much fun doing research. The sorts of work we're doing involves groups, sometimes large groups of people. We're trying to write seminal papers that introduce these new things such as attacker-defender (or defender-attacker, so-called bi-level optimization) models. For instance, the Bastion paper appearing elsewhere in this issue optimally merges activities of all antisubmarine warfare (ASW) platforms, something never done before (Brown et al. 2011).

We're trying to write these pieces so they are theoretically innovative, with exposition of as good quality as we are permitted within the real estate we are allowed. Whenever possible, we provide numerical examples that readers can reproduce independently. And, we provide our software free of charge, at least to DoD and its contractors. Al Washburn maintains a public homepage full of free software (http://faculty.nps.edu/awashburn/). These papers are like mini-textbooks, and they may end up being chapters in compendia of military OR and/or civilian OR. It's just not my nature to sit down and spend two years of my career writing a book on completed, past work. I'd be pleased to help someone else, and I really admire my colleagues Al Washburn, Moshe Kress, Wayne Hughes, and others, who are not only scholars of the first magnitude, but skilled wordsmiths who can write clean first drafts that make sense. I'm a lot slower than that. A recent paper of ours went through 39 iterations over several months for a single revision, if you can imagine that (Alderson et al. 2011). Writing is hard work for me and takes a long time. My production rate is slow.

*Kirk Yost:* I will press you on the textbook question one more time, because the most important ideas you teach are not in mainstream texts.

*Jerry Brown:* That's very flattering. But when I look in the mirror in the morning shaving, I recognize that I might be able to contribute as a co-author to such a text, but I'm not likely to finish a monograph like that.

We have published pieces to fill in what we view as gaps in textbooks and the open literature (Brown 1997, Brown and Dell 2007, Brown and Rosenthal 2008). Kirk, these are full of the sort of tidbits you seem to have come to value and can't find in textbooks. I don't want to slight any of my professional colleagues, but those who have time to write textbooks may not also have time to gain the sorts of experience that you were exposed to here in Monterey as a doctoral student. It takes a lot of time figuring out what not to do.

*Kirk Yost:* Can you talk about the explosion of improvements in optimization software in the 1990s, when most people thought it was a mature field with little left to be exploited?

*Jerry Brown:* It has been faster hardware, but more importantly better optimization methods. I just signed a purchase order for a 16-gigabyte laptop with eight processors. In a

typical evening at home I use more computer power than it took us to get to the moon and back.

*Kirk Yost:* Dr. Robert Bixby, the principal author of CPLEX, says in his presentations that the theory was there, but wasn't being implemented in the products. Do you agree?

*Jerry Brown:* Yes, I agree with that.

*Kirk Yost:* Do you think that's still true today?

*Jerry Brown:* The main advances in linear programming came about because a few researchers took the time and trouble to build a linear program package from scratch. It turns out there's a little more involved in doing this than you might think when you walk out of your first optimization class.

Integrating new ideas with a commercial optimization product is hindered by lack of direct access to internals. Open-source products such as the Computation Infrastructure for Operations Research (COIN-OR) permit this, but the overall performance of COIN-OR is uneven. What you need is a unified design, scrupulously debugged and tested core routines, and features purpose-built for your design. Benders' decomposition does not work very well as a bolt-on option, but delivers spectacular performance as a unified feature. Hundreds of researcher-years have gone into the development and efficient implementation of cuts for integer programming. Now we can solve these mixed integer linear programs at large scale with what 10 years ago would have been astonishing speed.

*Kirk Yost:* What's your philosophy about heuristics, such as genetic algorithms, versus classical optimization?

*Jerry Brown:* I have two concerns with these heuristics. First, as we read too often, ''the computational complexity of this problem means we have to use a heuristic.'' More often than not, there is no reduction proof to support this defensive complexity speculation. Second, our business is solving hard problems, on laptops, in seconds. Using a complexity justification to justify less sophisticated methods without first having at least tried traditional mathematical optimization is, well, disappointing. We have some very powerful software to try, and when you don't even try, you give up a bound on the achievability of a better solution.

It surprises me that so few people working on heuristics spend the same amount of time developing bounds in the objective quality of their solutions as they do developing better solutions. The developing-better-solutions part is quite fashionable and the developing of bounds for those solutions seems to be not quite so fashionable, if not rare. The compelling appeal of these heuristic techniques is they're easy to teach, easy to motivate, and easy to implement. Nothing could be easier than tabu search.

But, I would be very uncomfortable betting my professional reputation on a PowerPoint slide based on a too-easy heuristic. I get very nervous that someone in the audience can get a qualitatively better solution because I didn't do my work with traditional methods or work very hard at developing an objective bound on how good my solution is, or could be. I owe my clients better than that. I need to find out how much of their money I might be leaving on the table.

Every year as an anonymous reviewer I encounter a few papers immediately adopting heuristics using the ''we have to do this because of complexity'' argument. I customarily ask the editor to ask the authors to provide their data. If they refuse to do this, as a scientist (and a reviewer) this gives me pause. If they provide the data, I rummage around my hard drive for something I might use to try to solve their problem. You'd be surprised how often a common commercial optimization package can solve these problems exactly, and much, much faster than the heuristic proposed.

*Kirk Yost:* Can you talk about the issue of getting a planner to pay $7,000 for industrial-quality optimization software when he's used to being issued a spreadsheet for free?

*Jerry Brown:* The providers of this state-of-the-art optimization software offer their best packages free of charge to universities. These agreements typically require that we credit the provider when we use their packages on research and certainly require that if someone walks off campus with one of these models, they get a full-up commercial license, which we make sure they do. In many cases this puts you in a situation where you can test the software free of charge during a research phase, and pay for it only if it works and you decide to use it. We are a major profit center for these software providers. Regardless, can you imagine any problem

that's worthy of you working on it for even a week that doesn't justify a $7,000 software license?

*Kirk Yost:* I bring that up often, and fail often, which is why I'm interested in your views.

*Jerry Brown:* It's just nuts. I've encountered folks who think nothing of spending hundreds of thousands of dollars on analyst labor, yet balk at buying a single seat with powerful modeling and optimization tools. Even more ridiculous, I have periodically heard, ''We'll save a lot of money by writing our own modeling and optimization package.'' Whew.

*Kirk Yost:* Didn't you confront this issue when you worked on routing C-130s around Iraq, and it became a problem?

*Jerry Brown:* It was not just the cost, it was the availability. We had to take to theater a laptop with all the software we needed at that time, and we left it there for the planners at the Combined Air Operations Center (Dell et al. 2006). In parallel, we developed a heuristic on a toggle, something we've done many times with our deployed software. We have a toggle on the dashboard that says ''Do you want an optimal solution? If you do, you've got to spend 7,000 bucks to have the software. Or, do you want a fast solution and instant gratification and here's the fast solution.'' The Air Tasking and Efficiency Model (ATEM) has been gifted to Headquarters, U.S. Air Force, and to U.S. Transportation Command. You'll have to ask them how they have used ATEM to address exigent problems, but I do observe that some results include email lists with a lot of names you would recognize.

We provide reach-back in our secret and top secret laboratories so that planners can tell us ''Listen, things have changed here in theater. Can you have a look at this to make sure your fast solution is still as good as we hope it is?'' We're keenly aware that, for instance, the optimization software we desperately need to do optimization-based decision support is not allowed to be used on Navy Marine Corps Internet (NMCI) computers. I am the custodian for a number of laptops we've bought and loaned permanently to victims of NMCI. I don't want to see my property list of mission-essential gear we have had to purchase and loan to our analysts. I know I have personally monogrammed linens waiting for me at Leavenworth Federal Prison, but rather than request permission (which with NMCI these days would take the better part of forever and more money than I can muster), I'm counting on forgiveness for getting the job done.

*Kirk Yost:* Does anyone in DoD have a rational policy for this?

*Jerry Brown:* Are you talking about the same folks who have prohibited jump drives, even though there are absolutely secure ones available?

The Air Force is pretty good, but I think the Army has perfect pitch. When they send an analyst to theater, they ask, ''From this checklist, what do you want on this laptop we're building for you?'' And the analyst deploys with a full-up round. The poor Marine analyst (or Navy individual augmentee) has to find an Army analyst, or buy his own laptop out of pocket, to actually get any work done that requires the tools of our trade. Those defending NMCI seem to view a computer as an email appliance with a spreadsheet and slide maker. A computer for an OR is a tool, a weapon. Denying Navy and Marine OR's access to full-up computers is a stupid and wrong information technology (IT) policy. I say again, this is a stupid and wrong IT policy. Have I made myself clear enough?

There's going to be some debate, but you can go back to first principles about whether this NMCI thing has made any sense at all economically. At one point NPS was scheduled to convert to NMCI, and I learned I would have to donate all our high-end optimization computers (and we have a lot of these in our labs) and, after some undetermined time for our software to be certified at some undetermined cost, buy them back for a lot of money. I went ballistic, and called in a lot of chips (so to speak). Today, NPS is in the .edu domain and not subject to (but has full communication with) NMCI, and the argument that saved us that our former IT director (and NPS MS-OR) Tom Halwachs made was, ''Who else do you have in the Navy to tell you what the next NMCI should look like?'' Whew. Had we been forced to NMCI, I don't think I would still be working here.

*Kirk Yost:* In the early 2000s, you started working on two-sided optimization. Can you talk about how that came to you?

*Jerry Brown:* I have to credit Distinguished Professor Kevin Wood for that. Kevin was

working in the early 1990s with U.S. Central Command, planning drug interdiction efforts. One of the early insights he contributed was that interdicting relatively small quantities of refined drugs is hard, but interdicting 55-gallon drums of precursor chemicals is much easier. These travel in canoes on the rivers. He came up with some models of network flows describing drug operations and how to interdict these, and it soon became clear with Special Operations Forces that the tactics these people were using were very adaptive. These smugglers were intelligent and observant. We couldn't hide our interdiction efforts and when we did succeed in snagging a shipment, they just changed their tactics, which led us to ponder, ''Gee, shouldn't we model this so that we actually have the adversary represented in a more realistic way?''

And then we suffered 9/11, saw the creation of the Department of Homeland Security (DHS) and the emergence of probabilistic risk assessment as their recommended way to represent terrorist threats. In DoD, we plan for adversarial intent (akin to probability assessment) and for terrorist capability. But we rarely depend upon intent. That DHS was exclusively relying on terrorist intent electrified me into action.

In 2007, I was asked to serve on an NRC committee evaluating the DHS Bioterror Threat Risk Assessment. DHS produces a report every two years consisting of a small classified set of PowerPoints to show to the President indicating, ''Here's what we're worried about, and here are the potential consequences,'' but backed up by an enormous technical appendix. Our NRC assessment was not pretty. Even after DHS complained and sequestered our report for many months ''for security concerns,'' when it was finally released, National Public Radio called it ''harshly critical.'' NRC didn't find much to like in overly complex models with obvious mathematical errors, lacking any standard model lexicon, and depending on millions of probabilities guessed by subject matter experts (SMEs) based on facts not known to science. Unfortunately, the NRC report was released on ''financial meltdown day'' in 2008 (National Research Council 2008). A group from this NRC committee wrote a paper with a plea for DHS to come to reason (Brown et al 2008b). Responding to the nuanced DHS use of the terms probability, likelihood, propensity, and so on, we also wrote a tongue-in-cheek paper that should give you a chuckle (Brown et al. 2008a). These nuances of probability terminology are completely bogus.

Probabilistic risk assessment of adversarial risk is still spreading in DHS and DoD. This is not a good thing. As Tony Cox and I argue, you cannot know what a terrorist knows, or will know in the future (Brown and Cox 2011). You cannot reckon the probability he will take any particular action. SMEs do not render consistent advice between themselves on terrorist intent, nor do they give the same estimates for the same conditions on repeated trials. SME estimates never assess zero (never) or one (always). Yet an adversary will make a decision that is equivalent to zero, or one, and nothing else. This is not science, this is voodoo magic.

I have never encountered a ''subject matter apprentice.'' Have you? A subject matter journeyman? These SMEs seem to appear by self-declaration, and I know of no other stated qualification.

We view modeling of intelligent, observant adversaries as a core competency for our students. I believe ours is the sole curriculum on the planet that requires every student to complete an adversarial modeling case study. We ask them to prepare both sides of the action, attacker and defender, where one opponent has to move first, anticipating how his adversary will respond to that move. We've got about 11 faculty researching these topics with our students, ranging from missile defense to ASW.

You might wonder how ASW becomes a defender-attacker optimization. A ship is visible and noisy, and can't be hidden from an enemy submarine, which will adjust its evasive track accordingly. A nuclear attack submarine (SSN) can search passively, or by active pinging. The latter gets a better fire solution, but exposes the SSN.

We have added a third level to the sequential adversarial decisions. Our tri-level model starts with deciding what to defend, what to fortify, what to harden, and so on. We let the bad guys see this because we can't hide it. These are huge commitments that will appear in the *Wall Street Journal*. They've got cellphone cameras, they can purchase satellite images, and they can use Google Earth. Once they observe your defensive preparation, they get to plan

and carry out their attack(s). Once they attack, we respond by operating the surviving infrastructure as best we can.

We have a viable, large-scale, high-fidelity modeling technique using nested Benders' decomposition that optimizes this complete decision portfolio at once, advising the best worst-case outcome. We've demonstrated this, for instance, working with the Office of the Assistant Secretary of Defense for Homeland Defense and America's Security Affairs (ASD[HD&ASA]), looking at the resilience of the electrical infrastructure and how that might influence mission assurance at places such as Vandenberg Air Force Base, California. We've also demonstrated it with the roads and bridges of San Francisco Bay. We've looked at many other infrastructures including about 150 case studies of infrastructures ranging from gas or oil pipelines, to protecting meetings of heads of state, to securing nuclear stockpiles, to traffic systems. We've modeled just about everything in terms of critical infrastructures, except for banking and finance. And if we find someone who's willing to partner with us and is a domain expert in banking and finance, which we are not, we're eager to help.

*Kirk Yost:* Your work analyzes a range of options for both sides, but the prevalent method is to rely on estimates provided by SMEs. Are you making any headway?

*Jerry Brown:* We've had some success, although we have to separate this out. We've got DoD concerns, DHS ones, and the private sector. In DoD we have a very apt audience because we understand what intelligent adversaries are about and how not to do things and get ourselves hurt. However, we have not had as much success as we would like changing the wording of many DoD guidance documents. We believe that's just a matter of time. It's not an error of commission that these documents have been written with unfortunate language; it's just an oversight. The typical directive says, for instance, thou shalt prioritize your targets and begin prosecuting them in decreasing priority until you run out of resources. We know from just basic knapsack problems that you're not going to get a reliably good plan that way.

We've also had an opportunity to demonstrate this. Our Professor Jeff Kline set up a benchmark in which we competed ourselves against a well-known missile defense planning system. We emulated: find your best defender first, fix that in position, then find your next-best defender, fix that, and continue until you have no more defensive assets to fix. We assume our opponent can detect our defensive platforms and change his plans accordingly. AEGIS puts out a lot of radar energy, and terminal defenders such as surface-to-air Patriot missile batteries are collocated with their defended asset, so you can see them on CNN. The relative effectiveness of the sequential fixing heuristic for our scenarios was zero—all the attacking missiles leaked through our defenses. Using the same set of defensive assets and a defender-attacker optimization, we defended two thirds of the same defended asset list (Logan 2007).

We've had a couple of occasions within DoD to present these demonstrations, and I think it's just a matter of time before these defense guidance documents get reworded.

In DoD, we do plan for enemy intent, which is the equivalent of probabilistic risk assessment, right? What's the bad guy likely to do? But, we also plan for enemy capabilities, where his courses of action are limited only by his resources. What's the worst thing he can do? We're better off in DoD using intent only if we have very good intelligence and if the planning horizon is very short. Otherwise, we always use enemy capabilities.

Recalling WWII, we had about the best intelligence you can imagine. We were reading Japanese Admiralty code messages at the same time their ships were decoding these. And we'd reverse-engineered the German Enigma encryption machine with our Ultra emulation. We had absolutely wonderful intelligence—for example, we were sure the Japanese were going to attack Midway. If Chester Nimitz had acted on enemy intent, he would've pulled our forces out of Hawaii and far forward, advantageously positioned to engage the Japanese and defend Midway, but he did not. He held back because he was cautious that if he deployed our forces, the Japanese could still attack Hawaii and this would have been a disaster. He waited until he had sightings, then he fully committed his ships. That's not intent; that's capability. If you look back in the annals of military history, I think you'll find very few examples of any forces committed based on planning in terms of enemy intent. Well,

any good planning. George Custer may have been an exception.

Let's move from the DoD across the Potomac to DHS. Let's ask a couple basic questions. After 9/11, why didn't DHS go to DoD to learn how to plan against intelligent adversaries? Why did they instead decide to go to National Laboratories? Physicists, of course, can do anything. And, in 2001, National Laboratories had run out of work because we aren't building new nukes, nor testing them. Our National Labs are hungry, looking for work. Congress is looking for work for the National Labs in their districts. DHS is formed. Congress allocates money to DHS and says, ''Go hire National Labs and do something about terrorism.'' And they did.

So what did the National Labs come up with? They looked back in the archives and found ''the Rasmussen Report'' from the Nuclear Regulatory Commission. Rasmussen was a professor at the Massachusetts Institute of Technology who chaired the committee that issued this report, and it is universally referred to with his name. The Rasmussen Report in 1975 made the incredible claim that engineers could predict the outcome of extremely rare events of high consequence, namely the probability that a light water nuclear reactor would suffer some fault that would cause a casualty leading to a major event. This got a lot of press at the time, with the probability of a major nuclear event said to be comparable to ''being hit by a meteor while walking down the street.'' Subsequent to the release of this report, we witnessed the Three Mile Island event. And then the Chernobyl disaster.

The Nuclear Regulatory Commission called another committee together in 1989 to ''look at this Rasmussen Report and see what's wrong.'' The Rasmussen Report was reviewed intensely. It was slightly revised and reissued with no substantive change. The National Labs were well aware of this Rasmussen Report because it's led over the years to what we call today ''probabilistic risk assessment.'' And they dusted this off and said, ''Well, clearly this is the way we should describe terrorists.''

As a side note, Rasmussen himself warned in testimony ''One of the basic assumptions in the (Rasmussen report) is that failures are basically random in nature (….) In the case of deliberate human action … such an assumption is surely not valid.'' Neither DHS nor its contractors seem to have noticed this.

What has evolved is a large number of planning systems funded by DHS and its constituent Coast Guard that in various ways assess the possibility (that is, the probability) of various bad things happening to us. Many of these are what we call TVC models—a probability that a terrorist will attack something, ''T''; a vulnerability to that attack, ''V''; and ''C,'' the consequence of that attack typically described either in fatalities, injuries, or economic costs. These TVC models have become widespread. Although I had read (and, frankly, dismissed) a couple of papers on this appearing in the literature soon after 9/11, I first became aware of the scope and influence of these TVC models when I served on the NRC Bioterror committee.

I have already mentioned that our evaluation was ''harshly critical.'' There have been other NRC committees formed to study other systems and, to date, when you bring in scholars who know something about modeling adversaries, you can expect harsh criticism and wire brushing of these TVC models. They're just inappropriate.

So, a long answer to a short question: we—the gang who agrees with me—have not yet had any discernable influence on DHS, other than DHS now says they're aware of our concerns and have addressed all of them. We have no idea what this means, because they haven't asked us for help. These systems still have no documentation suitable for independent technical review, and they're not yet cataloging data essential for substantive systemic analysis. DHS is very defensive of very large investments on models based on questionable fundamental assumptions, with answers presumably used to guide allocation of grants to state and local agencies.

There are also a lot of boots on the ground gathering data describing our infrastructure. That's a good thing. It's necessary to know what your infrastructure is, where it is, and how it operates. DHS obviously doesn't want to hear what we're trying to tell them. This is unfortunate.

Because you asked, let's go a little further. These TVC models are applied to individual components of infrastructure, not on infrastructure systems. But infrastructure systems have function.

The electric grid has components—transformers, generators, bus bars, and transmission lines—but its function is to provide power to its customers. It makes no sense at all to apply a TVC model to individual components if you don't know how each component functions as part of its system. What we have advised is, if you're going to plan things about an infrastructure, first you should understand that infrastructure and how it works. (Does this sound reasonable to you?) You may be surprised to find that damage to or loss of some particular component has no influence at all on system function.

Another component might also have no influence at all. But if both these components fail at once, say the only two exits from the building, you die. That means you have to understand how the system functions as a whole. That's not as easy as myopic component-wise TVC. But, it turns out if you look at this as we have, these systems are managed, or can be, with OR models. If you look at natural gas distribution systems, they're controlled by optimization models describing the operation of pipelines, storage facilities, and pumps (Avery et al 1992). The same thing's true for crude oil. The same thing's true for traffic management (Alderson et al. 2011). Same thing's true in virtually every infrastructure system, where you'll find there's a system operator (or regulator, or economic motive) whose job it is to make sure nothing bad happens, to guide infrastructure function, and perhaps beneficially motivate system users.

For instance, with the electric grid, there's an independent system operator (ISO). We've talked with the ISO in California. He has 40 million customers and must appear before our legislature every time some of these customers suffer a power interruption. He cares very much about serving his customers reliably and well. He has some extremely high-resolution engineering models that are used to continuously advise how to manage generation and spinning reserves to maintain load balance for his 40 million customers. He controls all of our generating facilities here on the West Coast, and contracts for power imports. Across our country, every electric grid has the same sort of ISO manager.

Do these ISOs plan for coordinated attacks by intelligent terrorists who have studied the basics of electrical power? No, they don't. The industry standard is to plan for a full-up system that can suffer any single component failed, and in a limited way maybe any pair of components. Some of these components are very vulnerable, remotely located and unguarded, and expensive to replace. But, they are very, very reliable. Why worry?

When we discussed this with the California ISO, we suggested we might be able find small, simple sets of components whose loss would have much more drastic effect on his grid than his engineering models predict. He was, of course, quite skeptical of that. We pointed to their operations map in the ISO control room, and asked, ''what if we take out these two components?'' This got his attention because he realized that it was going to be very dark in a large part of California for a very long time. And he said, ''How did you know that?'' We replied, ''because we have the same model you do, and we embedded it in an attack planner that finds the worst case you can respond to.''

My points are simply these:

1. You cannot predict what a terrorist will do. You cannot know what he knows, or predict what he will be thinking in the future. Thus, you cannot guess what he is going to do. You can try, and perhaps gain insight by role playing, but in the end you cannot guess his ''probability'' (that is, his decision).
2. You cannot assess system vulnerability or resilience by myopic component-wise analysis, ala currently fashionable TVC models.
3. You can assess system function. You can learn how an infrastructure system operates, its management protocols, and how it is used by its customers. More important, you need to model this operation to be able to reasonably predict how the infrastructure can respond to any injury to its components.
4. You can assess the level of adversary effort required to damage or destroy an infrastructure component. We do this for a living in DoD, and have cataloged massive databases, for example, joint munitions effectiveness manuals.
5. You can assess, or parametrically evaluate the amount of adversarial investment (manpower, money, and so on) required to mount an attack. We also do this for a living in DoD, especially in Special Operations.

6. An operator model can reveal sets of components, which might individually be undistinguished in any particular way, but whose simultaneous damage or destruction has catastrophic consequences.
7. The economic replacement cost of a critical infrastructure component is irrelevant. If a damaged or destroyed component is critical, it will be replaced, regardless of cost.
8. Effective defensive measures for critical national infrastructure systems are expensive and will be visible to those who wish to do us harm. Adversaries will adapt their plans in response, so we are well-advised to assume they will know about our defensive preparations when we decide what to do.
9. TVC models have motivated gathering data about our critical infrastructures, and this is a good thing. Now we need to go further and specify how these systems of components function, and are managed in the event of failures or attack.
10. Don't be fooled by synonyms for the term probability, used to imply something other than probability.

We've demonstrated how to do such analysis by examples. For instance, we've just finished two student thesis studies by invitation of the U.S. Coast Guard Captain of the Port of Honolulu, one on the operation of the containerized cargo imports into Hawaii (de la Cruz 2011), and the other on Hawaii's import, storage, refining, and distribution of fuel oil and refined products (Ileto 2011). These students met with the refiners, electric utility, commercial shippers, and so on. We're very grateful to the U.S. Coast Guard for making these officials available to us to reduce required travel. Each student built an operator model of his system. The logistics of containers and fuel is well understood. Then, they each looked for ways to interdict their system to see what the best response to the worst case could be. They found particular sets of components that are extremely important to the continued function of these systems, and these systems are vitally important to the Hawaiian Islands.

We hope these case studies, and many others like them, will eventually have influence at DHS.

And, by the way, before the DoD readers of this snicker, I am sorry to report that TVC models have bled from DHS over into DoD. For instance, I have seen one example dealing with vulnerability of Navy shore facilities. All the criticism and warnings above apply equally here.

Tony Cox shows by simple numerical examples that you can get, using these TVC models, not only the wrong answer, but the reverse of the priorities you should be using (Cox 2008). Assuming the terms are statistically independent, which defies common sense, leads you to grief. For instance, if V increases significantly, you would expect this to influence T, wouldn't you?

(As I teach all my students, the independence assumption can get you killed! The most stunning DoD case I recall was a model of an integrated enemy air defense system that assumed independence between all radar returns.)

But I do understand how my containers are handled. I do understand how my refinery is run (with a linear program). I do understand how oil and gas are transported (with linear programs).

The electric grid is also controlled, in real time, by optimization models. I want to use things that I do understand such as how the system operator responds to casualties and mischief. How does he keep the system running? How does he plan this?

That I understand. And I do understand how terrorist and military actions take place. We've got the Al-Qaida training manuals. We've got intelligence. We train Special Operations Forces to do the same things to our enemies. We have manuals, unclassified manuals, on explosives and demolition. We know how many people it takes, and exactly where and how to take down the Golden Gate Bridge. We know this because a student Red Team showed us how. The sort of modeling that we're doing (bi-level, or tri-level) we feel is based on things that we do know or should know.

I don't want to guess what an adversary is thinking. I can't. I care about defending my country, our society, and our way of life from the worst-case thing that could possibly happen to our infrastructure. If I can do that, I may also make that infrastructure more resilient against engineering failures and Mother Nature.

Finally, let's move to the private sector. Congress, in its infinite wisdom, passed and extended the Terrorist Risk Insurance Act, indemnifying private sector organizations from losses inflicted by terrorist actions in excess of private insurance coverage. Business has responded reasonably enough by doing almost nothing except perhaps naming a Director of Corporate Continuity and establishing a back-up data center. They're whistling in the dark.

*Kirk Yost:* When do you think the two-sided methods will become mainstream OR topics?

*Jerry Brown:* The tutorial we wrote on this is the most highly cited one in the history of INFORMS, so something good is happening (Brown et al. 2005).

*Kirk Yost:* Can you talk about two unpleasant areas where optimization was heavily used, the financial crisis of 2008 and challenge of modern air travel?

*Jerry Brown:* Serving on the NRC BMSA board, I've learned more than I ever wanted to know about our monetary, financial, and investment systems. We took testimony from Treasury officials, from major investment banks, from traders, and so on. Days of this.

There are some very sophisticated models being used for trading, including trading derivatives and other exotic investments. I don't think this was a failure of modeling. These are smart people and they're influential. This was an egregious failure of investment institutions and Federal regulation. It was also a failure in the sense that people motivated by making a lot of money put a lot of lipstick on a lot of pigs, and got away with it, and to this day haven't been brought to the dock. But we haven't found any generally agreed mathematical smoking gun. BMSA found a couple of topics that NRC might look at if Congress asks. I don't anticipate any Federal regulator will ask. But, these topics do not include stochastic modeling or the underlying optimizations still being used by, for instance, portfolio managers.

*Kirk Yost:* You did not see errors in the portfolio models that probably were all sourced in the OR literature, I would think.

*Jerry Brown:* Not as much of that appears in literature as you might think. That's considered to be a proprietary advantage by the people who are paying the bills. I have met some ex-students whose suits cost more than my first car. This is a sophisticated business.

We have people on the BMSA panel who are experienced, very senior, very accomplished economists—for instance, mathematicians and modelers, Wall Street types—and they would've been on this like a cat if they thought something had been done incorrectly.

*Kirk Yost:* One of your colleagues wrote an article that noted optimization seeks extreme solutions. Airline travel nowadays is extreme in the sense that the airlines have downsized to the minimal possible size airplanes, minimal possible seat spacing, and so on. And I was wondering what you have to say about that.

*Jerry Brown:* That's a result of deregulation and Adam Smith's hidden hand. This is happening because the market will bear it. If people are willing to pay more money to travel in greater comfort, there'll be more such seats available.

We have a mass market that wants to pay the minimum possible to get from City A to City B, and is willing to put up with a few hours of discomfort to do it. If you work for the government, like me, you're expected to use the cheapest, lowest-class service available to this mass market, so your last-minute travel will be in the last available seat that doesn't recline in the back middle of the five-across seats. Just suffer with it.

My advice for U.S. airlines, if they want to save a lot of money, is to dissect their proforma labor contracts with their pilots and cabin attendants. Over years, the sheer length of these contracts has grown to far exceed the impressive volume of Federal Aviation Regulations. There are reasonable credits for working at night, layovers, and so forth. However, letting your flight crews live wherever they want and fly (often at no cost) an arbitrary distance and time to get to their official domicile to begin a duty period needs adult intervention. The Federal Aviation Administration is looking into crew fatigue as a result of this. Let's cross our fingers that the National Transportation Safety Board doesn't have to join this hunt after another incident.

Any industry that lets its high-paid executives work for the first part of each month for a specified number of hours, then take the rest of the month off, partitioning such labor records in strict monthly buckets, needs its head

examined. And that's exactly what we have in the U.S. airlines these days.

*Bob Sheldon:* You have a lot of former students who will be reading this oral history, as well as current and future students who will be reading it. Any comments you would make to them about their profession?

*Jerry Brown:* I have enormous respect and admiration for our students, and I am grateful to have had the opportunity to work with these amazing people.

I am trying to make a few changes here at NPS. I want our local junior college to staff and teach a basic English exposition class for us. American secondary education has collapsed, and even some inputs we're getting from the service academies have managed to keep it a secret from themselves and others that they can't compose a complete paragraph in English. We finally confront this here when it comes time to review the mandatory MS-OR thesis draft. Whew. That's too late. We need to screen early in our curriculum and help these junior officers get squared away.

This can't happen to you as an OR. OR is about describing a problem back to the client so the client declares, ''Yes, that's what I meant to say.'' Exposition is all, and clarity of exposition is a symptom and a concomitant with clarity of thinking. These are innocent victims, but they really, really need to take a remedial ''bonehead'' English exposition class until they can pass a test writing a complete, clear paragraph.

I've also advised a number of my students and colleagues to participate in Toastmasters, as I have done. This is a very effective way to invest one lunch hour a week learning how to improve verbal exposition. It can be a lot of fun, and it works. Our junior officer students who have not yet discovered their exposition problems are soon going to be the go-to experts when they graduate. They're going to be expected to write point papers for Monday briefs about material that gets dropped on their desk at 1700 on Friday afternoon, and they can expect to be appointed to make presentations to senior executives. They need to know how to speak. They need to know body language. They need to know when not to put their hands in their pockets, how to dress, how to face an audience, moderate voice, and conduct themselves. This is an important part of our profession. This is an important part of our education here, and I want to enhance this.

I'm pleased that MORS has prizes for expository excellence, both written and verbal, and I encourage MORS to continue that. It's important. MORS and NPS OR have the MORS-Tisdale competition among members of each MS graduating class, started by Rick Rosenthal, who named it for his late student Steven Tisdale. This is our most important single award, decided by an expository competition in front of an audience of all students and faculty, including senior executives invited for the occasion. The winner is judged to be the best exposition of the best analysis.

*Kirk Yost:* Rick Rosenthal did a lot to bring optimization tools to the masses. Could you comment on Rick's contribution to optimization instruction at NPS?

*Jerry Brown:* Rick introduced us to optimization modeling languages, in particular, to GAMS (http://www.gams.com). This reduced the effort to build a new model from days to minutes. Rick had boundless enthusiasm for teaching students and mentoring young scholars, and many readers of this will recall his charm and warmth (Bausch et al. 1991, Brown et al. 2007, Newman et al. 2011, Brown and Dell 2007, *Naval Research Logistics* 2011).

*Kirk Yost:* I have heard that the classified version of *MOR* was your idea. Is that true, and how is it coming?

*Jerry Brown:* That is true. NPS Professor Robert ''Bob'' Koyak is the editor (rakoyak@nps.edu). The MORS *National Security Operations Research* journal is now in operation. I believe this is going to be put out as an electronic paper that's on a push from SIPRNet. This is currently the only way we should be publishing real stuff while we still have our boots in theater. We would like to be able to publish for the consumption of others within the MORS community some of the things we've done over there, and we can't. We also think we have a lot to learn from others. The only opportunity we have had is to give and listen to talks at our MORS meetings, and that's not as satisfying or instructive as having a complete archival document.

*Bob Sheldon:* Is it natural to take some of those classified papers and sanitize them and make them unclassified or does that prove too difficult?

*Jerry Brown:* We're not a classifying authority here. And, how do you "sanitize" an idea? Of course this stuff is secret. It involves protecting our personnel and making them more potent. Once we're out of there, it might be reasonable to go back and make a case, "Okay, here's what we've done, and how it worked. What part of this is operationally still a matter of some sensitivity, and what part of this is now so routine and well-known we can publish it and make our taxpayers proud of us?"

*Bob Sheldon:* Anything else from you, Kirk?

*Jerry Brown:* Kirk, you never asked me the hardest problem I ever solved.

*Kirk Yost:* Everything you work on looks hard to me. But I will ask the question, what is the hardest problem you ever solved?

*Jerry Brown:* It was at UCLA. A guy handed me an x-ray crystallography problem. And I worked on that for about five months. I just rediscovered my notes here a couple weeks ago. I don't even understand my own notes anymore. But the x-ray crystallography problem is fascinating. It's what we now call reverse optimization. What you have is a bunch of digital evidence of what the answer is, and you seek the question most likely leading to that answer. To this day, I have to admit that was the hardest thing I've ever done.

*Kirk Yost:* Are you satisfied with the progress you made on it?

*Jerry Brown:* Yes, we made good progress, and now there's a whole area in physics that studies this, and quite a bit more theory, probably beyond my ken. There are a lot of related areas in microscopy and things like optical identification of fingerprints, eye prints, facial recognition, and so forth. It's fascinating stuff. I'm glad we have smart guys who can work on it.

*Kirk Yost:* In your view, what is OR and why should we care?

*Jerry Brown:* Fundamentally, OR is about discovering simplicity in complexity; discovering clarity in confusion. Let me read to you how Mike Mullen put it well during his interview with INFORMS (Horner 2010):

> *"One of the great things that the graduate education in OR taught me was how to think much more critically than I had before, and really, to frame a problem, … And where that really helps me in this job is being able to still frame a problem in my mind and to look at it differently than many people who bring those problems to me."*
>
> *And then I have an opportunity to ask the right questions. … It's become a pretty natural part of how I do business: … the ability to frame a problem … and then ask hard questions that push the system in a direction of an answer that clearly wasn't forthcoming by the time it got to me."*

People most frequently come to us, especially in military OR, not because they want to, but because they feel they ought to, or have to. They're typically faced with complex problems and feel for whatever reason—either our reputations from prior successes, or just sheer hope—that somehow we might be able to help with these problems.

If you look at the way we do help, you will find a common pattern for success—one not described in any textbook or manual. And I think these standard things help explain why our graduates have been so successful in senior policy positions.

The first thing we're trained to do is to define and use a standard lexicon, and we employ that language carefully. We then use that lexicon to write down in our native language, in our case English, but in any native language, write down our understanding of what the problem is (Brown 2004). That's step 1:

1. What is the problem?

We usually write two versions of this. We write one version that is the executive version, suitable for a general officer without such training as ours to read, and to understand. And another aimed at our OR colleagues.

I've also advised to have someone who is untrained in OR read your problem description back to you. A spouse will work. If, when they're reading this back to you, they hesitate or stop and look up at you, or they need terms defined that they don't understand, such as "algorithm" (this term is the third rail of such descriptions), then you need to edit and rewrite.

Next, you have to decide:

2. Is this problem important?

In government we can sometimes get involved in studies about differences that can't make a difference. The earlier you conclude

you are engaged with a problem not worth solving, the better. This conclusion shows how you finish your problem description, because the potential client who owns the problem has to recognize this. If the potential client just wants to use your imprimatur to burnish some routine decision, it's up to you whether to cooperate.

Next, you have to find out:

3. How will this problem be solved without your help?

It turns out tribal wisdom can be pretty effective, especially in DoD where people have risked much to learn how to solve problems, and how not to solve them. Here, it is wise to actually visit the operations center, office, command, or wherever these decisions are made. A personal visit and interview of participants can be most enlightening. It reveals the tone of the organization, the level of sophistication of participants, and, perhaps most important, the willingness to actually participate. No matter how much senior officers and management may admire some nifty possible new improvement, if their subordinates aren't convinced, incentivized, and on board, you are dead in the water.

I'm keen on looking for any post-it notes, handwritten spiral binders, or other paper reference materials—these are probably not on any computer system and very likely contain gems of wisdom. I'm also aware that a phone call can beat a clever decision support system every time, because such a call can relax a requirement, modify a mission, change an objective, and so on. You can't get a sense from afar of whether such horse trading is used. When we take our problem description back to the people who brought the problem to us, and if they read that description and say, ''Yes, that's what we meant to say,'' that's a good sign we're making progress.

(I'll bet a number of MOR readers have experienced some technical briefing, when the audience starts to get lost, and all turn to the sole known OR in the room for clarification. Does this ring a bell?)

Surprisingly, this is the successful end of many engagements. Having merely clarified the problem statement, sorted out distractors, stated what courses of action are available, and examined current practice, you may be finished. For example, I have been asked more than once to schedule the Navy's fleet of executive aircraft. After due diligence, I have always concluded this is not worth the effort. On-call demands and shifting priorities with no likely way to forecast these makes an operations center whiteboard a pretty effective tool for visibility and decision making. And, besides, my understanding is that any ''scheduled'' air transport is the exclusive business of our Air Force. Nah.

If we decide to continue, the real fun begins. We may get to do some preliminary mathematical modeling. But, regardless, we next have to plan, design, and formally commit to answer:

4. What do you propose to do?

This is the meat and potatoes of our profession, but we have to hesitate to jump to this stage before passing all prior qualifications. And, a key corollary question we must answer up front is:

5. How will we all know when you have succeeded, or failed?

Remember, OR is (or should be) science. Throughout, our mantra is, ''if it's not written down, it never happened.'' PowerPoints can help, but never substitute for writing. These writings are the key step in design before you do anything else. This brings us to the last step:

6. Is the documentation of your success sufficient for external professional and technical review?

I have encountered important decision support systems in DHS and DoD, notably recent ones using probabilistic risk assessment for intelligent adversaries, that are documented exclusively by PowerPoints, if at all. And, even these scant materials are held in confidence. (Not classified, just held back.) This is shameful. If I am asked to evaluate such a system, you can expect strenuous objection. On occasion, I have determined that the lack of documentation is an unambiguous telltale that the proponents don't know what they're doing. This is dangerous.

These six guidelines suggest for either side of the table how to structure, engage, manage, and conduct a defense contract involving OR.

An operations researcher should be prepared to seamlessly and comfortably transition from the verbal description of the problem to the mathematical description of the problem to perhaps any modeling that's required to address the problem, and especially be effective in explaining ''the what'' and more importantly ''the why'' of the results that you get from such modeling.

*Kirk Yost:* You've been elected to the National Academy of Engineering (NAE), the first NPS faculty member to receive such an honor, and most military operations researchers don't follow the activities of that organization. Can you explain why that should be important to us?

*Jerry Brown:* The National Academy of Sciences was created by President Lincoln in 1863, during the Civil War, to seek help from civilian engineers and scientists to advise the Union on issues that were vital to the conduct of the war. For instance, ''is metal cladding of naval ship wooden hulls worth the time and expense?'' The NAE was created a hundred years later in 1964 as a sister organization, not so much devoted to the pure sciences as to the new engineering sciences such as (today) aerospace, bioengineering, chemical, civil, computer science, electronics, operations (that's us), materials, mechanical, and earth resources engineering.

I learned of my election by the members of NAE via a cellphone call from my chairman at the time, Jim Eagle, while standing in line with Jeff Kline at Dulles, waiting to board the first of flights home from Washington. Jeff and I were seated separately in the lousy coach seats we are required to occupy, and we had completed our mission, save writing a report we could not do in public. A cabin attendant showed up with a cold beer from Jeff. Thanks, Jeff—best beer I ever enjoyed.

The mission of the NAE is to objectively advise on questions about technology and policy. There are currently about a dozen members who have contributed directly to military operations research. Among us, for instance, the late Seth Bonder, Peter Cherry, Don Gaver, Dave Maddox, Bill Perry, Steve Pollock, Steve Robinson, Larry Stone, and Al Washburn. Typically, NAE gets involved with the National Academy of Sciences and the Institutes of Medicine, the three sister organizations, through the NRC, which is the coordinating organization. The NRC's foremost frequent client is the U.S. Congress, with DoD a close second. Studies are commissioned to advise on technological questions that bear on emergent policy issues.

In such a case, NRC will form a committee typically numbering a dozen or more, composed of members of the Academies as well as academics, scholars, and other domain experts. A committee will meet maybe four to six times, take testimony for a day or two at a time from experts, and deliberate (either with a press gallery, or in closed session). Between meetings, members have homework to do, correspond extensively, and plan with NRC staff who arranges invitations for the next meeting. Eventually, the committee writes a ''consensus report,'' which is anonymously reviewed by about 10 reviewers and an editor, reviewed with the client organization or the subject of the study, as directed, and then released to the public (http://www.nationalacademies.org/publications/). All this is aimed to respond to, inform, and advise legislators and administration officials our best advice. The idea is to influence policy, and, in some cases—you always have to follow the money—change appropriations.

NRC also manages studies boards for the uniformed services.

*Bob Sheldon:* A distinction between theoreticians and practitioners. For the field of optimization there are people who do theoretical optimization, and there are people who solve real-world problems. Sometimes it's viewed as a dichotomy, but you seem to embrace both of those; you're both a practitioner and a theoretician. Could you comment on that?

*Jerry Brown:* Both are essential. You need to try to develop and maintain deep roots, and especially be open to new ideas. Sometimes it takes a while to really internalize which of all these new theoretical results can be put together with other results and have some consequence. On the other hand, having some actual practice with real-world problems gives you instincts about where you need to apply yourself theoretically, and what will work and what won't. I have no particular bias about pure theoreticians or pure practitioners except to say that I lament the fact that pure theoreticians don't at least

have some real experience to help shape their thinking and their instincts.

And pure practitioners can get in trouble if they don't understand the underpinnings of the tools they're using. We see embarrassing evidence of these extremes all the time. So there is a middle ground. I admit I've always written papers with as few theorems as possible. If you're absolutely forced to write a theorem to justify what you're doing, then maybe that's a new result. If you're writing theorems just to pepper a paper with them, then you're just fooling yourself. Most such theorems I see could have, instead, pointed to prior ones.

*Bob Sheldon:* Offline we were talking about your experience flying while you were in Newport, and I think some people will be interested if you care to relate that.

*Jerry Brown:* It's a story of how sometimes when you get involved in military and Navy regulations, funny things happen, and there's nothing you can do about it. I was an officer candidate at Newport and the Navy and Marines were quite desperate for aviators. At that time if you could pass an aviation physical and had 20/20 vision, they encouraged you so strongly you might say they coerced you into taking aviation familiarization training. I was put on a bus to a local airport, introduced to an instructor pilot, and we took off for our initial familiarization flight over Narragansett Bay. My instructor started me with some basic maneuvers. This went well, so we quickly progressed to stalls, departure stalls, spins, hood work, unusual attitudes, and he finally asked me to land. Taxiing back to the ramp, he declared, ''You're a ringer. You already know how to fly. What are you doing here?'' I replied, ''Because they told me I should be here, so here I am.''

We both revealed all to OCS. We were encouraged to continue my aviation familiarization, so my delighted flight instructor and I had a lot of fun with aerobatics, and will neither confirm, nor deny, regularly enjoying apple pie and a cup of coffee on Martha's Vineyard.

*Bob Sheldon:* Anything else that you care to relate?

Jerry *Brown:* We are most grateful for sustaining pure research support from the Air Force Office of Scientific Research, and the Office of Naval Research. This enables us to parachute in to problem situations on short notice. (NPS has no mission funding for research—a fact that surprises folks seeking our help.)

Most of all, I'm grateful to my loving and trusting spouse who knows how much I love this job. She understands and appreciates the consequences of our work, and tolerates the long hours and those occasions when I have to disappear without prior warning or later explanation.

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