The Defense Department's $2 billion research agency does things differently. But its unorthodox management style seems to work, and it's winning converts

Pentagon Agency Thrives on In-Your-Face Science

The exploding landmines were so close that Gary Settles could feel the shock waves as the blasts gouged meter-deep craters in the earth and sprayed deadly shrapnel into the air. The Pennsylvania State University, University Park, mechanical engineer, safely sheltered inside a concrete bunker on a Florida military base, was getting a reality check of sorts. He and other researchers had been brought to the base by their funder, the Defense Advanced Research Projects Agency (DARPA), to get a closeup look at the pernicious power of the explosives and to instill a sense of urgency to a $25 million effort to invent radically new mine detectors that mimic a dog's keen sense of smell. The experience was "certainly out of the ordinary," says Settles, who usually can be found in his lab, studying gas and liquid flows with lasers and high-speed cameras. At DARPA, however, "out of the ordinary" is standard operating procedure.

DARPA is not your typical federal research agency. Whereas the bigger—and more mainstream—agencies, like the $3.5 billion National Science Foundation (NSF) and the $16 billion National Institutes of Health (NIH), typically use peer-review panels to pick grant winners and then stay out of a researcher's way, the Pentagon's leading research funder takes a decidedly different approach. For 41 years, it has given a small group of program managers extensive power to direct high-risk, and sometimes wacky, research projects. Right now, for instance, the $2 billion agency is funding work on hopping robots that could scout battlefields, software that could instantly translate any Web page into English, and beetles that might be trained to home in on enemy ammunition dumps. "If you've got an idea that will revolutionize the world and doesn't violate too many of the laws of physics, we're listening" says DARPA's Larry Dubois, who manages the Defense Sciences Office, one of seven major divisions at the agency (www.darpa.mil).

Once sold on an idea, the agency likes to get in a scientist's face. "I wanted to show them exactly what we were up against," says DARPA's Regina Dugan, explaining why she organized Settles's field trip. Dugan and other program managers also expect their researchers to attend team meetings, file monthly reports, and work cooperatively with other contractors. "It's a different culture; you just don't see this with NSF," says Settles. The agency also manages its money differently. Most government science managers hand out grants that are open-ended and almost never rescinded, but DARPA writes contracts that call for deliverables and allow less promising work to be canceled easily. "It's our duty to kill off projects that aren't working," says program manager Alan Rudolph.

Fieldwork. DARPA's Regina Dugan (left) shows military brass a new mine finder in Bosnia.

Although some researchers grumble that DARPA's approach is heavy-handed, it has produced some spectacular results. The Internet, night-vision goggles, and radar-evading stealth aircraft all grew out of DARPA-funded science (see sidebars). Indeed, the agency's track record has so dazzled some policymakers that they want to use its freewheeling approach as a model. A White House panel, for instance, recommended in April that NSF invigorate its computing research program by adopting DARPA's "strong manager" philosophy, and a few members of Congress recently proposed reorganizing the Department of Energy's troubled nuclear weapons research program into a DARPA-like independent agency. It's too soon to know whether those proposals will fly, but NIH officials have already begun testing whether DARPA-esque management methods, such as assembling interdisciplinary research teams and pushing them to share information, can produce breakthroughs in cancer-detection technologies.

Even insiders, however, say that DARPA's approach has its weaknesses, and that it may not be appropriate for other agencies. Congress, for instance, must decide "how many swings [an agency should be] allowed to take before making a hit like the Internet," says Rudolph. And even when its projects do succeed, DARPA has had trouble moving findings into the military or the marketplace. In materials science, for example, the agency has "developed these interesting materials," but often "they sit on the shelf," says Steven Wax, another program manager.

Perhaps the biggest challenge facing DARPA and other agencies thinking of following in its footsteps is the difficulty of recruiting managers cut from the right cloth. "The DARPA model works best when the person handing out the awards is an intellectual peer of those receiving them," says sociologist Ed Hackett of Arizona State University in Tucson, a former NSF program manager who has studied the use of peer review and other funding styles in federal agencies. "Recruiting those people [from academia or industry] is very difficult. Part of the reason [the DARPA approach] works is that it is done sparingly."

An antidote to groupthink

From the very beginning, DARPA was designed to be different. President Dwight

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Eisenhower created the agency in 1958 after an investigation following the Soviet Union's surprise launch of Sputnik blamed delays in the U.S. military satellite program on bureaucratic infighting and an unwillingness to take risks. Determined to prevent future lapses, Eisenhower ordered Pentagon planners to create an agency that, in the words of a DARPA-published history, would be "anathema" to the military R&D establishment and would recognize that "great leaps forward cannot be made by committee planning." Instead, DARPA would rely on a corps of activist researchers to look beyond near-term military needs and fund areas with great potential to revolutionize war-fighting. Today, "the emphasis remains on searching for new ideas," says DARPA director Frank Fernandez, who joined the agency last year after more than 20 years in the defense industry.

That search has taken DARPA in many directions. The agency has been a major source of funding for computer and software developers, and also invests heavily in materials science, microelectronics, and robotics. It has also made a mark in aeronautics, helping both the Navy and Air Force develop missiles and new aircraft. And 3 years ago, it launched a new biology program, hoping to attract top-notch scientists with ideas for defending against bioterrorism that may be too far-out for traditional NIH funding (*Science*, 7 February 1997, p. 744). The broadening of DARPA's traditional focus on the physical sciences and computer technology has already fostered unconventional strategies for rapid detection of infectious agents and even gene sequencing (*Science*, 11 June, p. 1754).

DARPA's spending targets are a source of some tension between the agency and its military customers, however. Whereas Pentagon planners often push for less risky research that will produce near-term payoffs, DARPA officials have jealously guarded their freedom to chase provocative ideas.

DARPA's Highs and Lows

The Defense Advanced Research Projects Agency (DARPA) may be part of the military, but its chief says the agency doesn't measure its performance in terms of clear-cut wins and losses. "Very rarely does anything at DARPA fail in the sense that we didn't learn something," says director Frank Fernandez. "Our failures for the most part are that we fall short of our goals." But observers say DARPA's work over 4 decades has included several notable hits and misses:

HITS

- Stealth Technology: In 1977, DARPA's Have Blue program flight-tested two radar-evading prototypes that evolved into the F-117 and B-2 stealth aircraft.
- Phased Array Radars: In the 1960s, DARPA pioneered large, ground-based radars capable of tracking Earth-orbiting objects. Some are still used today.
- Massively Parallel Processing: The 1970s Illiac 4 project put DARPA at the forefront of high-end computing.

MISSES

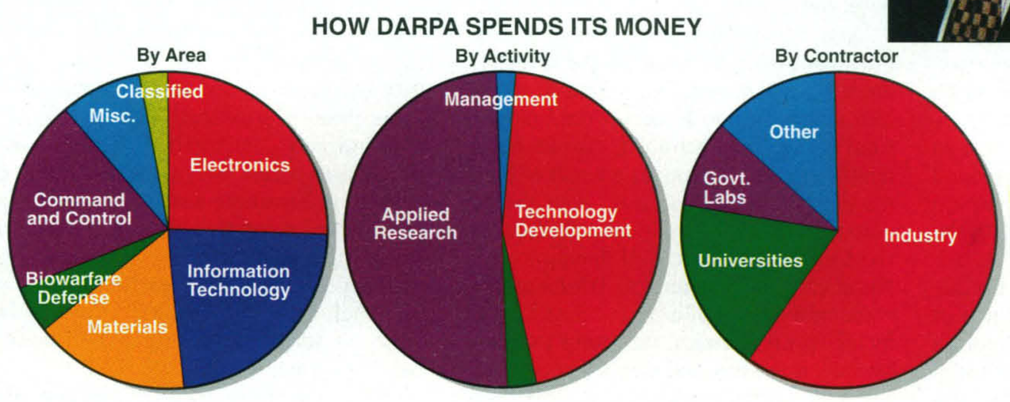
- Naval Task Force Management: A 1980s plan to use artificial intelligence software to manage complex naval engagements never materialized.
- Intelligent Robots: Robots smart and robust enough to fight on their own remain years away from the combat zone.
- Battlefield Awareness: Researchers are still struggling to find software and sensors that can keep tabs on battlefield developments without giving participants an overdose of information.

The two cultures "don't think all that similarly," says Fernandez. To bridge the gap, he recently told Congress, the military must "learn how to experiment," while DARPA researchers must "learn the art of warfare." In the meantime, Fernandez meets regularly with Pentagon brass to discuss the agency's priorities, which are also reviewed by several outside panels.

On the front lines of DARPA's work, however, are the agency's 125 program managers, who are recruited for their technical savvy and desire to leave their mark on a field. They are known within scientific circles by a panoply of nicknames that range from "idea scavengers" and "miracle hunters" to "eccentric" and "idiosyncratic." Although such traits might be undesirable at most federal agencies, they match DARPA's recruiting rhetoric, which boasts that "the best program managers have always been freewheeling zealots."

They are also zealots with flush portfolios. A DARPA program manager will typically spend up to $40 million or so on contracts to industry, academic, and government labs for one or more projects. Although managers face a variety of bureaucratic "reality checks" in the spending of funds, including regular reviews by DARPA brass, some become influential figures in their subfields, capable of nudging established research communities in a particular direction or creating collaborations where none existed before.

But their influence usually doesn't last long: Managers stay for an average of 4 years, and each year they must fight for their piece of the budget. "It's an environment that rewards hustle and bureaucratic skills as much as real understanding of the technologies," says historian Alex Roland of Duke University. Adding to the pressure is the fact that DARPA tries to complete up to 20% of its projects each year. "We don't do renewals," warns Dubois, although some programs are reformulated to get a new lease on life. Still, "the opportunity

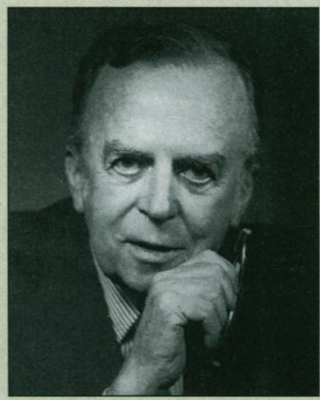


CREDITS: DARPA

Venture capitalist. DARPA head Frank Fernandez will put $1.9 billion this year into risky research.

The Real Father of the Internet

Hundreds of Defense Advanced Research Projects Agency (DARPA) managers have tried to put their stamp on an emerging field. But one towers above the rest: Joseph C. R. Licklider, the psychologist and computer scientist who in the 1960s launched what became the Internet. "Lick," as he was known, epitomized the mix of playful imagination and down-to-earth management skills that current DARPA funders strive to emulate. "He helped set the standard for the proactive DARPA manager," says historian Alex Roland of Duke University in Durham, North Carolina, who is working on a history of the agency's computing research program.



Model manager. Licklider sought "a new way of doing things."

Licklider came to DARPA—then called ARPA—in 1962 after stints as a lecturer at Harvard University and at the nearby engineering company Bolt, Beranek and Newman. Fascinated by the social and technological implications of the new phenomenon of networked computer systems, he decided that DARPA needed to get on board. He accepted the task of directing the agency's information processing program only after being assured that he would be allowed to pursue his vision of interactive computing, spelled out in a now-famous 1960 paper on "man-machine symbiosis" (memex.org/licklider.html). "I just wanted to make it clear that I wasn't going to be running battle-planning missions," Licklider told an Internet historian (www.columbia.edu/~rh120) shortly before his death in 1990 at the age of 75. "I was going to be dealing with the engineering substratum that [would] make it possible to do that stuff."

Once on the job, Licklider quickly reshaped the program to fit his vision. He canceled contracts with some companies and moved the money to selected university labs, which he believed were more innovative and more capable of building a community of interested scientists. The companies "were studying how to make improvements in the ways things were done already," he recalled. "I was interested in a new way of doing things." In the kind of whimsical wordplay that still marks DARPA program descriptions, Licklider said that he was trying to develop an "Intergalactic Network." The phrase was later shortened to "Internet."

Like today's DARPA managers, however, Licklider had to push a fractious group of researchers in a common direction. "I am hoping there will be ... enough evident advantage in cooperative programming and operation to lead us to solve problems," he wrote in a 1962 memo that urged his team to work together. Their efforts, and DARPA's investment in the hardware and software that allowed distant machines to link up, eventually produced e-mail and the Internet. By 1964, when Licklider left the agency (he would return for 2 more years in 1973), his views had become the compass for the agency's work in the field well into the 1970s. And his funding style—described by one academic as "Johnny Appleseed on a mission"—helped build top-notch computer science departments at many universities. "The significant advances in computer technology, especially in the systems part of computer science, were simply extrapolations of Licklider's vision," says Robert Taylor, one of Licklider's successors at the agency.

Replicating Licklider's success, however, hasn't been easy. In the 1980s, for example, DARPA tripped over efforts to boost "artificial intelligence" (AI) systems that would help pilots fly complex jet fighters or admirals manage chaotic naval engagements. "The initiative failed to realize the grand vision of AI's pioneers," says Roland, noting that vision isn't always enough. The technology underlying AI has yet to mature, say experts, and there is disagreement about whether it ever will. In contrast, the networking systems that Licklider helped foster have become ubiquitous and changed the way people live and work, enhancing his reputation as the DARPA program manager nonpareil. As Roland notes, "sometimes it also comes down to luck."

–D.M.

to have a major, lasting impact in a short time is tremendous," he says.

Pressure to produce

Dugan's "electronic dog's nose" project and Rudolph's Controlled Biological Systems (CBS) effort illustrate both the influence that DARPA program managers can wield and the pressures they face in producing results. The two projects—one about to end, the other just beginning—also highlight the agency's relentless search for novel technologies.

When Dugan, a mechanical engineer, arrived 3 years ago from a Pentagon think tank in Washington, she knew that her new employer shared her growing interest in finding better ways to locate abandoned landmines, which pose an increasing threat to U.S. peacekeeping forces in the Balkans and elsewhere. Mines can be difficult to identify with current metal-detecting technologies. And a high rate of false signals means that mine clearers spend hours digging up metal odds and ends not related to mines. But there "was no promise I was going to be able to sell a program," she recalls.

After months of research, Dugan set her sights on what her bosses agreed was a promising approach—detectors that, like a trained dog, could sniff the chemical vapors produced by a buried mine's explosive charge rather than homing in on its metal parts. Such an electronic dog's nose would not only reduce the number of false starts but also help detect newer mines that have fewer metal parts.

Before she could assemble and manage the interdisciplinary team needed to build a dog's nose, however, Dugan had to plunge into unknown intellectual waters ranging from biology to electronics. "In the beginning, there is a tremendous amount of information you have to absorb," says the 38-year-old Dugan, who earned a doctorate at the California Institute of Technology in Pasadena before coming to Washington to work on a variety of defense-related issues, including the chemical signatures produced by nuclear missiles and the problems associated with detecting unexploded armaments. "I'm a fluid dynamics person, but I had to learn about olfaction in a hurry," she says.

The crash course paid off when DARPA agreed in 1997 to invest $25 million in Dugan's program over 3 years. Soon after, with the help of an advisory board, she drafted a request for proposals and selected the 13 academic and industry contractors for the research team. Settles, for instance, was contracted to document how dogs sniff without interrupting the flow of scent across their nasal membranes. (The answer: Their noses are designed to inhale fresh air from above and then exhale down and to the sides.) At the same time, neuroscientists were asked to apply to new detectors their insights into how animals can use just a few kinds of cells to differentiate among a wide range of odors (as the eye uses just a few cells to sense millions of colors). The team also included concepts not based on dog models, such as a California company's attempt to adapt an existing airport bomb-sensing system for field use.

Picking the team, however, was only part of what Dugan describes as "juggling 100

CREDIT: KOBY-ANTUPIT & MIT RESEARCH LABORATORY OF ELECTRONICS glass balls." Another challenge was to unite everyone behind the goal of meeting DARPA's tight deadlines for producing prototypes. "It was pretty routine to see some resistance to [DARPA's] level of involvement" at the beginning, she says, particularly among university-based scientists who had never experienced the agency's hands-on management style. The process was aided by a series of semiannual team meetings, including the mine demonstration, some hands-on training with existing mine detectors, and a visit from a man who lost his legs in a mine explosion. "There was a lot of social engineering going on" during the events, Dugan says.

Dugan isn't ready to release details of the dog's nose project, now entering its home stretch, except to say that the team recently demonstrated "proof of principle" for one chemical-sensing system. And the most promising device may not mimic a dog's nose at all. Rather, the scaled-down airport detector produced by Quantum Magnetics of San Diego spots buried mines by beaming low-power radio waves into the soil and locking onto a unique signal produced by the explosive charge. But neither approach will move ahead toward a military use unless Dugan convinces one of the armed services to pick up the cost of continuing development. "We're in the throes of important negotiations," she says.

Even if the Pentagon doesn't bite, however, Dugan's work may still pay off among companies involved in the project, which retain rights to their devices. Indeed, once their term is finished, DARPA program managers often find themselves back in private industry or academia working on the same problems.

Going buggy

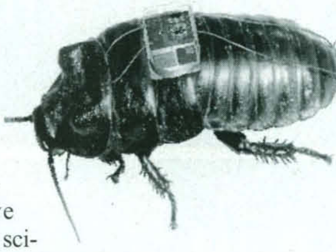
As with Dugan's interest in mines, Rudolph's training as a zoologist led directly to the agency's $10 million, 3-year CBS project. Begun last year in a bid to harness the abilities of insects and other animals for military purposes, such as monitoring enemy positions, the project's nearly two dozen initiatives include exploring the practicality of training beetles, moths, and bees to home in on the chemical signature produced by landmines or chemical weapons plumes. Another idea probes the aerodynamics of flies with an eye toward developing microaircraft, while a third is studying the feasibility of creating electronic interfaces to bug brains. That could open the door to equipping the insects with interactive sensors, perhaps even "remote control" devices that direct the insects to crawl or fly in a particular direction.

Rudolph, one of the few zoologists ever to work at DARPA, jokes that one of his aims in coming to the agency after nearly a decade at the Naval Research Laboratory was to create "smart bugs, controlled bugs, and robo bugs." But on a more serious note, Rudolph also hopes to forge links between scientists and engineers working on animal locomotion or perception. "DARPA does seem to be more open to ideas that cut across disciplines," says Michael Dickinson, a fly aerodynamics researcher at the University of California, Berkeley.

Like several academic researchers new to DARPA's ways, Dickinson says he was "a little nervous at first" about his new backer. But he has come to appreciate its approach, he says, in particular its project meetings that give project engineers and life scientists a chance to "learn to speak the same language."

DARPA's foray into zoology aims to create "smart bugs, controlled bugs, and robo bugs."

—Alan Rudolph



DARPA Lite

Such dialogue is also one goal of the National Cancer Institute's (NCI's) new Unconventional Innovations Program, which has been dubbed "DARPA Lite" by some observers. Pushed by NCI chief Richard Klausner, it plans to spend $48 million over the next 5 years to turn high-risk studies into new technologies for early cancer detection.

In designing the pilot program, which will make its first awards this fall, "we tried to extract what we thought were the most valuable practices at DARPA, NASA," and other agencies, says Carol Dahl, director of NCI's office of technology. Although NCI's traditional peer review panels will play a major role in selecting projects, she says agency managers will be "much more involved in program management than usual" and will prod researchers to share information. Among the program's high priorities is developing devices that can detect subtle molecular signals produced by growing cancers—such as the presence of telltale chemicals in the blood—and then transmit the information to external monitoring devices. Inventing such noninvasive sensors, a program announcement notes, "will require the input and collaboration of investigators … not traditionally engaged in cancer research."

Although some NIH officials and outside scientists resist such directed research, NIH director Harold Varmus says he would like to see more of it. "I'm always asking my institute directors for more DARPA-like projects," he says. Such a philosophy would mean taking the lead in developing fields such as bioengineering, he believes, rather than waiting for scientists to propose ideas.

Other agencies are watching the NIH experiment, but there are few signs of similar ventures popping up anytime soon. One limiting factor is finding enough DARPA-type program managers. Other agencies "would face some difficulty scaling up [the DARPA approach]," says Arizona State's Hackett. "You couldn't possibly afford 4 years away from the [lab] bench; you'd be dead," says John Kauer, a DARPA-funded neuroscientist at Tufts University outside Boston, expressing a common sentiment in the community about a practice that, for example, is common at NSF but rare at NIH. And industry scientists often balk at the lower government salaries, a problem Congress tried to address last year by giving DARPA special authority to offer better salaries and benefits to up to 20 new hires. So far, DARPA officials have used the arrangement to reel in about a half-dozen prospects, and Fernandez says that new employment arrangements have made it easier to reassure academics and military personnel that there can be "life after DARPA."

Despite the disadvantages, however, even Kauer says "DARPA would be a very interesting place to be." Rudolph confesses that his stint, which runs for 2 more years, has been "an incredibly exciting time. While the demands are enormous and it can be draining personally, I would do it again." The idea has even occurred to University of Illinois, Urbana-Champaign, electrical engineer Chang Liu, one of Rudolph's CBS researchers. Although the young academic says he wouldn't want to make a career move until he earns tenure, he's intrigued by the chance "to get the pulse of a particular field and orchestrate some innovative research. Mostly," he adds, "it would be fun to play god."

–DAVID MALAKOFF

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