Innovation at DARPA

July 2016

Innovation at DARPA

A Long History of Innovation

DARPA, the Defense Advanced Research Projects Agency, was founded early in 1958 by President Eisenhower. Initially called ARPA, it was created in response to the shock of Sputnik and other early Soviet missile achievements that suggested the U.S. might be falling behind its Cold War rival in technological achievement and especially in the technologies of war fighting and defense.

The agency encourages, funds, and manages research carried out by the military, private industry, and academia to fulfill its mission of avoiding and creating technological surprise. Over its almost six decades of existence, it has supported and guided work that has "changed the world"—a phrase frequently heard at DARPA to ensure a focus on transformative innovation as opposed to incremental improvements in existing technologies.

DARPA's many important achievements have included seminal roles in the development of the Internet (initially known as Arpanet), stealth aircraft, miniaturized GPS technologies, unmanned aerial vehicles, flat-screen displays, and the brain-computer interface work that is making it possible for subjects to use their thoughts to move artificial limbs. In the process of directly funding and managing the development and these and many other technologies, the agency has also functioned as a catalyst for groundbreaking research and development undertaken by industry and academia.

 Its long history of successful innovation contributes to the agency's continuing success. Internally, that track record sets a high bar of achievement and shows what is possible. (Only partly joking, Biological Technology Office program manager Matt Hepburn has said, "If you don't invent the internet, you get a B.") Externally, that history of valuable work gives DARPA the credibility it needs to help maintain financial support and decision-making independence, even in the face of the failures and partial successes that inevitably accompany ambitious efforts to do radically new things.

Many organizations innovate in their early years and lose that inventiveness over time. DARPA is unusual and possibly unique in maintaining its pioneering spirit and achievements for so many years.

Sources of Success

The most important factors that define the DARPA creative culture and explain its long and continuing history of innovation are:

- **Limited tenure** and the **urgency** it promotes

- **A sense of mission**

- **Trust** and **autonomy**

- **Risk-taking** and **tolerance of failure**

Limited tenure and urgency

The short tenure and continual rotation of program managers and office directors and deputies are probably the single most distinctive features of DARPA's culture and the most important contributors to continuing innovation. Those people, a majority of the agency's employees, generally hold their jobs for four or five years. The end of their time at DARPA is always in view: their expiration date is printed prominently on their ID badges, a constant reminder to them and their colleagues that time to accomplish important work is limited.

According to the office directors and deputies who hire them, program managers who come to DARPA must be "fired up to do exciting things," must have "their hair on fire," determined to achieve something new and important during their short time at the agency. Information Innovation Office program manager Mike Walker notes that the sense of time ticking away is "the heart of the whole thing. It is an impetus to venture into the unknown, to get people to put something forward, to build the prototype warts and all."

In addition to fostering that sense of urgency, limited tenure means that new people are always being hired, bringing new ideas and their passion for those ideas with them. Microsystems Technology Office Deputy Director Yiftach Eisenberg says, "Turnover means we can capture what's happening out there, and move on quickly if something isn't working." One office director estimated that DARPA has a 25 percent annual turnover rate.

In most organizations that would be considered a problem; at DARPA, it is intentional and invigorating. A short tenure means that people come to the agency to get something done, not build a career. Defense Sciences Office Director Stefanie Tompkins says, "The longer you're in one place, the more tendency you have to become risk-averse. You start to refine what you're doing as opposed to throwing out what you're doing and starting fresh."

Justin Sanchez, Director of the Biological Technologies Office, also sees a connection between limited tenure and a willingness to risk failure in pursuit of ambitious goals: "If you're in a place where you only get fired if you mess up, you do just enough not to mess up."

Many organizations see the departure of talented people as a loss of important technical knowledge—the organization's memory of what it knows. At DARPA, people think more about the downside of having a long technical memory: that some of what is remembered may be wrong or outdated and stand in the way of important innovation. Long-time employees sometimes use the fact of a past failure to prove that something can't be done, but what was once impossible may be feasible now thanks to the development of new tools and technologies, or the increased urgency of a need. Hiring people who are ignorant of past failures sometimes opens the door to breakthrough success.

Here is one well-known example of a technology that was impossible until developments in related fields made it achievable.

The Right Time for Stealth

The U.S. Department of Defense and the military establishments of other countries have long sought to make their aircraft difficult to detect by defense technologies, employing, for instance, absorptive materials to make them less visible to radar. In the early 1970s, advances in radar-guided defense systems made U.S. military aircraft increasingly vulnerable and created an urgent need for dramatic improvements in so-called stealth technology to make them as nearly invisible to radar and other defensive technologies as possible.

DARPA supported research that developed previously unreachable levels of stealth effectiveness and led to the creation of the F-117A stealth fighter (operational in the early 80s) and ultimately the B-2 bomber. The impossible became possible in part because of the development of new radar-absorbent materials. In addition, computer-mediated fly-by-wire technology developed by NASA in the early 70s made it possible to design and safely fly

aircraft with radical new shapes that made radar detection more difficult. Less aerodynamically stable than traditional aircraft, these stealth craft depended on the thousands of rapid adjustments computers could make to maintain controlled flight. Without these new technologies, the F-117A and the B-2 would not have been possible.

Rapid and widespread turnover would also seem to threaten the agency's cultural memory of its aims and values and its ways of getting work done. That has not been a problem at DARPA, where employees maintain a vivid understanding of the agency's goals and approaches. One important reason is the clear criteria for hiring and the terms of hire. Bringing in people who are passionate about far-reaching innovations for only a few years attracts individuals who already value DARPA's goals and approaches and eliminates the kinds of candidates who might make the agency a more cautious and bureaucratic place. DSO program manager John Main says, "If you want a security blanket, DARPA is not for you. The blanket is ripped out of your hands four times a day."

People who come to DARPA recognize their responsibility to maintain its unique culture. In the words of Justin Sanchez: "While you're here, you're the steward of the culture. Then you pass it on."

Sense of Mission

DARPA's reason for being—"to prevent and create technological surprise"—expresses its role in promoting the security of the United States and the safety and success of military personnel. This vital mission draws people to the agency. Program managers talk about the call to serve, about giving back to a country that has been good to them.

 DARPA's determination to "change the world" suggests the scope of its mission. The agency offers program managers a chance to "be a part of shaping the future," says one program manager. The importance and ambition of the mission help fuel the drive toward innovation. People are inspired and energized by the effort to do something that affects the well-being and even the survival of their fellow citizen (and often the citizens of the world), as opposed to the "innovations" that might make a commercial product a bit more salable.

The mission also adds to the sense of urgency, since some of the agency's work aims to counter existing or looming threats to war fighters or the general population. One program manager working to respond to what he considers an almost certain future cyber-attack,

says, "If you pass up the opportunity to be part of the solution, you become part of the problem for the rest of your life."

Reflecting on both the program manager's limited tenure and his sense of being a small but vital part of an essential, larger mission, DSO Deputy Office Director William Regli says, "When you leave you know you're done, your time is up. You say, 'I'm one of the bricklayers of the cathedral.'"

Trust and Autonomy

Trust is a precondition of autonomy. You only grant people the freedom to make decisions and carry out their work as they see fit if you believe they will do it responsibly and well without someone looking over their shoulders. To be effective, trust must go in both directions: the trusted employee must also trust her employer to be faithful to the values and goals of the organization and to the terms of their working relationship.

The freedom to make decisions and take action without having to obtain the permission of mangers or supervisors is critical to innovation at DARPA. Microsystems Technology Office Director Chappell puts it this way: "Get the best people, then trust them." Office directors and deputy directors describe DARPA as a "bottoms up" organization where research topics come mainly from program managers and potential program managers who are passionate about an idea.

Office directors often have an idea of the kinds of projects they would like to see carried out. But the creative ideas typically come from below and projects only happen when a project manager is passionately committed to the work. Information Innovation Office Director John Launchbury says, "There are no marching orders. The marching orders are: create innovation."

This does not mean, however, that every innovative idea becomes a program. DARPA has a rigorous approval process for deciding which projects to fund; agency leadership must agree to support a program before millions or tens of millions of dollars are committed to it.

Risk-taking and tolerance of failure

DARPA is committed to cutting-edge innovation, the kind of work that will change the world. That level of ambition—trying to do things that have never been done before,

working at the edge of the possible—necessarily brings with it the possibility and in fact the likelihood of failure.

Openness to new ideas, risk-taking, and tolerance of failure are essential elements of DARPA innovation. Proposals are rigorously scrutinized, but no idea is dismissed out of hand as too bold to consider. BTO Office Deputy Director Barry Pallota says, "No idea is too crazy. The reaction is never, 'That's impossible.' We say, 'How would you do that? How would you get there? Write down the steps.'" And Stefanie Tompkins says, "If you're on the fence, err on the higher-risk side." She adds, "Why study the feasibility of a project for six months if you can get further and learn more by starting the work?"

Ideas are more likely to be rejected because they are not far-reaching enough than because they are too risky and ambitious. Launchbury says, "If none of our programs fail, we're not stretching far enough." Phillip Alvelda makes a similar point: "If half the people don't respond to a publicly-announced challenge saying it's impossible, we haven't set the bar high enough." As BTO program manager Matt Hepburn says, "If it's not transformative, change it."

This does not mean, of course, that any crazy ideas will get funded. Thinking about "where to draw the crazy line," Tactical Technology Office Deputy Director Pamela Melroy considers the size of the investment in especially risky projects. A $10 million gamble is one thing, she says but "if you're spending $80 million, you'd like it to work."

The how and why of failure also matter. Tompkins says, "If you fail because you're sloppy and lazy, that's not good. And it doesn't happen much here." The right kind of failure comes from being ambitious, pushing to the edge of what is possible, and often generates valuable knowledge even though program goals are not met. As I2O Office Director John Launchbury says, "'Failure' doesn't mean the whole thing collapses. Even if the end result isn't what you were hoping for, technologies developed along the way may have great value. They feed into the ecosystem; something new is known." BTO Office Director Justin Sanchez says, "If something doesn't work out, we feed what we learn into something else."

Proposals submitted to DARPA are reviewed by government experts with advice on specific topics from subject-matter experts both within and outside the government. The Source Selection Board makes recommendations to help the agency decide whether or not to invest

in a proposal. It provides advice about technical risk associated with prospective programs, working to differentiate between the barely feasible (and potentially groundbreaking) and the absurd.

The board's judgment is highly informed and useful, but occasionally the experts are wrong about radical advances that defy conventional wisdom about what is possible. The agency's tolerance for risk and its goal of achieving major breakthroughs mean it will sometimes ignore the experts, as this story shows:

They Said It Couldn't Be Done

An engineer wanted to develop new armor for military vehicles that he claimed would improve survivability in IED attacks by a factor of five. The experts DARPA consulted recommended rejecting the "crazy" idea, saying that improvement by a factor of two would be a major accomplishment and was probably the limit of what was possible. DARPA decided to ignore their advice and fund the program. The result? Survivability was increased by a factor of ten.

Many organizations claim to welcome creative failure but discourage and sometimes punish it in practice. An organization genuinely committed to risk, like DARPA, must *demonstrate* that it accepts and values failure that comes from taking big risks that promise big returns and are likely to generate valuable learning even if they don't succeed. An important way of doing that is to recognize and reward valuable work that fails to reach it most ambitious goals. For instance:

Learning at Mach 20

The Hypersonic Technology Vehicle HTV-2 was designed to launch from a rocket and glide to earth at Mach 20 (about 13,000 mph). The first flight test, in April 2010, ended nine minutes into the proposed 30-minute mission when the craft began to roll violently. A second flight, in August 2011, also ended after about nine minutes, apparently because frictional heating tore away parts of the vehicle's skin. Nevertheless, program manager Chris Schulz was named DARPA's Program Manager of the Year for 2011 in recognition of the aspirations and achievements of the program.

One danger of embracing many high-risk projects is that too large a proportion of the available resources of money, time, and talent will be spent on things that don't work. The

talent and dedication of DARPA's people and its skill in identifying promising work help mitigate this danger, as does the fact that all DARPA-funded programs have a set, limited lifespan. The agency's readiness to end projects and shift resources to more promising work is also important. Pamela Melroy says, "I've never seen a place as willing to stop funding." If potential further results do not justify continued investment, programs stop. "We descope the contract to work performed plus a final report," Melroy adds.

Airborne Launch Assist Space Access (ALASA) system development provides an example of a program curtailed largely because it was judged unlikely to achieve its primary goal.

Ending ALASA

The aim of DARPA's ALASA program was to significantly reduce the cost of getting small satellites into low-earth orbit by using conventional aircraft to lift a newly-designed, single-stage launch vehicle to high altitude, where it would be released and complete the journey to orbit. In addition to being much less expensive than ground-based launch vehicles, the system would not require the lengthy preparation time or face the weather delays that existing launch systems are prone to.

The new vehicle was designed to use a nitrous-oxide-acetylene monopropellant that would make its propulsion system smaller and cheaper than systems that separate fuel and oxidizer. Tests showed that the monopropellant was dangerously volatile, however, and DARPA ended development of the launch vehicle at the end of 2015. Contributing to the decision (in addition to the fuel problem) was the fact that commercial launch vehicle providers were making their own strides toward lower-cost orbital flights.

DARPA's contracts are evaluated on the basis of the milestones programs are expected to reach at various points during their lifecycles. The emphasis on milestones makes it possible to evaluate genuine progress and identify valuable results as well as to judge whether continued funding is justified. DARPA program managers establish these milestones up front, crafting them to reflect the nature of the overarching objectives of their individual programs—be it insights from basic research or a technology prototype for a new military system.

In many organizations, projects take on a life of their own, continuing to absorb resources despite their failure to achieve results. DARPA's sense of urgency, it emphasis on programs of limited duration, and its willingness to end unproductive work all guard against that tendency. So does the rotation of program managers. Coming in with fresh eyes and no

established loyalty to program ideas or performers, new program managers help identify non-productive program elements in existing programs and feel free to change or cut them.

Programs and Program Managers

Work at the agency is project-based. Programs typically last for only a few years, defined and limited by explicit progress milestones and the goal of developing a new important technology or capability that can further DARPA's mission. They are instigated and managed by program managers within DARPA and carried out by contractors the agency calls "performers," a term which suggests the emphasis on getting work done rather than the contractual relationship between the government and another organization.

The Program Managers are the heart of the system. "Nothing happens unless a program manager is passionate about it," says Launchbury. Although the leaders of DARPA's technical offices help shape their research portfolios, the subjects of individual programs reflect the expertise and fervent enthusiasm of program managers. Work that the offices would like to support simply does not happen if no program manager can be found who is both capable of carrying it out and fully committed to it.

Given the importance of program management and the constant turnover, office directors and deputies are constantly looking for new people to fill that role. Hiring new talent is an essential and time-consuming part of their work. Program managers must be brilliant people with brilliant ideas they are passionate to develop. Former STO Office Director Nils Sandell says he looks for an individual who is technical strong and with some project management experience but also who is "a bit of a dreamer and not constrained by thinking 'this we know to be true.'" He looks for an ineffable quality, "a rare combination of vision and practicality."

DSO office deputy William Regli says good DARPA program managers are people with intellectual self-confidence who are willing to participate in discourse and don't consider ideas their personal property. They have "less possessiveness of intellectual ideas than most people in academia," he says. "They have generous brains." You can't know until new hires start working just how good they will be. Stefanie Tompkins notes that 30 percent of the new hires are "amazing" but you can't know in advance which 30 percent it will be.

The brevity of the DARPA assignment eliminates people who are looking for a safe and stable career. Adaptive Execution Office Director Dale Waters describes the job this way: "Give bright, innovative people money to do something fast and furious and then kick them out the door." MTO Office Director William Chappell says, "Working at DARPA is an honor, not a stepping stone." So why do talented and successful people say yes? Why leave a tenured university position or a thriving career in industry to accept a pay cut and a guaranteed lack of job security?

Having the freedom and resources to do important and even transformational work is a powerful attraction. Many program managers come to DARPA to work on ideas that they have thought about and championed for many years without ever having had the resources of time and money to work on them. TTO program manager Dan Patt describes being at the agency as an opportunity "to be a part of change, a part of shaping the future." He sees his work on human-machine teaming as using technology to accomplish essential tasks in a new and better way.

BTO project manager Philip Alvelda is working on the next generation of the brain-computer interface technology that has made it possible for people to use their thoughts to move artificial limbs. (See "Tapping into the Brain.") He asks, "How many people can apply their exact expertise to contribute to our going from the industrial age to the age of control by mind? Of all the places on the planet, this is the place that could make that happen."

Tapping into the Brain

A *60 Minutes* story in 2015 highlighted a remarkable DARPA achievement: Jan Sherman, a quadriplegic woman, was able move a robot arm by thinking about it thanks to an electrode implanted into her motor cortex. This was a "watershed moment," according to Phillip Alvelda, who came to the agency in part to build on that earlier work. He notes that the monumental effort required not just developing the brain-computer interface but also new surgical procedures and software, and had to seek and obtain FDA approval.

For Alvelda, that was just the beginning. "It's nothing compared with what we should be able to do with state-of-the-art technology," he says. "Each of the hundred wires in that implant was hearing 50,000 neurons: a noisy mess and a computational problem. I think it's possible to make a next generation photonic system. Instead of that noisy communion, can we build something with a million or more channels talking to individual neurons? Thinking DARPA style, I ask, 'What if we are more ambitious: not just a brain interface, but

---

the equivalent of what happened in the computer industry when we built the first modem?' In early versions of ARPANET, custom wiring cobbled together 1000 computers. Then the Ethernet modem made it possible to connect your computer to any other. I want the equivalent of the modem to get from billions of neurons in your head to your computer. If we are successful, what happens when brains are tightly coupled to computers?"

It is not surprising, then, that some program managers who describe themselves as being "bored academics" in their previous positions were willing to exchange the security of a stultifying routine for the chance to do extraordinary work in a place where "life can be different every day," according to DSO program manager John Main.

Main also sees "strong thread of patriotism" in DARPA program managers. "They want to use their significant technical skills to help the country," he says. "There are not many ways a PhD scientist can contribute to national security." Quite a few program managers worked earlier as DARPA performers; the importance of that experience to their careers and their accomplishments also fosters the desire to give back.

Seeking Ideas and Winning Support for Them

DSO program manager John Main notes that there is an art to choosing the right goals for every program: it needs to be aggressive enough to create energy and vision, to require a stretch to get there, without being beyond the possible. So program managers, whether evaluating the ideas that brought them to DARPA or looking for new ideas, must understand the current state of the art to avoid, on the one hand, duplicating work already being done and, on the other, devoting resources to something that is impossible given currently available technology. Making that judgment requires reading the literature but also and especially communicating with experts in the relevant fields.

Travel by program managers and office leadership is key to keeping up with what is happening in the world of research. One-on-one meetings with researchers provide up-to-date information on the state of the art and suggest promising new research possibilities. DARPA personnel use their relationships with others in their professional communities of practice to keep abreast of current research. In addition, DAPA frequently holds conferences and sponsors workshops as part of the effort to keep informed about developing

technologies and inform the research community of its areas of interest. All of these direct contacts are probably the agency's most important source of information and new ideas.

DARPA's Broad Agency Announcements (BAAs) specify areas of interest to the agency and the goals in those areas that potential performers must strive to achieve. For instance, a 2016 BAA from the Tactical Technology Office for development of an experimental spaceplane is looking for performers to create a booster that can carry more than 900 pounds to orbit ten times in ten days. In addition to being an essential step towards an active program, the proposals submitted in response to the BAA provide valuable information about the likely boundaries of what is technically possible.

Another way the agency learns about what is happening in a given field is to send out Requests for Information (RFI Special Notices) asking those experts for information on their current work in those fields. Because DARPA guarantees that the responses will not be shared or made public, researchers in academia and industry readily share information that they would otherwise keep to themselves. It is, says Main, a uniquely efficient way to understand what is happening and get a handle on what might be possible. The BAAs, and meetings DARPA holds to discuss the agency's research interests, can spark ideas even in individuals and groups that are not funded by DARPA. "BAAs help create the culture," says William Regli.

Along with BAAs, which are open to all, the agency has used competitions to seek innovative ideas from the widest possible range of performers. Like the Ansari XPrize and NASA's Centennial Challenges, DARPA challenges are open to any and all groups and individuals; they entirely avoid the danger of closing off possible new avenues of progress by favoring known experts. They are a valuable, relatively low-cost complement to classic R&D funding, most useful for technology that has been developing for a while, a way of seeing what is and isn't possible in a given field and stimulating further work. Challenges in autonomous ground vehicles, robotics, response to disease outbreaks, and other fields have encouraged important progress in those areas.

DARPA is recognized for the programs it manages and funds. By stimulating the discussion of new ideas and helping to create communities of practice around those ideas, it is also a

valuable catalyst for work that companies and universities undertake without that direct support.

The passionately held, visionary ideas of program managers drive DARPA research, but every idea needs to be approved by the agency director and deputy director. As BTO program manager Matt Hepburn says, "We have extraordinary latitude as long as we can defend it."

As suggested earlier, DARPA leaders want to say yes to ambitious proposals, but those proposals must meet the agency's demanding criteria of being creative and courageous enough to have the potential to change the world and at the same time be within the realm of the possible. And the program managers who present them must be able to explain them clearly and persuasively enough to convince people who are not experts in the relevant field that they are worth supporting.

DSO program manager Tyler McQuade vividly recalls the demands of the process:

> When building a Tech Council presentation, I spend large amounts of time on background learning, interacting with stakeholders inside and outside the DoD, building a case for why an investment will lead to significant outcomes and for why DARPA is the right agency to pursue the effort. The organization has an amazing infrastructure that forces PMs to refine our thinking at every stage. Once we get to the Tech Council, our new ideas are very refined and we are ready for the highest quality scrutiny that money can buy.

The Heilmeier Catechism has been and continues to be an invaluable tool for illuminating that process of refinement and judging which are the most promising ideas. George Heilmeier, ARPA's director in the mid-1970s, developed a set of questions to be answered by the proponents of every new program that have become ingrained in the culture. The catechism contributes to a disciplined approach to thinking about possible programs. In addressing it, program managers ensure that the work's potential is great enough, that it hasn't been done before, and that the program is feasible. It is also another element that communicates and maintains the culture.

Heilmeier's questions seem obvious, but answering them helps identify the proposals that meet DARPA's goals of supporting work that can lead to genuinely important technological advances that are unlikely to happen without the agency's support. The Catechism helps

reduce what one program manager calls "a bushel full of good ideas" to the one or two that most deserve investment. And, says, Mike Walker, the Catechism forces program managers to find a way to talk about what they want to do in terms that other people can understand.

The Heilmeier Catechism

- What are you trying to do? Articulate your objectives using absolutely no jargon.
- How is it done today, and what are the limits of current practice?
- What's new in your approach and why do you think it will be successful?
- Who cares? If you're successful, what difference will it make?
- What are the risks and the payoffs?
- How much will it cost?
- What are the midterm and final "exams" to check for success?

Phillip Alvelda and Matthew Hepburn also describe the months-long iterative process of revising and refining presentation materials. Making the case for their proposed programs first within their own technical offices and then to the agency-wide tech council gives them multiple opportunities to clarify and strengthen their proposals. Alvelda notes that you have to find "the sweet spot" between a high-level briefing and a technical description that provides adequate detail about approaches and aims of the proposed program.

The final decision is always made by the agency director and deputy director, part of a process carefully calibrated to avoid the kind of lowest-common-denominator choices committee voting sometimes makes.

Communication and Community-Building

Some of the work DARPA program managers do is like the work of program or project managers in any organization. They are responsible for overseeing budgets and schedules, helping to solve technical and logistical problems that performers face, managing communication and collaboration among the groups doing the work, and doing whatever is necessary to help the program meet its milestone goals.

In most organizations, though, managers are assigned to carry out programs designed by someone else. In addition to coming up with, evaluating, and advocating for new program ideas, DARPA program managers have primary responsibility for transitioning the new technology they are creating to development for actual military or civilian use. This often means working directly with the services and with companies that can turn a hand-made

prototype or proof of concept into a product. Among other abilities, these tasks call for good communication skills; it is not surprising that office directors and deputies mentioned the importance of hiring program managers who are excellent communicators.

Matt Hepburn notes that a big part of program management is keeping track of "what's going on, and who is spending on what." You have to do "whatever it takes" to do that: "reports, emails, calls, program reviews." And, he says, "You've got to get out. I hate travel but sometimes you've got to get there, see where they work and who's working for them. You have to get everybody in the room on site. Get to know them."

Phillip Alvelda agrees: "You have to travel. Good collaboration tools are few and far between. When you have passion for something, even the best online tools are not the same as getting fired up in the lab."

Many program managers recognize building relationships and communities as one of their most important responsibilities. I2O program manager Mike Walker says, "Engineering progress happens through the coffee house and my job is to build the coffee house." Dan Patt says, "The project ends but the community has lasting value."

The creation of community that outlives a given program is an important factor in successful transition to new technology use, since members of the community are likely to contribute to the work of developing actual products. And the community, energized and inspired by DARPA work, may ultimately produce innovations that go well beyond the ambitious but limited agency program.

Transition

Even the most revolutionary and promising new ideas can't "change the world" until they are put to use by the military or by society as a whole. That is why working to develop innovative ideas and prototypes to maturity, to see them move from theory and demonstration to practice, is an essential element of every DARPA program. Program managers work to bridge the gap between the successful demonstration of a new technology and its commercial development and practical application.

I2O Deputy Office Director Brian Pierce says, "Even for basic research, we ask the question, 'If I'm successful, what is going to result from this that is of use?' We do *projects*, meaning

the work will have a real impact if we're successful." DSO program manager John Main notes that one of DARPA's responsibilities is to look at basic research in universities which is typically divorced from specific military or commercial capabilities and find the nuggets it can use to set implementation goals.

Program manager Matt Hepburn notes that transition to use by military customers or the commercial market is a hard process that may take as much as five or ten years. He says, "Part of our job is to de-risk a new technology sufficiently for the private sector to invest in for product development. In the biomedical space, the necessary investments tend to be enormous."

A variety of factors can keep the innovation from making it out of the "valley of death" alive. As Hepburn suggests, the cost of turning a prototype into a product is a potential stumbling block. The technological challenges of moving from a demonstration model to commercial production can be daunting. In some cases, too, reluctance to replace familiar approaches and processes with new ways of seeing and doing can impede or prevent the adoption of demonstrable improvements.

Program managers have primary responsibility for transitioning their program achievements to use. The Adaptive Execution Office supports the process with its resources and expertise. It works to clear away obstacles and "level the playing field" so that program managers without past experience working with the military can have the same chance of success as those who have had that experience and the connections that come with it, says Office Director Dale Waters.

The AEO works with program managers throughout the lifetime of their programs to help bridge the gap between their innovative ideas and the practicalities of design and manufacture of products that can strengthen the military and serve the wider society. There is no one best way to do this. Waters says, "You can't build an algorithm for transition; every program is different, every customer is different."

The office is a conduit for essential communication, offering program managers information about military needs and informing the services about DARPA work that could make them more effective. A DARPA program that provides a vital military capability will sometimes become a "program of record," its further development and deployment directly funded by

the military. At other times, a promising technology is picked up and developed by the commercial sector before it is put to military use.

The office sometimes helps program managers work directly with the services to adapt their ideas to the ground truth of military life—to move from a brilliant idea to a practical device. "We need to bring in people with knowledge of the services and knowledge of DARPA for the right meetings at the right time with the right people," Waters says. Here is one example:

The Right Sensor

 In Iraq and Afghanistan, troops exposed to IED explosions have suffered brain trauma, sometimes even when they have no visible injuries. To try to gather data that would help them understand and ultimately reduce those injuries, the military initially equipped soldiers with accelerometers to measure those damaging impacts.

DARPA program manager Jeff Rogers believed those were the wrong kind of sensors. Over-pressure created by the explosions was causing the trauma, so he believed what was really needed was a pressure-wave sensor. He was convinced that pressure-wave measurements would be more useful and cut down on the false alarms that accelerometers were prone to. With the help of the AEO, he met with Special Forces personnel at Ft. Bragg and described the sensor he was developing. They said, "No, we'd never wear that." The conversation helped define what they *would* wear and led to the design of a little bubble sensor. Soon, 10,000 of the devices were built and were being worn by U.S. forces in the field.

DARPA's drive for transition to use and fundamental change means it strives to invest in what the agency calls "platforms"—not just specific products, but both the technical foundations and communities of practice that can support generations of development. Matt Hepburn says they work to "kick start" new industries that will continue to build on the initial breakthroughs.

As in the following case, a narrowly targeted research project may develop techniques or technologies that can ultimately have much wider applications.

Developing a New Capability

The aim of DARPA's "Big Mechanism" effort is to develop automated analysis of massive quantities of data to the point where computers will be able to identify causal relationships and other meaningful patterns, currently a labor-intensive manual process.

The program is focused on the Ras protein's role in the interactions that cause cancer. The hope is that an intelligent automated analysis of the extensive literature on the protein's role will yield useful new understanding of how cancer works, knowledge that might contribute to prevention and cure. That would be an invaluable result, but the program has a wider aim: to illustrate the potential and develop techniques for using Big Mechanism on many problems, including the need to analyze masses of intelligence information as quickly and thoroughly as possible. In another words, to develop a new platform.

The Contract Management Office

In common with the agency's research offices, the Contract Management Office focuses on how to get things done, unlike some contracting groups than have as their main "goal," strict adherence to contracting rules and traditions—even when they delay or obstruct valuable work. CMO Deputy Director Scott Ulrey says DARPA's CMO "minimizes policy within the office and avoids redundant and unnecessary practices"—not to break the rules but to comply with them with the least possible bureaucratic overhead. The office is expert at using the flexibilities inherent in government contracting and avoiding unnecessary processes and procedures that unquestioning observance of regulations can bring with it. The CMO also has the power and ability to write special contracts that reflect the realities of how innovation often happens—both the need for speed and the role of small companies that cannot afford the overhead of complex contract management.

In general, Department of Defense contracting offices consist of personnel trained in the long-established rules and regulations specifically designed to address the unique requirements of the military. These rules and regulations have evolved over decades to address risks inherent in contracting, ensure competition to the maximum extent practical, address policy requirements, and acquire affordable systems and services from traditional defense contractors who are experienced in Federal and DoD contracting. Those contractors—typically large organizations—have the business systems in place needed to work in this highly regulated environment. Avoiding potential risks and spelling out requirements in minute detail are common practices.

Unique acquisition practices within the existing system have served the Department of Defense well and still do, but they also cut the Department off from the many other kinds of innovators it needs to succeed. The demands of traditional government contracts are often more onerous than commercial contracting within the private sector, so much so that they discourage some organizations from working with the government. This is most likely to happen on small programs whose funding does not justify the expense in time and personnel to manage the complexities of a traditional government contract. DARPA's focus on short-term, urgent, cutting-edge work makes it especially important to develop contracts that small, innovative organizations can work with.

The Contract Management Office reflects and supports the urgency of DARPA work, finding ways to negotiate contracts as quickly as possible and get projects started. "We are mission oriented, not process oriented," says Ulrey. He frequently describes DARPA's and DoD's flexible contracting options at one-on-one meetings with potential performers and at Government-sponsored conferences to counter the belief that government work is too complex and not worth the effort and overhead required.

Ulrey and CMO Director Timothy Applegate talk about "creative contracting," developing unique instruments that match the particular needs of DARPA programs and contractors. One example is the Cyber Fast Track program. This program was executed in FY 2011 to attract boutique cyber companies and independent cyber researchers who had never done business with the Government before to provide radically new cyber technologies and offensive-minded innovation to fix security issues for the war fighter. The acquisition strategy employed creativity in using the General Services Administration's Federal Supply Schedules to reach otherwise unreachable performers.

In 1989, the agency was given statutory authority to develop "Other Transactions," or OTs, a commercial-like contract that could be free of most of the acquisition statutes and regulations to which government agencies must typically adhere and which often discourage some of the most innovative commercial companies from performing research and development work for the Defense Department. Pursuant to 10 U.S. Code § 2371, the

original authority was designed to attract commercial companies that, traditionally, had never done business with the government other than as a vendor selling commercial products. This authority is designed to make investments at the R&D stage in new or evolving commercial technologies, enabling DoD to participate in the technology development and ensuring that the results would satisfy government requirements as well as achieve commercial goals.

Contracts for Medical Research

The use of the authority has resulted, for instance, in a collaborative OT awarded to MedImmune to pursue the development of an advanced high-throughput system for the rapid generation of antibody libraries and identification of protective and therapeutic antibodies against certain bacteria. Another OT supports Pfizer's work on therapeutic options to treat uncommon viruses in a large population inexpensively. The OTs allow these commercial companies the flexibility to use their existing commercial accounting and business contracting practices for these programs.

While the original OT authority has been useful and effective at DARPA, it quickly became apparent that it wasn't expansive enough. While participating in the R&D stage is necessary and important, DARPA's investments will not have maximum impact unless those inventions or technologies are taken to the prototype stage and, ideally, into production as well. In 1994, at DARPA's request, Congress expanded the OT authority to allow the DoD to conduct prototype projects outside the normal acquisition process. This expanded authority created the option of using OT authority in a much broader spectrum of programs that were further down the road to development.

The vast majority of CMO awards are fairly traditional DoD procurement contracts to companies already engaged in Federal and defense contracting, and are used to acquire goods or services for the direct benefit of the Government. CMO also awards grants and cooperative agreements to universities and nonprofits to assist in conducting basic or applied scientific research. OT authority is important but, says Ulrey, "You don't need special contracting all the time. You can be innovative within the existing system."

The qualities of the CMO staff are critical to its success. Ulrey says, "You want people here with a lot of experience. This is not a training ground. We want people who have gone

through the pitfalls, creative people looking to try new ways of doing business." Talking about recruiting new staff, Applegate says, "We want people who have demonstrated innovativeness. Tell us where you created a unique instrument. We're looking for measured risk-takers who understand what customers are trying to do and say, 'Here's how you can do it.'"

As in other areas of DARPA's work, trust is important in developing streamlined contracts. When trust is lacking, the proposed working relationship tends to be adversarial, which means every performance element must be fully and explicitly spelled out, along with the details of rigorous and intrusive oversight. DARPA's good-faith contracts are built on the assumption that the agency and the project performers have the shared goal of doing the work well. That trust eliminates the necessity of writing compliance-oriented contracts. Here's one example of an OT for prototype development that evolved from the original OT authority:

A New Kind of Contract

The 1994 Phase I contract for the Global Hawk, an unmanned aerial vehicle, did not include the lengthy statement of work with a multitude of specifications that is typical of many government contracts. Instead, it had a two-page description of the desired performance: the semi-autonomous vehicle would be able to reach 60,000 feet and spend 24 hours aloft, among other desired capabilities. The only requirement of the program was that the vehicle cost no more than $10 million per copy at acquisition. How those goals were to be achieved within that target price was up to the contractor. That contracting arrangement contributed to the speed and efficiency of the work. While a traditional airframe program could take upwards of twenty years, the Global Hawk program was completed in seven years and then transitioned to the U.S. Air Force.

One of the key strengths of DARPA's CMO is its contracting officers' ability to recognize that there are many contracting options available and that situations need to be assessed individually to determine the best fit. The unthinking application of any one contracting vehicle is discouraged. Instead, contracting officers realize that each technology situation, each proposing company, and each DARPA office has its own goals and expectations, and it

is up to those officers to find the contracting tool that will satisfy and appropriately balance those sometimes conflicting needs. Their high levels of expertise and training, supportive management, and the open-minded atmosphere that the CMO is able to maintain all contribute to successfully meeting that challenge. So does frequent conversation among contracting officers, who informally share their expertise and inventive problem solving.

The Anti-Bureaucracy

If "bureaucracy" suggests uncompromising adherence to established rules and procedures, a hierarchy of decision-making power, and a tendency to avoid risk (often by delaying action or avoiding it altogether), then DARPA is an anti-bureaucracy. Barry Pallotta says, "This is not a culture of 'no.' It's a culture of getting things done." The Contract Management Office offers one important instance of that anti-bureaucratic spirit.

Here's an example of the kind of thing that does not happen in a bureaucratic organization:

Five Days

STO Office Director Nils Sandell brought a potential program management hire to the DARPA offices on a Wednesday to meet with the current program managers in the office. On, Friday, two days later, the candidate met with the agency director. The following Monday, he had a security clearance and a badge and moved into his office, where his computer and phone line were waiting for him, ready for work.

Contract managers, lawyers, human resources personnel, finance, security, IT and other support personnel (who are often the most bureaucratic of bureaucrats in some organizations) share DARPA's commitment to getting things done. They too recognize that the program managers are the most important people at the agency—the ones who make things happen—and their whole purpose is to support the PMs. Whether it is a question of responding quickly to as computer problem or writing a contract with a performer, they work to eliminate program disruptions and delays. Mary VanderLinden, head of human resources at the agency, says of newly arrived program managers and office executives, "They have a limited amount of time to do the magic they're going to do. Our job is to make it as easy as possible for them to hit the ground running."

DARPA's support personnel function as part of what William Chappell describes as the "shield" innovators need to do their work effectively; they protect office leadership and

project managers from the external bureaucratic demands that would otherwise sap their energy and attention.

The agency's embrace of risk, the autonomy it grants its staff, and its emphasis on speed all run counter to typical bureaucratic behavior. The flatness of the organization eliminates almost all of the complicated machinery of multiple levels of permissions and reporting that slow action in bureaucratic organizations. Above all, DARPA's determined focus on mission—on getting important work done—rather than on internal rules and processes makes it the anti-bureaucracy and the extraordinary catalyst for innovation that it has been for more than half a century.