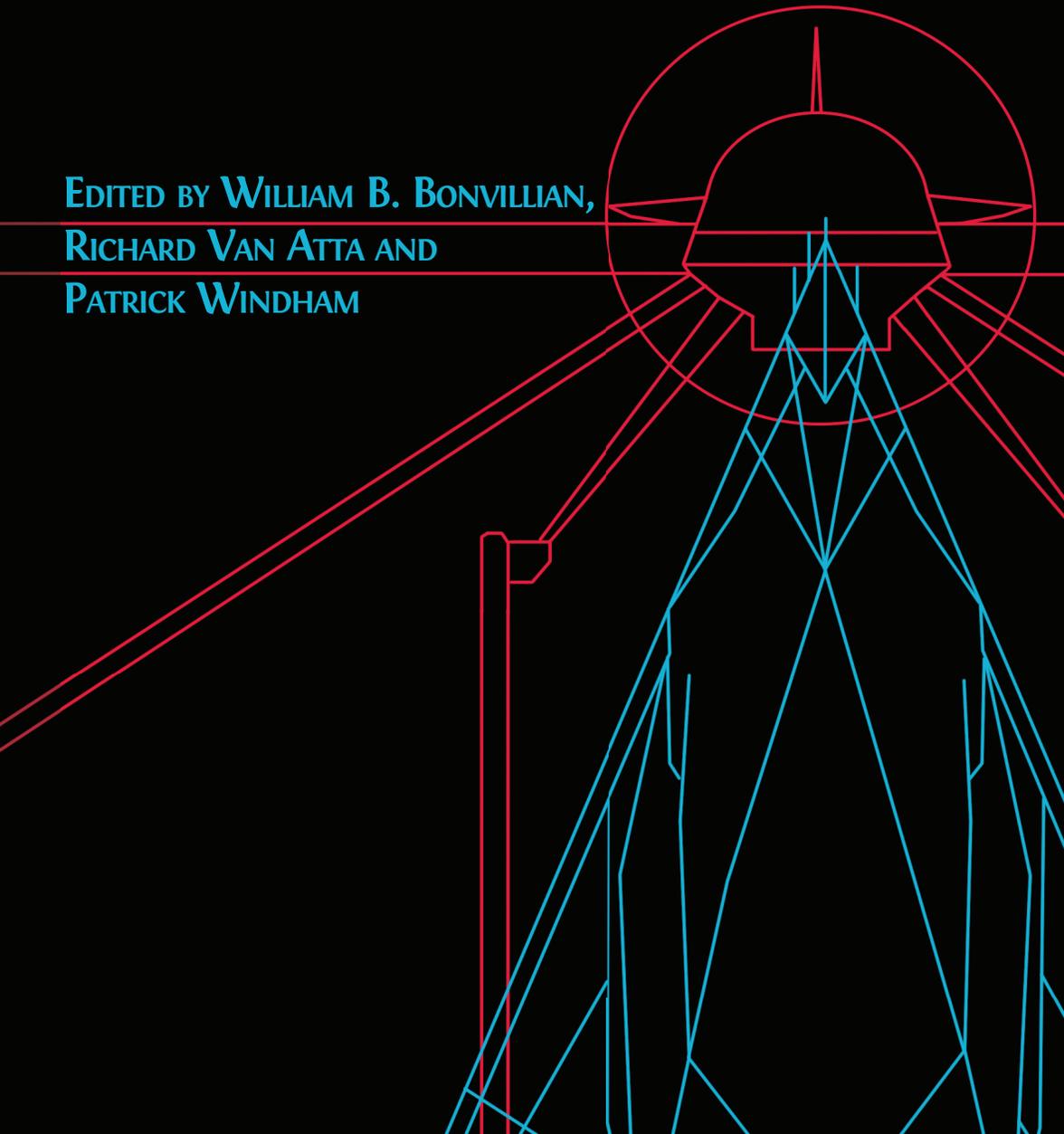


The DARPA Model for Transformative Technologies

Perspectives on the U.S. Defense
Advanced Research Projects Agency

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10. DARPA—Enabling Technical Innovation¹

Jinendra Ranka

The Role of DARPA

DARPA is a unique institution that is consistently evolving. Every program manager you ask will give you a different view of DARPA. Everyone has a different opinion, whether it be a DARPA program manager, a performer on a DARPA project, a small business, the academic community, other government organizations, or the public. This is important to understand and is a result of how DARPA is structured, and how DARPA works with so many different technical communities on ground breaking high-risk projects that can have enormous potential. There are plenty of failures to criticize, but the successes have changed the world. DARPA is a very individualistic agency and I simply am presenting my view as a former DARPA program manager.

My experience at DARPA was very different from that given in the next chapter, and illustrates the diversity of the agency. I was a program manager in the Strategic Technology Office at DARPA from 2008 to 2013. I had spent the prior few years at MIT Lincoln Laboratory working as a scientist who enjoyed research, but had minimal management experience. Though I had a background in academic, commercial,

¹ This chapter is based on a presentation that Dr. Ranka made at the Workshop on “How to Support Disruptive Change: Lessons from the DARPA Model”, National Graduate Institute for Policy Studies, Tokyo, 25 February 2014.

and government research, I had never directly worked on a DARPA program. I knew little about the agency outside of the ARPANET.

DARPA has a relatively flat organizational structure. All program managers have a limited time at DARPA and are driven to accomplish as much as possible in that short time. The need to replace approximately twenty percent of the program managers each year requires the agency to be aggressive in hiring while being careful not to sacrifice technical excellence. Soon after a highly intensive vetting process with a DARPA office, I met with the agency director and had the most unique interview of my career. Three weeks later, I was a program manager at DARPA working on the ideas I wanted to pursue.

DARPA's history is important to understand as it has shaped the agency culture. The government created ARPA four months after the 1957 launch of Sputnik. The key people involved were President Dwight Eisenhower—a former general who distrusted the military industrial complex and who wanted a new agency that could coordinate closely with the technical community and could develop technology rapidly—Neil McElroy—the new Secretary of Defense, a former president of Procter & Gamble, who had absolutely no defense or military experience, was not a scientist or engineer, but knew what it took to run an organization and be effective—and James Killian—a scientist and the president of MIT, who was instrumental in the creation and design of ARPA. It was intentionally created to work with the research community for the Department of Defense, but was created outside of the military services. The agency's original charter was quite simple: "ARPA will do what the Secretary of Defense wants it to do".

DARPA and Innovation?

DARPA's mission is to develop breakthrough technologies for national security. In a similar fashion, ARPA-E was recently formed to advance U.S. energy research and IARPA for the intelligence community. DARPA is part of the Department of Defense and works closely with the different military services, but does not directly serve any of them. DARPA projects focus on the long term, and the agency is willing to take risks the services may not be willing to consider.

Program managers focus on high-risk/high-payoff projects that typically run for four to six years each, with well-defined metrics to measure success and ensure the truly hard problems are being addressed. DARPA looks at a broad range of national security problems and then invests to develop prototype technologies that solve those problems. Many of these technologies have broad uses, civilian as well as military, but, ultimately, all our work is anchored to our defense mission. Research for the sake of advancing scientific understanding is important, but it is not DARPA's mission. DARPA is there to create and prevent strategic surprise for national security.

DARPA focuses on adapting and executing faster than traditional government institutions are structured to do. DARPA must understand how to innovate and evolve rapidly, to address current problems as well as potential future technology gaps. Over the past two decades, advanced technology has shifted focus away from government and military dominance and towards the commercial sector. As such, the threats we face are rapidly evolving. While traditional military threats continue, we now also need to address cyber warfare, communication, encryption, social media, manufacturing, and much more. The traditional defense agencies were not designed to quickly address such disparate and complex technical areas as they rapidly evolve. DARPA has been addressing these problems for years and continues to make further investments.

DARPA is also structured to remove barriers to innovation. True innovation and innovative technologies do not appear based on a prescribed schedule, and can be hampered by aversion to risk, bureaucracy, funding limitations, lack of focus, and poor coordination. In a risk-averse culture, funding is often directed toward incremental technical improvements rather than riskier efforts which may provide dramatic new advancements. Coordination is important as the projects connect the research community to real users of the technology, with real problems and constraints. Similarly, limited user insight can be another barrier. You may have an idea, but you are not sure how to properly transition it to the user community or marketplace. It doesn't matter if you are in government, commercial, or academic research: these are challenges that we all face in technology development. To address this, DARPA programs are designed to be aggressive and focused. The

agency provides the resources needed, attracts the best technical people to develop and run well-defined programs, and provides the oversight and coordination to ensure the best chances of success. DARPA doesn't simply fund people to work on hard problems, but funds new attacks to those problems through R&D projects that may be high-risk, but have the potential of achieving high payoff, high-impact results.

After a program is approved by the DARPA director, the program manager is given a significant amount of control. They effectively become the CEO, COO, CTO, and CFO for the program. The PM is provided with a long-term budget, with enough flexibility and finances to actually accomplish the proposed program. But this flexibility is coupled with accountability. The DARPA director and the office director act as the board of directors, and review program progress based on the vision, metrics, and deliverables that were originally proposed. Typically, the agency director and office directors will have had experience as a DARPA program manager. They know what it takes to run a DARPA program and will not hesitate to terminate or require course corrections for a program that does not meet performance metrics, or provide additional resources to programs that are successful at the "DARPA Hard" challenge.²

Developing and Running DARPA Programs

How does one actually develop a program idea? You first need to understand the problem you would like to solve and the current solutions. What are the limits to the current approach and what has been tried in the past? Is there a simple path forward, either technical or non-technical? A high-tech solution is not always the best answer. You also have to look and see what is possible. What are the fundamental scientific limits for the problem you are trying to address? What are the potential manufacturing limitations from now to the foreseeable future? What may can be done beyond that? From the answers to these questions, you develop a vision of what is possible, and you define goals, metrics, and a plan on how to actually achieve that vision. In a sense, you are not trying to predict the future, you are the one driving it.

2 The concept of a "DARPA Hard" problem is also discussed in this volume's Chapter 5.

As an example of looking at the future, imagine it is 1990. You look at the growth of computer processing power and communication network speed. The growth in the number of transistors in a commercially produced integrated circuit has been following Moore's Law, doubling approximately every two years. Now ask what is possible twenty years from now, in 2010, if computer processing power continues to increase at the same rate? In 1990, student computer use at universities was not widespread, with most students sharing limited computing resources. Yet, if computing processing power and network bandwidth followed the historical trend, as they were far from the fundamental limits of circuit size or capacity, you could easily predict that within the next decade desktop and laptops would be widespread across campuses. By 2010, hand held computing devices would dominate the marketplace and be capable of streaming high-definition content in real time. In fact, DARPA contributed to many of the technologies in your smartphone—not just the processor, but also displays, voice recognition, and inexpensive GPS receivers. DARPA tries to envision what future technologies and applications are possible, and then sets out to create that future with a specific goal in mind. The mindset is not the six to twelve-month product development cycle that the commercial world is driven to.

Now, the agency understands that many programs will not succeed. Typically, five or ten out of one hundred programs meet their goals and are transitioned to the user community. However, this does not mean the other programs have failed, at least from a DARPA perspective. It just means that the original vision or the transition is not fulfilled. A revised program may succeed, and valuable lessons may be learned from a technical dead-end. A failure, in DARPA's view, happens when a program does not succeed because of lack of due diligence, because a program manager did not understand the problem correctly, did not clearly define the program, did not develop effective goals and metrics, or did not properly understand the risks involved, and did not look at ways to mitigate those risks. A failure occurs because you did not do your job as a technical expert and as the DARPA program manager, not because the problem was too hard to solve at present.

This definition allows the agency to work on very hard and high-impact projects. As a program manager, you are not worried about

failure because the task is too difficult. The only thing you need to ensure is that you do the job you joined DARPA to do.

Hard and high-impact projects are always going to be risky. You cannot be fearful and avoid risk that is inherent to a program. You just need to understand what the risks are and find ways to address them. When new risks are identified, do not just push them aside. You identify them and you aggressively attack those risks to make sure the program succeeds.

As a program manager, and as a technologist, you also need to find a certain balance. Fundamentally, I am an optimist. I know technology has enormous potential. But at DARPA it is important to understand the need for a sense of pessimism. At DARPA, so many people come in and present ideas they believe to be new and novel, and in the end, most ideas have resurfaced time and again, and, from your experience, you know that these ideas have fundamental flaws. You realize that good new ideas are rare, and good new DARPA breakthrough ideas even rarer. Despite this, it is important to be optimistic about technology development, and to learn to thoroughly question everything. That is one of the key aspects of the DARPA culture: if you do not look closely and question, you will not understand the nature of the problem, and its possible solutions. You will not understand what difference a new approach might make and you will not understand which ideas are promising and which are not.

A program manager must be respectful of people's ideas. One thing that I learned at DARPA—maybe one of the most important—is that when someone comes to you looking for funding for a new idea, they are actually exposing vulnerability to you. Any good idea, anything that challenges long held beliefs or practice, will have a number of issues. It is always easier to focus on those weak points rather than to try and fully understand the potential and possibilities of a new concept. In that situation, you have the option as a DARPA program manager to focus on all of the potential faults, or you can take a balanced approach and look at the possibilities as well as the questions that need answers. Observe the substance of the idea, the supporting science, and the implications. If you always focus on the faults, or mock an idea, people will be hesitant to approach you with new concepts. Though very few ideas will be of interest, and most will either be poorly thought out or presented like a TED talk, you have to be very respectful for every idea

brought to you. Understand that your job is not only to pursue your own ideas, but to foster and select good ideas that are presented to you.

In turn, the ideas you pursue must focus on producing tangible results. At DARPA you need to be program- and project-oriented, rather than an investigative researcher. DARPA develops prototypes to show what the future can be. If your end result is simply a paper or presentation, you have not proved what is possible. If you demonstrate a robot climbing a wall to the world, on the other hand, then people truly will believe it is possible.

New ideas must have a valid approach. You must demonstrate that the physics and science are valid and at least have gone through the first-order calculations. At DARPA, a program manager will often fund “seedling” efforts prior to a program. Seedlings are quick efforts that provide evidence for a program that moves an idea from disbelief to doubt. There will always be missing pieces that you know must be worked on. This is acceptable, as long as you have a possible approach and develop metrics to measure your progress. You need to have thought in detail of at least one possible technical approach, a straw man solution. From this, you can estimate cost and schedule. Also, if you are going to ask people to propose solutions to your program, you need to be reasonably confident there is one possible approach. However, you should never limit a program to only that one approach. A diversity of approaches is important to any successful program.

Key to making this process work is by clearly defining goals and metrics. Metrics specified for the early phases of a program help ensure you are making progress and tackling the “DARPA Hard” challenges by focusing on the technical problems. Concise final goals and metrics in R&D provide a clear definition of what are you trying to accomplish to the outside world. This is immensely important to DARPA program manager, as the metrics define what she or he is investing in, the capability, what are the hard challenges, how is success measured, and what is the impact. For potential proposers, it provides clear guidance on what their solution must be capable of achieving.

Performance metrics help identify the key technical challenges and capabilities, independent of possible solution. This allows a program manager to gauge how different solution in the program are progressing and how well they are overcoming the key challenges. Metrics may change as a program progresses and the technical challenges evolve, and

as you learn more about the problem and have a better understanding of the missing pieces to the solution. There are always missing elements to a program, where even with your straw man design and scientific vetting, you are not sure they are technically possible. These DARPA Hard challenges are valuable as they provide new capabilities, assuming you succeed.

How each DARPA program is managed can vary greatly between different program managers. What the program managers have in common is the freedom and flexibility to be successful in a high-risk effort, and a fixed timeline to succeed.

Important Questions to Ask

All DARPA programs have to answer a basic set of questions, known as “The Heilmeier Catechism” (or “Heilmeier questions”), named after former DARPA director George Heilmeier. They are listed in Box 11-1. They are fundamental questions that any technology development effort should be asked. If there are parts that do not have an answer, the program is not yet ready to start.

George H. Heilmeier (DARPA director 1975-1977) developed a set of questions known as the “Heilmeier Catechism” to help Agency officials think through and evaluate proposed research programs:

- 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 is new in your approach and why do you think it will be successful?
- Who cares? If you succeed, what difference will it make?
- What are the risks?
- How much will it cost?
- How long will it take?
- What are the mid-term and final “exams” to check for success?

Box 11-1. “The Heilmeier Catechism”.

Source: <https://www.darpa.mil/work-with-us/heilmeier-catechism>

As a program manager, you need to have something new in your approach and you have to know what difference that is going to make. Is it a 2x improvement with 10x the cost or is it a 10x improvement at half the cost? It must make a difference that the end user will care about. It must have a significant impact. You have to be able to estimate how much it will cost and how long it will take. You need specific goals, metrics, and milestones in order to clearly define the program. Answering these questions does not imply a program has a high chance of success. In all honestly, I don't know of any way to determine if a new program is going to be successful, but I think there are ways to determine if a program has significant flaws and has not been properly thought out. High-risk projects need a clear vision.

Timelines

When DARPA hires a program manager, that decision does not mean that the agency has approved that person's proposed programs. Hiring you means they like the ideas that you are presenting and understand that you are a technical expert in that field. It could take anywhere from a few weeks to a few months or even years to actually get approval for your program.

Program managers come to DARPA because they have an ambitious idea to pursue and their interest in supporting national security. They typically do not come to run other people's programs, though managing existing programs is part of the job. The true excitement in DARPA is in seeing your own idea from start to completion.

All DARPA program managers are term limited. A PM's initial employment contract with DARPA is for two years. At any time if you do not believe that the agency is adequately supporting you, then you can leave. If the agency does not think you are doing a good job, then they will not renew your contract. The typical tenure at DARPA ranges from three to five years. Having a limited tenure for program managers is important as it fosters a sense of urgency for a PM in pursuing their program vision. For the agency, this helps ensure that creativity and productivity remain fluid.

After a program is approved by the Director, the program manager writes a Broad Agency Announcement (or BAA) that describes the

program, the metrics, how companies and universities can propose to the program, what is required in a proposal, how proposals will be evaluated, timelines, and the general governing rules. It usually takes about one month to complete and get approval to release the BAA to the public. Proposals to the program BAA are typically due between forty-five and sixty days after the BAA is released. The program manager will often hold a workshop to review the program vision and metrics and provide a forum for others to discuss and form teams to respond to the BAA.

The amount of technical information required for a proposal is substantial. A proposal needs to describe how a performer plans on meeting the program metrics, with a detailed technical analysis, schedule, and cost estimate. It takes several people about a month of time to put together a good proposal—a substantial resource commitment. Companies that have an idea or solution to propose are willing to invest the resources because they believe in DARPA, and they know that there will be a fair and extensive evaluation process that focuses on the technical merits of the proposed solution. Companies know that if their proposal is selected, DARPA has the resources and funding to see the program to completion. This reputation is important, as it encourages a wide range of companies to propose to a BAA. They also trust DARPA to properly protect the intellectual property and ideas disclosed in a proposal.

It will typically take two months for the proposals to be evaluated by the PM and a team of government experts, and final selection of the proposals to be funded. Another three months is required to put a company or university under contract for the program. In total, it takes about six months from approval by the Director to when the selected performers start their technical work on a complex, multimillion-dollar R&D effort. That is incredibly efficient for any government agency, and this speed is one of the beauties of DARPA and its structure. If a PM is only going to be at DARPA for four years, a slow bureaucratic government process would be a problem. The DARPA structure is there to ensure that technical excellence and speed are not orthogonal.

Additional Thoughts on Why DARPA is Needed

I wish to add a few more points about why DARPA is needed and why it is valuable. If you look at many of the modern technical innovations

that drive the world economy, they are based on fundamental scientific developments that arise from periods of intense investment. Truly new fundamental technologies and innovative ideas that can change society are rare. They also tend to be highly reliant on government support, especially from long-term basic and applied research. The U.S. Government spends over \$3 billion each year to ensure that DARPA continues to push the limits of science and technology, plus many billions more at other federal R&D agencies.

DARPA is one part of the government S&T funding structure. DARPA's role is to show the world what is possible, building prototypes that demonstrate new capabilities. In the process, DARPA advances science to overcome technical roadblocks. It is a place of ideas. It is not afraid of risks, as risks are inherent in any innovative idea. At the same time, it is not an academic institution, and it is important to stay within the realm of reality. Rigor must be maintained, with well-defined goals and milestones. It is essential that it is understood, from both the management and technical perspective, that these are hard programs.

DARPA has followed this approach for over sixty years, and has earned the respect from the technical community based on what has been accomplished. This reputation provides very important political capital that no agency can ever afford to lose. DARPA is one grand, continually evolving experiment, which observes what works and what does not work, and which continues to persevere, making changes where necessary. As long as DARPA maintains that culture, DARPA maintains that political capital.

DARPA does not work alone. It relies on the technical performers whose proposed program solutions DARPA funds, and extensive collaboration with the military user community. Once a new technology is developed, it has to be transitioned to the military and commercial realm. In the end, it is the need and market that drives the transition, with the Department of Defense as the targeted customer.

The DOD is an early adopter for expensive, high performance system and often continues the support until the commercial space becomes sufficiently mature.

DARPA continues to push future innovations. In 2004, DARPA held a grand challenge to look at autonomous vehicles. In the first challenge, the best team only completed 12 km of the 240 km route. One year later,

at the second challenge, five teams crossed the finish line. Ten years later, we have the initial glimpses of commercial autonomous vehicles, based largely on the work of those teams. Ten years from now, autonomous vehicles will be common in the commercial world. DARPA is continuing with robotics today, with the DARPA Robotics Challenge (see Chapter 11, below). What will all this work lead to in 2023? DARPA looks at the future, see what's possible, and then tries to drive technology and create that future.

A Flexible and Supportive Agency

The DARPA Director and Office Directors are responsible for developing the agency strategy and technical thrusts. They need a continual influx of program managers to come in with ideas to build programs in those areas. If an advanced technology agency wants to be successful, it not only needs to hire technical experts as program managers, but also provide a way for these people to succeed. DARPA has found an effective way to do both of these things. It enables its program managers to succeed.

When you come in as a DARPA program manager, there is no rulebook to guide you, but rather you learn what you need to do with the help of the DARPA support staff. This is one of the reasons that the agency is such an individualistic organization. A DARPA program manager can often spend up to 25 percent of their time on the road. A typical tour at DARPA can be exhausting, but the agency makes sure you have the support you need.

A friend once told me that if you have something that you wanted to get done, needed to get done, then DARPA was the place to go. There are not many places that would give you a greater opportunity to change the world while working with the best and brightest. The DARPA mix of innovation, speed, and human experience is singularly unique, and when it is time to depart, you will leave with pride in what you, your colleagues, and the agency have accomplished.