What is DARPA?
How to Design Successful Technology Disruption

Alex Waibel[*]

Karlsruhe Institute of Technology, Karlsruhe, Germany
Carnegie Mellon University, Pittsburgh, USA
waibel@kit.edu, waibel@cs.cmu.edu
+49-172-724-6380, +1-412-260-0307
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Introduction

Throughout history, humanity's successes and failures and the survival of societies and nations have derived in large parts from technical innovations and disruptive technologies that have replaced the status-quo with new and better ways of doing things. It is thus understandable, indeed necessary, that nations and governments ask what mechanisms and instruments they should put in place to encourage scientific discoveries and to create technical breakthroughs, particularly for technologies with a transformative, strategic dimension that a nation can ill-afford to miss or fail to understand, control and shape.

Many funding schemes and government programs already exist around the world that aim to support scientific discovery and societal innovation. Many are curiosity driven scientific endeavors that -like art- advance our understanding of the world and our lives and our identity as humans. Others attempt to promote more pragmatic goals and improve engineering and development processes. All are important and necessary mechanisms to drive science forward.

In Post-World War-II history, one funding organization, however, stands out for having been particularly successful in creating, advancing and transitioning technologies in ways that have dramatically altered the way we live our lives: DARPA, the United States' "Defense Advanced Research Agency". DARPA is credited for having invented and developed some of the most remarkable innovations in recent history; innovations that were so disruptive and revolutionary that they have led to entire industries that have gone on to rapidly transform all our lives on the planet. Among them: The Internet, GPS, modern Personal Computers, Stealth Planes, Gallium-Arsenide Semi-conductors, Speech Recognition, Machine Translation, and Self-driving cars. These and many more modern technical marvels can be traced back

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[*] *The views and conclusions contained in this paper are those of the author and should not be interpreted as representing the official policies or endorsements, either expressed or implied of DARPA, the U.S. Government, the European Union or any of its representative governing bodies.*

to DARPA programs. While DARPA's technologies were mostly shared and opened to anyone's benefit, DARPA's first mover advantage has granted the United States a leadership role in many of the resulting applications and industries, despite or *because* of its open sharing. DARPA's remarkable success and impact has been acknowledged and admired around the world, so as to raising calls for similar agencies elsewhere.

But what exactly is DARPA, and what is the key to its success? What is its magic, its "secret sauce"? How did DARPA create and manage disruption so successfully? Disruption comes with surprise, but how can surprise be planned and engineered? And finally: Is DARPA's success a uniquely American phenomenon or can its success be emulated and implemented somewhere else to the benefit of society?
In short: What actually *is* DARPA?

This paper attempts to answer these questions.

History

During the depths of the cold war, the United States was in a heated competitive struggle with the Soviet Union for economic, military and ideological supremacy. While this competition played out on many fronts, a most visible show of force of who had the better approach, the better system, played out in the race to space.   On the backdrop of prior threats (Germany's development of V-2 rockets) during World War II, the United States was actively adopting, promoting and extending modern rocketry in view of building and maintaining military supremacy in Air & Space, and to establish modern satellite technology for future communication and intelligence. To its dismay and surprise, however, these early efforts were overshadowed by the Soviet Union's success to launch Sputnik, a first satellite that managed to beam and transmit messages and music from outer space, before the United States could realize this feat. In order to never again be blindsided by others with external surprises, the US decided that it needed a mechanism by which it could create its own surprise and disruption internally, before others would, and to lead and control such technological transformation. As an instrument toward this end, the United States in 1958 established the Defense Advanced Research Project Agency.

DARPA's mission to produce technological disruption was viewed as a strategic instrument, essential for the survival of the United States and its position in the world. Deeply rooted in its DNA, therefore, are a perennial search for grand challenge problems with potentially dramatic strategic impact, and a culture with a focused hard-hitting sense of urgency to accomplish the mission. As the agency took shape, leadership, budgets and administration were arranged and optimized to permit the formulation of such game-changing capabilities at the greatest possible speed.

Over the years this led to a remarkable string of technological breakthroughs that have changed the way modern society now operates. The successes –even though often initiated with a capability motivated by defense needs- are most visibly seen in commercial and societal capabilities and the rapid emergence of new industries: The Internet, the first modern Computer, GPS, Speech Recognition, Machine

Translation, Self-Driving Cars, Machine Learning, AI, and many more [1] [2], are all disruptions that have profoundly changed the way we live our lives today; and they can all be traced back to DARPA.

Focused Budgets

The first and important ingredient to DARPA success, are –of course- large concentrated budgets. To realize disruptive, transformative visions, a generous budget must be assured. DARPA's overall annual budget has gradually grown over the years to now $3.17 Billion US. This is, indeed, a healthy sum, but considering the US's overall expenditures for government sponsored R&D in excess of $B 500, and DARPA's flat or slowly growing budgets, DARPA was and is only a small fraction of the US's investments in science. It is also a modest cost compared to the US's overall annual DoD budget of $B 639. A single stealth bomber costs 2$B and is in a comparable order of magnitude! Considering these numbers in an international context, DARPA's and the US's R&D budgets are also on par with other parts of the world both in terms of absolute cost (Fig.1) and as a percent of GDP (see Fig.2)[†].
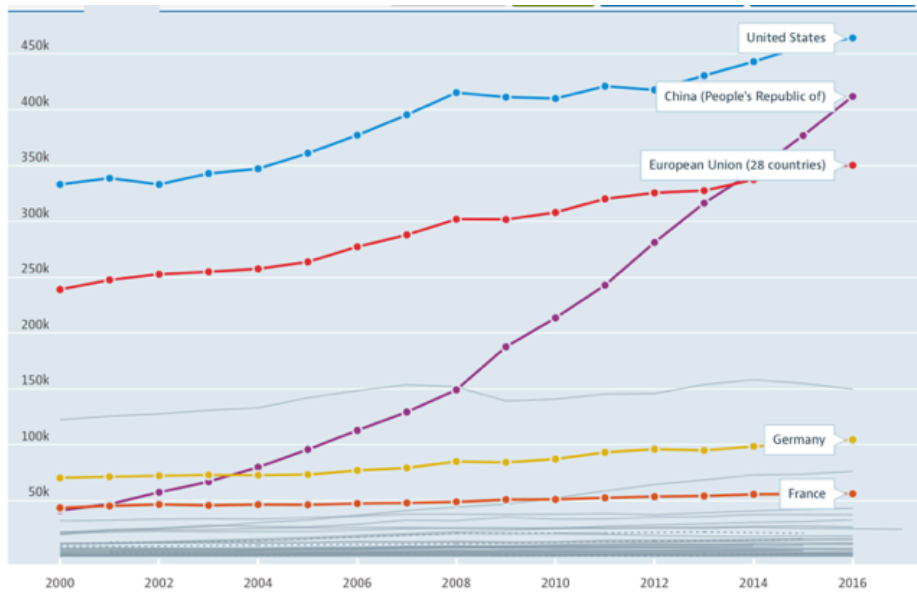

Figure 1 R&D budgets in different regions of the world, in $Millions

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[†]with China racing ahead and on course to soon overtake the United States.
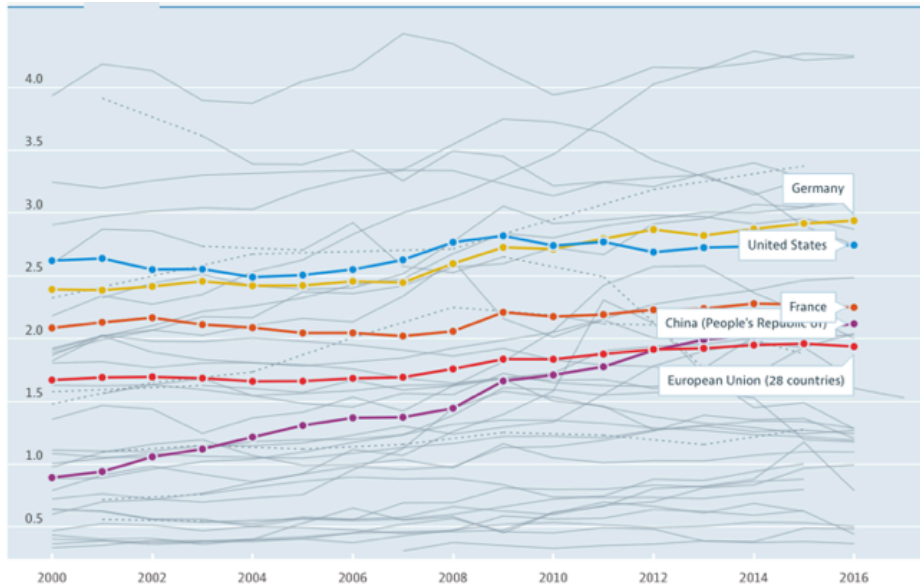
Figure 2 R&D budgets in different regions of the world, as % of GDP

With budgets comparable to others, how can we then explain DARPA's remarkable success and societal impact? DARPA's overall budget is only parts of the answer. Complementing it, and perhaps more important, is the greater concentration of its budgets on fewer best performing teams. In comparison to other government research funding sources, DARPA programs have large budgets <u>per program</u> and distribute them to fewer participants ("performers" in DARPA-speak), thus creating a larger more concentrated budget per site. This allows a DARPA site to work intensely and speedily on the program's ambitious objectives. With a carefully selected portfolio of the best scientific teams, larger budgets per team and more intense competitive pressure to achieve the objectives (see section on Evaluation), DARPA programs achieve a greater concentration of talent, mission and performance focus.

Large and focused budgets and a mission are thus certainly one element of DARPA's success, but money alone does not suffice. DARPA's success is also due in large parts to its ingenious organization and management style.

The "D" in DARPA: Military(?), Strategic Research

There is no question that DARPA is a research agency reporting to the Department of Defense. As we have seen, its creation grew out of a perceived national emergency resulting from the USSR's surprising success in space with Sputnik during the cold war. DARPA's organization under the Department of Defense may thus not be surprising. Internally, it is organized into several offices that fall into two broad classes: Systems Offices, and Technology Offices. Some of these have a direct military link and are involved in development of tactical military systems. Technology Offices aim to create enabling technologies that are needed for such missions, but also involve scientific work on capabilities that serve broader societal needs. This includes fundamental research in fields such as: materials, mathematics, electronic components, information technology, etc... Such enabling technologies therefore go beyond the scope of defense or warfare alone and contribute considerable knowledge and technological

advances for the United States High Tech industries and ultimately its economy. While such fundamental research is beneficial in general, their military justification and their organization under DoD is in many ways also beneficial for science to be accomplished efficiently, as it provides political will at the highest level, prioritization of capabilities, and intense focus on pragmatic and usable results. In any democratic society, where budgets and programs are constantly under attack from special interests and easily derailed by the vagaries and debates of the political day, such strategic focus is not to be underestimated. It provides DARPA's fundamental science programs political support at the highest level that ensures longevity of its programs and concentration of budgets. An agency with the mission to deliver technologies and capabilities that are considered critical to a nation's and a society's survival, can focus energies and concentrate large budgets to achieve success.

For basic science, the "D" in DARPA therefore does not necessarily imply military application in the strictest sense or exclusivity (this is frequently misunderstood outside the US). Many of DARPA's technology programs intentionally work on "dual use" technologies, i.e., technologies that deliver benefits to national defense _as well as_ civilian, industrial, and humanitarian development. Many of the chosen technology goals are chosen to benefit all of society (e.g., the internet, GPS, self-driving cars, machine translation, etc.). Contractors, too, are not necessarily part of the military establishment. Many scientists participating in DARPA programs don't have "security clearances" and many DARPA projects are done in unclassified, open environments. Universities, for example (who in the US have open publication policies and cannot perform research requiring security clearances[‡]), frequently work on DARPA programs without knowledge of or participation in military interests or deployments. Among participating researchers, many are not US citizens, and can publish their work freely. Even foreign research groups and Universities are regularly invited and funded to participate _abroad_, and they publish their work internationally. The only guiding heuristic for DARPA is that the scientific program accomplishes the targeted technological advances in the shortest possible time with the best possible team available.

DARPA problems are chosen to be far-out, hard and strategic problems, and are defined much more broadly than for a narrow military capability only. Indeed, in DARPA's history, DARPA was not always a _Defense_ Research Agency: the "D" has sometimes been omitted altogether depending on the president and administration in charge (for example, last, during the Clinton administration).

The "P" in DARPA: A _Projects_ Agency to Accomplish a Mission

In many ways, DARPA acts as a funding organization that provides support to research groups in the government, industry and in academia like many others. It does, however, operate quite differently from traditional instruments for funding research in that it funds research not based on the interests of the scientific community, or the engineering needs of participating industries, but to dream up and to create entire new concepts and disruptive capabilities that address a national strategic need. It thus organizes _projects_ that are mission and problem driven, not curiosity driven.

[‡] US top Universities have open publication policies. They cannot restrict, delay or inhibit researchers' academic writings or students' theses and cannot accept responsibility or liability for their published views and conclusions.

It is important to note that DARPA's approach does not replace or eliminate the need for other sources and instruments that support science and engineering research. In the US, they are complemented by alternate fundamental and applied science investments (both civilian (NSF, DOE, NIH) and military (ONR, AFOSR)) that together create a full ecosystem for funding in critical areas. Indeed, those instruments are necessary, critical and complementary to DARPA's mission, but basic science for science's sake is not DARPA's central concern or not within the scope of its projects.

So, what then are DARPA research problems and how are they chosen? By its definition and raison d'être, DARPA's selection of research topics differs from other research funding organizations that are commonplace in the US, Europe and elsewhere. The National Science Foundation (NSF), the Deutsche Forschungsgesellschaft (DFG), the Bundesministerium für Bildung und Forschung (BMBF), and the framework programs of the European Commission are defined predominantly by the scientific interests and recommendations of the scientific community or participating companies. These agencies act as mediators and moderators of the discussion and managers of financial accountability. They select and organize panels to discuss program definition, prepare requests for proposals and manage the coordinated review and selection of proposals via panels from the scientific community. Prospective contractors prepare proposals specifying work packages, tasks and milestones around what they propose to do, and proposals are selected by peer-review. Once a project is selected, government contracts and consortial agreements regulate contractors' responsibilities, tasks and sharing of IP. Subsequent assessment of project performance and contractor accountability is then monitored mostly by administrative and contractual measures, i.e., if a contractor or a team delivers what they had proposed to do and if they spent their funds reasonably in the way they proposed.

DARPA, by contrast, is singularly focused on "Project"s, leading to a technical disruptive capability. Even though programs consider the input from the scientific community, programs are ultimately defined by creating certain governmental, societal or strategic objective. They are typically reviewed by experts and decision makers in the government. The Mission is not defined by participating (industrial) contractors in a team or academic interests, but by the government with input from the community. Periodically, also, brainstorming sessions around problems to be solved are organized to receive input from top experts in pertaining fields (in IT, for example, so-called "Information Science and Technology Study Groups (ISAT)"). A vision is then formulated as a DARPA Project with practical, measurable goals. For example: create a protocol for an open information exchange infrastructure → Internet; build a car that can achieve certain performance objectives (e.g., drive through the desert or in a city to reach a destination) → the self-driving car DARPA Challenge; translate arbitrary text from Chinese to English well enough, so that defined usefulness criteria are met. Such visions and grand challenges define the core directions of DARPA programs. Their concentration and mission-oriented focus has wide ranging implications for DARPA's organization and operation.

The "A"s in DARPA: An _Agency_ to Create _Advanced_ Technologies

DARPA was called into being to create internal technological surprise to prepare and to prevent technological surprise from elsewhere; to lead technological disruption, rather than to be disrupted by

it. Such a proactive move as best defense required an organization with extraordinary creativity and vision for the future, and extraordinary speed and intensity in its execution. It had to be nimble and flexible, unbureaucratic and efficient, and it had to be decoupled and de-conflicted from existing private and public interests.

The organization that resulted was an agency that is small and independent; it has almost no administrative functions[§], and has no laboratories or infrastructure to maintain.   But it is wired to efficiently connect the best scientific minds with the highest levels of decision making to create impactful visions and ideas and to execute on them efficiently, speedily and forcefully (with sufficient budgets).

Specific measures in its operation include:

1. Efficient Program Creation – Creation of DARPA programs require the technical expertise of the best and brightest scientists and experts, but also the political will and power to decide and move large budgets quickly. Wiring the best technical expertise with the highest level of government decision making under DoD was the most effective.
2. Efficient Execution – The execution of DARPA programs requires technical expertise in government and fast and efficient decision making, unimpeded by bureaucratic burdens. DARPA is not an institute or company. It funds R&D work in other organizations and outsources all administrative functions and monitoring to other independent organizations. Its program managers enjoy broad discretionary powers, but are term limited.
3. Efficient Technology Transfer – To accomplish rapid adoption of new technologies, DARPA programs connect research projects to government customers and use cases. The government thus does not only distribute funds for research, but it is the primary customer. As such it manages evaluations of technology and facilitates trial deployments in government institutions.
4. Independence - DARPA's mission is to provide technical leadership for the nation and is organized under the department of defense. As such, the customer and sponsor of public funds are both the government and thus aligned and unencumbered by private, commercial or academic interests. As DARPA reports directly to the Office of the Secretary of Defense and to congress, it is also independent from individual branches of the military and can serve all public interests.

In the following we examine in greater details how these measures are achieved.

Creation of a DARPA Program

How are DARPA programs defined and created, when government functions must employ administrators (not scientists) and when the scientific community is not defining or funding the programs. Indeed, there is no government entity that pre-specifies particular research programs top down[**]. DARPA Programs are defined by an iterative design process between a community of the best experts/scientists in each pertinent field and the highest levels of government concerned with various

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[§] Only some minimal internal administration.
[**] even though it commissions, funds and later uses the results of such programs

threats and opportunities. However, this process is intentionally wired as a fast and direct dialog between scientific experts who propose programs and high-level decision makers who can move large budgets.

The process begins with brainstorming between DARPA representatives and the scientific community. For the enabling technology areas at DARPA this is done individually or in conferences (ISAT studies). Such brainstorming at the scientific level is –of course- not dissimilar to equivalent activities by other agencies and countries (in the EU for example "Concertation" Meetings or Strategy Conferences and Position Papers). They are driven to achieve concrete practical, yet visionary goals. Resulting visions are then formalized, vetted and "pitched" by a "program manager" or someone who aspires to become program managers. These program managers are key (more on this below): they are scientists with a detailed understanding of the technology to be developed and an understanding of the government and military, and they are at DARPA only for a limited time (3-4 years). The criteria for selection of a program are relatively simple and have been most succinctly formalized by one of DARPA's early directors, Dr. George Harry Heilmeier. Heilmeier was an engineer, entrepreneur, manager, and one of the pioneers of Liquid Crystal Displays and understood the creative, pragmatic and scientific dimensions of innovations deeply. He instructed his team of DARPA directors and managers, to address 8 simple questions when pitching a DARPA program. The questions have become part of DARPA folklore and are now commonly referred to as the Heilmeier Catechism. The questions are:

- 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?
- How long will it take?
- What are the midterm and final "exams" to check for success?

The resulting program pitch is first proposed and vetted with the DARPA office director, and finally delivered to the DARPA agency director. Due to the small size of DARPA, this process is relatively quick and efficient and allows for several iterations. Once a program is successfully pitched at DARPA, it is then proposed to the Pentagon and (along with other programs) submitted to Congress[††] for budget approval. And by the time a budget is received, each program has been reviewed and optimized by the DARPA office director, the agency director and congress.

The DARPA Program Manager

Perhaps the most important ingredient and key to the definition and success of DARPA programs is the DARPA Program Manager (PM). His/her role, credentials, personality and hiring are perhaps the most unusual amongst funding agencies around the world and matters significantly to the success of DARPA. His/her powers, program definition, selection of participants, discretionary budgets, and influence over

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[††] Depending on the size of the program

technical directions are broader and more dynamic than those of his/her peers. But his/her tenure is limited in time and scope. The differences in management approach are essential in driving DARPA programs' success:

- Broad authority to execute – DARPA PM's have broad authority over their programs. They define and pitch the programs, they select or fire (in DARPA-speak, euphemistically referred to as "down-select") contractors (in DARPA-speak: "performers"), and they organize government reviews and evaluations. Most importantly they have broad authority over their budgets. They decide on budget allocations within their program and have the freedom and flexibility to seed new activities spontaneously, or reduce and redirect existing activities, so as to respond dynamically to new developments and insights, performance of the contractors and budget constraints. These flexibilities create speed of execution and intensity of focus.
- Limited Tenure – The broad powers given to DARPA PM's are paired by their limited tenure. DARPA PM's are _not_ career bureaucrats with indefinite tenure, but scientists that are replaced as their programs come and go. They are hired for a limited time (typically 3-4 years) and are frequently "on loan" from scientific government labs, universities or industry and they may return to these organizations after the completion of their tour at DARPA. Some come back for another tour at DARPA later but with independent and new program ideas. If they come from a non-government entity, they are on temporary leave (with full rights to return) from that organization and the government covers their salary during their time at DARPA.
- Technical Expertise and Government Insight – DARPA PM's are usually scientists, technical experts in the field pertaining to the mission of a given program, although they generally also understand and desire to serve the government and to make contributions to the public good. But they come to DARPA mostly motivated by and focused on achieving a technical vision, their program, not by expanding institutional territory or rank at DARPA. After the completion of the program, he/she typically returns to their home institution and the scientific community. A DARPA PM's professional success thus depends entirely on the creation and technical achievements of their programs. A PM also does not manage by overseeing contractors' bureaucratic or administrative compliance (this is done by separate contracting agencies) but ensures accountability through technical metrics and merits leading to mission success.
- De-conflicting – As DARPA PM's come with limited tenure and with an institutional background that is not always from the government, special care is taken to de-conflict DARPA PM's activities from their original community or organization. They must disclose their financial interests and disassociate themselves from conflicting interests and engagements at least for the duration of their tenure and a certain period after.

Tech Transfer - The Government as Customer

Implied in the mission-oriented approach and the definition of national strategic objectives, is the fact that in a DARPA program, the government as sponsor is actually also the customer, and a customer is expecting results. Other (civilian) funding agencies provide support for research that _the funded parties would like to do_ (NSF, DFG, EC...), or that solves _one of the partners' problems_. But in these cases, the government does not collect the results for its own use. It merely monitors compliance with the proposed work plan. In fact, due to legal constraints, government entities are often _not even permitted_ to directly engage in, direct research or transfer results for their own purposes[‡‡]. DARPA, by contrast represents the US government as customer, and is commissioning research on its behalf. This does not

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[‡‡] As a result of this separation, for example, many European government entities now use Google translate for casual translation needs, despite decades of research investments by European Science Ministries and the European Commission.

mean that DARPA acts as engineering shop for government bodies or military applications. But it does mean that DARPA projects are tasked to accomplish real capabilities, create disruptive technologies that solve an actual public problem and they have to identify actual customers who have that need. DARPA therefore is not a dispassionate distributor and administrative steward of public funds for projects that funding recipients wish to do, but an agency that contracts the best scientific teams to solve specific national problems[§§].

The importance of this is significant: Having the sponsor of funds be the beneficiary of the results keeps a mission-oriented project focused and avoids possible conflicts of interest that can arise when the direction of research and the recipients of the funds are the same. A customer (with subject matter expertise, no less) paying and expecting results is naturally de-conflicted from the contractors that deliver the goods or services. They then are aligned and incentivized in their common goal to achieving a successful result that the customer can use. And as such, it makes managing the development and evaluation of progress much more straightforward: A product either works or it doesn't[***].

Metrics, Evaluations and Coopetition

Unlike curiosity driven research, DARPA programs aim to achieve a practical vision, grand challenge goal or capability effectively and quickly. Mission success is therefore not accomplished by fulfilling originally proposed milestones, but by reaching a targeted capability. If new technologies, methods, insights appear during the course of a program, DARPA management and programs reserve the right (indeed, they are expected and encouraged) to change and adapt. It is in the hands of the program manager to decide quickly and aggressively on new directions, if the context so warrants to achieve the mission.

But how, then can accountability be assured, if compliance with an original plan is handled so liberally? This is generally achieved by relying on extensive performance evaluations. Depending on the nature of the technology program (recall, that there are systems and technology programs) such evaluations can take on different forms. For systems, broader systems tests may need to be performed.

If technology capabilities are to be achieved, evaluation can be done through the use of well-defined metrics. "You improve what you measure." says the old adage, and DARPA technology programs usually implement a rigorous process for such performance evaluation. For many technology programs, DARPA managers first work with the scientific community in government, industry and academia to define common benchmarks and metrics that properly assess performance to gauge if a capability has been achieved, and the progress achieved by a program along the way. Automatic Speech Recognition, Machine Translation, several subdisciplines of Natural Language Processing, Object Recognition, Vision Processing, and many others, were routinely evaluated in this manner through common benchmarks and performance metrics. Such an evaluation-based approach was gradually adopted worldwide[†††]. It

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[§§] The actual implementation of transferable impact and deployment is managed either directly via sponsoring government agencies, tech transfer agencies/laboratories, or via commercial vendors or open source.
[***] Or at least its benefits can be assessed.
[†††] Often around DARPA defined benchmarks and metrics

has elevated these fields from black art to objective science, leading to the tremendous advances in capabilities and performance we enjoy today.

Evaluation metrics and benchmarks are used to measure progress, and every contractor or site has to subject their research to such objective measurements (for example, word error rate, translation error rates, driving duration, obstacle recognition, etc.) and report their results. If evaluations are carried out on standardized benchmarks (as can be the case for many IT capabilities), they are comparable across sites and lead to (sometimes intense but friendly) competition between the contractors. All benchmark results are assembled and assessed by a neutral government body with expertise in rating and evaluating benchmark measures. The function to evaluate can be performed by an independent government institution, such as NIST, the National Institute for Standards and Technology. Such an evaluator presents (at DARPA project conferences) the joint results and contractors present and discuss their own results in technical detail. The competition combined with openness and objectiveness of such evaluations creates intense, detailed, discussion between the scientists, and thus unparalleled focus, thoroughness and insights in a problem that other scientific venues cannot achieve. Although the competition might be considered adversary, the discussion and openness generate partnership and collaboration. The resulting "coopetition" creates focus, intensity, and speed toward realizing the common objective. Indeed, it has been shown over the years that multiple competing teams building entire systems achieve results more efficiently and cost-effectively for the program, than teams working on different components, despite the apparent duplication of efforts implied by such coopetition. Each team has fewer dependencies and interface issues to worry about, and the speed of insights across competing teams leads to faster progress.[‡‡‡]

Straight from a program's initiation, DARPA program managers focus on technical discussion in view of achieving the program's goals. The program is then managed by the PM through periodic evaluations, project meetings and site visits. Most of the discussion at project meetings center around reporting, presenting and scientific discussion of evaluation results. With benchmarks, evaluations and performance metrics as the "yard-stick" contractors are selected, deselected, encouraged or reprimanded. Scientific metrics, thus, provide objective criteria to enforce accountability of contractors in view of the technical objective, rather than merely monitoring contractors' compliance with contractual milestones or administrative procedures. In such a regime it is also not impossible, but common, that earlier plans, milestones and even contractual commitments are modified or discarded, when new discoveries and insights lead the program in more promising directions.

Of course, it may be argued that any scientific program around the world would hold project meetings to discuss scientific results. But a DARPA program's focus of such activities around evaluations, performance metrics and benchmarks, combined with the PM's technical insight and authority to select, deselect, redirect, activity based on objective progress assessment, drives all discussion and budgetary

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[‡‡‡] *This approach of competitive performance evaluations was long often rejected in European projects, on the argument that it would be an unacceptable duplication of efforts. Because of its success in certain scientific communities, however, it could be argued and was adopted in various EU-Projects, successfully. For example, EU programs CHIL, TC-STAR, EU-BRIDGE, adopted coopetive evaluations in the areas of speech recognition, machine translation, computer vision, human-computer interfaces, leading to effective progress and successful results.*

considerations rapidly and dynamically toward achieving scientific objectives. It accelerates progress, since unpromising detours and poor initial investments are pruned away more efficiently.

Not all fields and technologies are easily evaluated by performance benchmarks, however. How, for example, does one create a benchmark to evaluate self-driving cars, cyber-security, software designs, airplanes, etc.? They may elude the definition of simple benchmarks. Yet, DARPA performs capability assessment for these, too, although in other forms.   For example, dialog translation systems have been evaluated in terms of task completion in addition to component evaluations, or self-driving cars have been evaluated in terms of mission completion, or in terms of a competitive race (e.g., the DARPA autonomous driving challenges through the Nevada desert or urban terrain).

The definition of metrics, benchmarks, task performance scenarios and challenges require time and effort, and must constantly be revisited as the technology advances or new difficulties and challenges are discovered. All too easily benchmarking exercises can also become an objective in itself, rather than a measure for a desired capability. This tends to bias efforts toward tweaking for a metric (immediate reward) and cause deferral of important aspects such scalability, robustness, usability, etc. Without periodically stepping back and realigning evaluations with the intended objective, metrics can otherwise obscure rather than illuminate scientific discovery and progress. Inventing and re-inventing various schemes to evaluating technology and task performance is thus a continuing activity at DARPA and the resulting metrics remain subject to continuing revisions. Periodic alignments are typically done by the DARPA PM's in discussion with the community and the contractors. The PM's independence, scientific expertise and broad authorities are -once again- essential to navigating these potential pitfalls of the DARPA approach.

Conclusion

The remarkable success of DARPA has been achieved through generous budgets but more importantly through an organization and management approach that differs considerably from research ministries and funding organizations in other parts of the world. In its differences, the DARPA approach is not replacing or reducing the importance of such other funding organizations or mechanisms. Rather, it depends on, builds on and complements them to turn technical insights into disruptive societal change. The DARPA organizational principles that set it apart include:

- **Effective Organization to Maximize Disruption:** this is achieved through
  - **Agency Independence:** Disruption does not always make friends. Programs have to be given sufficient independence so as not to be influenced, terminated, or derailed by the interests of established players and stake-holders. While DARPA is under DoD, it is independent from the different services.
  - **Wiring Scientists with High Level Decision Makers:** Definition, vetting and pitching of programs by scientific program managers within a small agency (DARPA) and with high level decision makers in congressional committees
- **Moonshot Problems:** Identification of technical problems or capabilities that are visionary and hard, but solvable and address strategic national priorities and a public good.

- **Budgets for High Risk Research:**
    - **Critical mass through sizable and sustained budgets:** Such budgets must be obtained efficiently to achieve a capability in a timely manner. This requires political will and high-level approval. In the US, this is best done through DoD.
    - **Flexible Spending:** Flexible spending authorization permits rapid adjustments and redirection and unbureaucratic initiation of new ideas.
    - **Expect Failure:** Readiness to spend large budgets on unproven ideas with an *expectation* of a high degree of failure.
- **Government as Customer:** The government provides the funds but also uses the results. This creates an arms-length transaction between the sponsor (the government) and the recipients of government funds, the contractors. It aligns all efforts, achieves effective execution, enables meaningful evaluation and optimizes efforts toward achieving the desired capability.
- **The Program Manager (PM):** A unique but perhaps the most important ingredient in DARPA's success is the DARPA Program Manager. He/she is not just a manager of funds, but his/her position comes with unusual properties:
    - Broad authority: The DARPA PM has broad powers to dynamically fund, launch, abort, redirect activities, based on scientific expertise and objective performance evaluation
    - Term Limitation: The limited tenure of a DARPA PM (typically 3-4 years) ensures that his/her aim is not to advancing a position or rank in the organization, but his/her entire reason for being at DARPA and thus his/her attention is focused on achieving technology and mission success.
    - De-conflicted scientists: DARPA PM's are scientists, experts in the field in question. They may come from other government labs or agencies or may be on paid leave from a scientific institution but are deconflicted from their home institutions. They thus bring subject matter expertise yet impartial management to leading a program.
- **Metrics and benchmarks and competitive evaluations**: Metrics, benchmarks, and competitive evaluations track/assess progress, success/failure; Metrics based evaluations provide objective tracking toward program goals, they generate focus, discussion and shared insights and they enforce accountability for PM and contractors despite the broad authority and flexible manner of program spending.

Epilogue: A European DARPA?

As a result of DARPA's remarkable success, the call for a **European** (D)ARPA has been made on numerous occasions. Europe has the size, the budgets, the needs and certainly the scientific experts and expertise, for such an idea to deserve serious consideration.

Europe has been leading many scientific discoveries and development over the years. It has a long track record of outstanding scientific efforts leading to world class results and discoveries. It has excellent educational institutions that have been and still are training some of the world's best minds. Europe also provides R&D funding that is on the same order of magnitude as in the US, indeed in some member country's case (measured as a function of GDP) even better than the US. Europe provides great

freedom and autonomy and generous long-term budgets to its scientists to carry out their research freely and with few constraints[§§§].

By budgets, training and creativity, European scientific efforts are among the best of the world and along several dimensions they are the envy of their peers elsewhere. And they have results to show for it as well: European programs have led to many breakthrough performances, discoveries and insights, and in many areas Europe leads in terms of numbers of scientific publications. To date, more Nobel prizes were awarded in the European Union (481) than in the US (375) and China (9) combined[****]. But despite these remarkable achievements (that surely should continue and be supported!), they have so far failed to have the same disruptive societal impact as tech development has in the US through DARPA.

So, what would it take to create an agency that turns European scientific advances and discoveries into disruptive change with tangible benefits to society? Is an agency with such a mission possible? Is a European (D)ARPA possible and what would it take to set it up?

To be sure, it is not easy to replicate the culture and success of DARPA. In the US, too, several attempts have been made to replicate the success of DARPA in similar mission-oriented research agencies, but with mixed results. In Europe also, various aspects of DARPA style research have been implemented (and improved output), but it can be argued that each of them by itself has not resulted in the same level of impact.

In contrasting these efforts, it is perhaps most striking, how DARPA's governance and decision making differs from most other organizations. When it was founded, its mission was to produce disruptive ideas and innovations so that change would come from within the nation instead of from external surprise. This has led to an organization, a culture and a political wiring that optimizes the likelihood and speed for disruption to occur. To succeed at this, it is important to realize that disruption is uncomfortable and unpleasant. It imposes change that established players and stake-holders may very well (and indeed have tried to) resist, slow or derail, when their role, influence and possibly their existence are threatened by such change. Optimizing for disruption thus means -first and foremost- to create an agency that is independent in governance, funding and scientific direction to shield it from such influences both public and private. To give it a chance to succeed, it then also has to be liberally and well financed, inspired and led by the best *technical* minds, impartial in its assessments, and fast and autonomous in its execution.

Is this possible in Europe? In the view of this writer, a successful ARPA can exist anywhere, where there is a true commitment to create one's own disruption, no matter how unpleasant this may be. To succeed at setting up an agency with such independence and autonomy requires a common conviction

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[§§§] Consider for example the endowments and staffing provided for University Professors and for institutes such as the Max-Plank Gesellschaft in Germany, the freedoms provided for CNRS researchers in France, and the generous, multi-year ERC grants for long term research programs at all levels.
[****] Source: https://en.wikipedia.org/wiki/List_of_countries_by_Nobel_laureates_per_capita

that internal disruption is better than external disruption. It allows a nation to create a future society and world that is shaped by its own values and priorities rather than having to accept it later by way of external change. But to succeed at setting up such an agency also requires the faith and confidence that something good will happen with such change, when the very best minds are focused on great goals and freed to run with their dreams under the least possible control or interference.

But what can produce the necessary political will and urgency to organize an agency with such independence and such a seemingly wasteful and open-ended charter? In the US it was the shock and threat of Sputnik, and the perception of urgencies, threats and challenges still guide DARPA as an organization under the Department of Defense. Would a European ARPA therefore similarly be required to be under a European Defense? It could, but other configurations are also conceivable. Whatever the chosen configuration, however, a European (D)ARPA would need to be driven by a sense of urgency and a joint political will to define and fund large concentrated programs for disruptive technology development. Such will, if not derived only from Defense, could be derived from other threats and challenges that are understood/accepted by the tax-paying public as matters of survival and thus an overriding common priority. These could include threats and needs in the area of public health, security, democratic discourse, economic survival, migration, integration, social welfare and many more.

Given an independent organization, political will and urgency, the ingredients of successful management (as discussed in this paper) would then also have to be addressed and implemented.

Does Europe have and require solutions to hard, visionary moon-shot problems? There certainly _are_ uniquely European problems that would deserve a grand challenge vision to which scientists could contribute radical new approaches. Just to name a few examples: handling the fragmentation in Europe, overcoming language barriers within Europe, improving cross-border trade and commerce, managing migration, preparing for an aging population, cyber-crime, the threat to European democracies via fake news and media manipulations, securing privacy, and many more. And beyond European problems, proactive leadership on a world stage should also include addressing global problems that Europeans are passionate about (for example, climate change, clean oceans, health, etc. [3]).

A European ARPA should also commission work on needed capabilities with the government as customer. Such an agency should be choosing problems and identify government champions as _recipients_ of the technology. Of course, problems can (and should) also be chosen in a dual-use fashion, thus eventually helping industry benefit (indirectly) from results, as well. Making the public be the customer and beneficiary of sponsored research, would improve efficiency, accountability, and create de-conflicted, arms-length transactions during the development of a program.

More effective mission oriented, scientifically savvy and technically focused leadership would also need to be achieved, by creating a European ARPA manager. With temporary tenure, scientific expertise, and broad authority, more effective, dynamic and engaged management could be achieved to execute more

quickly and effectively on grand visions. With a technical expert yet de-conflicted program manager, and with competitive metrics-based evaluations, accountability could be achieved around mission capabilities, rather than accounting compliance.

European science funding (while generous and world-class in fundamental research) suffers from a lack of such management that is needed to lead to technological disruption. Although science ministries are motivated and eager to affect technical innovation and do employ competent and able leaders, their personnel's permanent tenure makes it impossible to have on staff known, respected experts, for every scientific field that is to be explored. Such permanence also tends to firm up organizational structures and relationships and does not encourage the independence from established stake-holders (public or private) that is necessary to move on disruptive innovation. This slows the process of decision-making and program creation down. Furthermore, it generates entanglements between governments and external scientific institutions that are needed for input and guidance, thus creating inherent conflicts of interest: Responsibility and guidance is outsourced to large research institutes that advise, guide, but also receive significant funds from ministries at the same time. This is particularly problematic, when practical goals are to be researched, commercial interests become pronounced and when commercial entities are part of the definition and execution of their own funded programs. In the US, too, such private interests periodically have attempted and could potentially have acquired control over public programs. For example, during the development of the IP Protocol for the "ARPA-net" (which is now known as the "Internet"!) several established players had moved to exert control over its implementation. But thanks to DARPA, its independence, its dynamic organization, and the public as customer, the Internet and many other DARPA technologies went on to benefit the public and thus have had the considerably broader impact that we now all enjoy; with much broader benefits for the public, the US, and the world, and with entire new industries in its wake.

Many points in this essay are -of course- understood, appreciated and actively discussed in Europe [3]. Indeed, many individual dimensions of these principles are implemented and common practice in various European programs. There are also programs under the European Commission specifically seeking to support high-risk Future and Emerging Technologies [4]. The critical importance of fast and effective innovation and transfer has also been recognized and argued [3] [5], and broader efforts are being established that begin to build out all the dimensions of a DARPA style approach as discussed in this paper. They include the recently formed Joint European Disruption Initiative (J.E.D.I.) [6], with a vision and organization that reflects a DARPA style approach. Organized similarly in spirit, it's aim is to establish a pan-European DARPA style funding organization. It has begun operation under a French-German partnership and aims to grow to include all European member states. Another effort is the European Defense Fund organized under the European Commission. It is to unite European scientific disruptive research under the umbrella of an emerging European joint defense [7]. All these efforts are the right steps in the right direction. But more needs to be done. These efforts must receive greater attention and generous financing at the highest level representing all of Europe, they must be supported by a joint political will, they must be built for and retain independence, and they must implement a multi-dimensional set of management tools that assure speed in execution and optimize impact of their results.

May Europe have its Sputnik moment and see the urgency of the challenges ahead and rally its scientific community around programs that help create a better, safer, stronger, free and peaceful future; for Europe and for the world.

Acknowledgement

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About the Author

Prof. Dr. Alexander Waibel
Carnegie Mellon University, USA
Karlsruhe Institute of Technology, Germany

Biography

Dr. Alexander Waibel is a Professor of Computer Science at Carnegie Mellon University, Pittsburgh and at the Karlsruhe Institute of Technology, Germany. He is the director of the International Center for Advanced Communication Technologies (interACT), a leading research center for AI, Machine Learning, Speech & Language Processing, multimodal interfaces, human-human and human-machine communication technologies. He is known for pioneering work on the "Time-Delay Neural Network" (1987), the first "convolutional" neural network, and for breakthroughs in computer speech interpretation systems that now make international communication easier.

System milestones from Waibel's lab included the first speech translation system in Europe/US (1990/1991), early multimodal dialog interfaces, the first simultaneous lecture interpretation system (2005), and Jibbigo, the first commercial speech translator on a smartphone (2009). His speech translation technologies were deployed in international humanitarian and disaster relief missions and are now tested for migrant health care application in Germany. His team also develops and operates (at KIT) the first and so far, only automatic simultaneous interpretation service for lectures at Universities.

Waibel is a member of the National Academy of Sciences of Germany, and Honorary Senator of the Hochschul-rektorenkonferenz (the Representation of all German Universities). He is a Fellow of the IEEE and received many awards for work on multilingual and multimodal communication systems. He published extensively (800+ publications, >30,000 citations, h-index >85) and holds many patents.

Dr. Waibel received his BS, MS and PhD degrees in at MIT and CMU, respectively.

At his center in Karlsruhe and Pittsburgh, Dr. Waibel conducted many fundamental and applied research projects under European (EU, BMBF, DFG) and under US (DARPA, IARPA, NSF) programs. He also founded and built 10 successful companies in the US, Europe and Japan. After the acquisition of Jibbigo by Facebook in 2013, he served as founding director of the Facebook Language Technology Group (2013-14).

Alex Waibel's passion for and track record in research, innovation and entrepreneurship over four decades in several of the leading economies of the world give him a unique perspective on technology disruption and management practices.