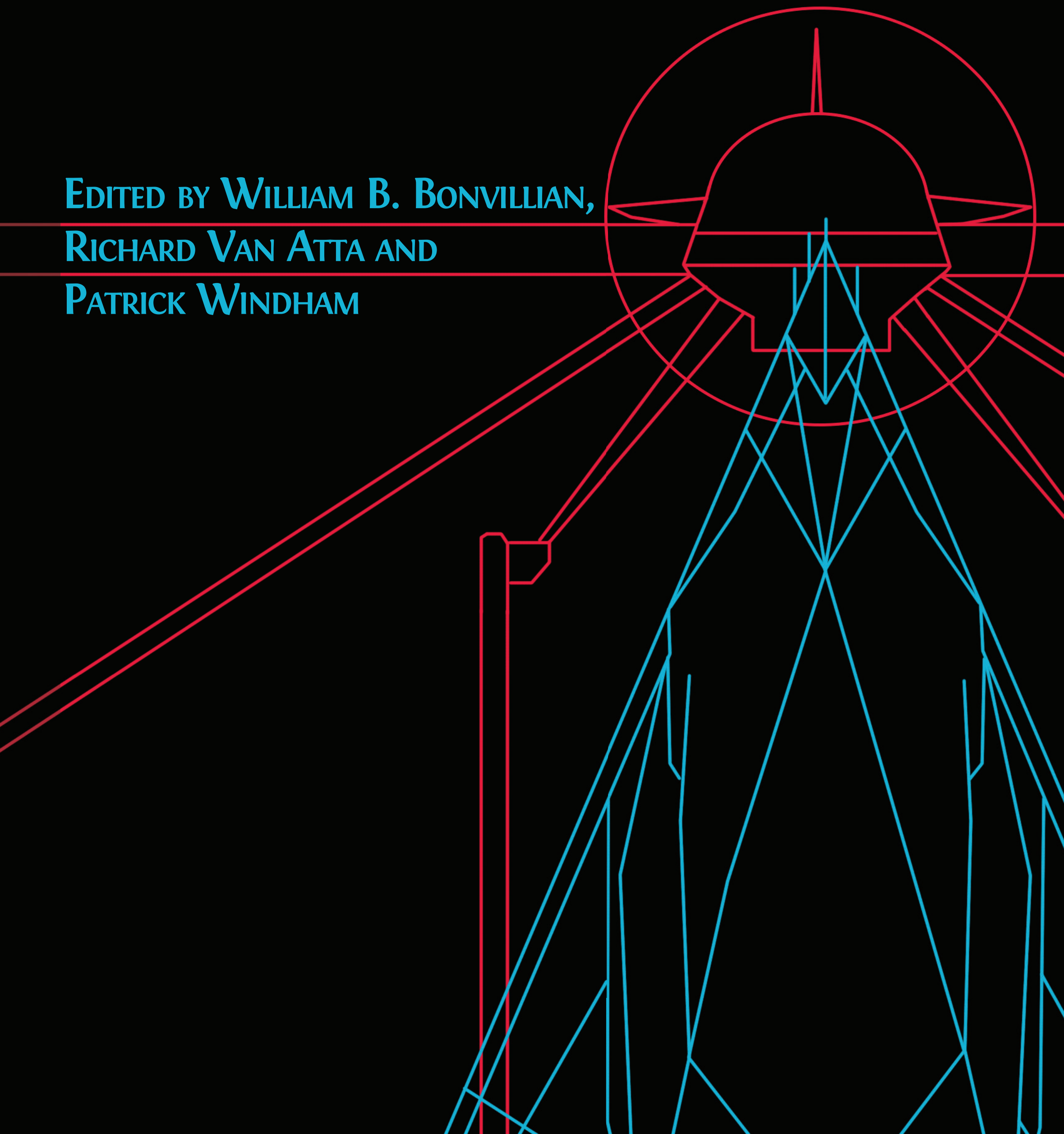
The DARPA Model for Transformative Technologies

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

Edited by William B. Bonvillian, Richard Van Atta and Patrick Windham



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5. The Value of Vision in Radical Technological Innovation[1]

Tamara L. Carleton

The Value of Vision in Radical Technological Innovation

This study provides empirical evidence of the role of vision in fostering technological invention, adding to the existing literature about radical innovation.[2] DARPA provides a long history of examples of technical program visions and how these visions are formed and communicated time after time. In this section, the four main findings of the study are discussed in detail and in context of the literature.

First, this study shows a relationship between the formation of a technological vision and the sustained creation of radical innovation, providing new knowledge about the role of vision in radical innovation. Since its inception in 1958, new programs at DARPA have required a vision to be started, which then guides subsequent work and development. Several dimensions arise regarding the role of vision, which entail functioning primarily at the program level, characterized as "DARPA

1 This chapter is an excerpt from Tamara L. Carleton's PhD thesis: Carleton, T. L. (2010). "The Value of Vision in Radical Technological Innovation", PhD thesis, Stanford University, Palo Alto.

2 E.g., Roberts, E. B., ed. (1987). *Generating Technological Innovation*. New York, NY: Oxford University Press; Tornatzky, L. G., Fleischer, M., and Chakrabarti, A. K. (1990). *The Processes of Technological Innovation.* Lexington, MA: Lexington Books; O'Connor, G. C., Leifer, R., Paulson, A. S., and Peters, L. S. (2008). *Grabbing Lightning: Building a Capability for Breakthrough Innovation*. San Francisco, CA: Jossey-Bass.

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Hard", and relying on the program manager as a vision champion. Second, this study describes the use of expert workshops and proof-of-concepts, used steadily by DARPA to shape partial visions into complete visions, which demonstrates critical efforts occurring prevision. Third, this study describes the importance of socialization in order to prepare and instruct program managers in their envisioning skills. Immersed in the culture at DARPA, new program managers learn from each other and their network connections. Fourth, this study provides new evidence about radical innovation governance models. DARPA relies on small group decisions by organizational leadership to approve promising new visions, running counter to the dominant literature about stage-gate reviews, peer reviews, and extended consensus-seeking processes.

A Process Model of Radical Innovation

As described in the previous chapter, DARPA follows certain high-level steps in its quest for radical innovation, and this process is reproduced in Figure 5-1. By documenting the process at DARPA, this study helps other researchers and practitioners to understand one organization's formula for sustained radical innovation. Documented processes are the basis for repetition and become the springboard for continuous and measurable performance.

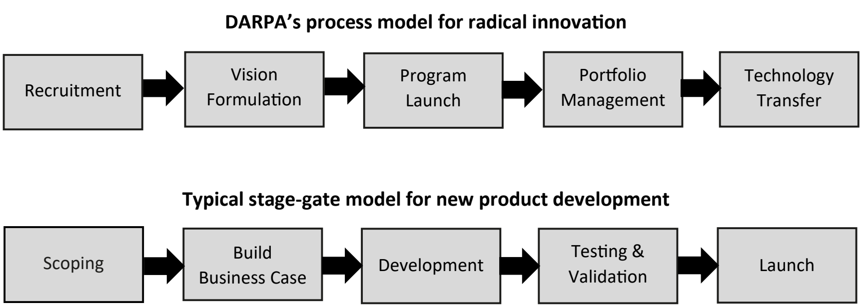

Fig. 5-1 Comparison between DARPA's process model and the stage-gate model. Although DARPA's process model of innovation looks similar to the typical stage-gate model for new product development,[3] the two models differ in terms of objectives, activity, and evaluation mechanics. (Figure prepared by the author.)

3 Cooper, R. G. (2001). *Winning at New Products: Accelerating the Process from Idea to Launch*. 3rd ed. Cambridge, MA: Basic Books.

In addition, some scholars may see a similarity between the depiction of DARPA's process model and the typical stage-gate model for new product development,[4] depicted in Figure 5-1. Both models are comprised of five stages that sequence categories of cross-functional activities, which help to invite a comparison. However, there are at least three key differences between the two models. First, the two models differ in objectives. DARPA's goal is radical innovation, which is intended to produce new technologies that ultimately may lead to new products. In contrast, the stage-gate process is designed to build and launch new products.

Second, the two models differ in their activity timing. DARPA's model is focused on the early stages that precede project scope. The stage-gate model is missing the preliminary or ideation phase, often called Discovery, which occurs before the start of the first stage of scoping.

Third, the two models differ in evaluation mechanisms. DARPA's process is fluid, and although transition arrows are noted between stages, formal decision points are not necessarily required before proceeding onto the next set of activities. In comparison, the stage-gate model is predicated on predefined deliverables and checkpoints with go/no go criteria at the end of each stage (these checkpoints are called gates).

New Dimensions of Vision

Vision plays a central role in DARPA's process of innovation; indeed, DARPA *starts* its process with vision. It matters where and how a vision is started, as does who starts and maintains the vision. DARPA program managers are hired deliberately for their visions of technology, even if partially formed. Then, program managers codify their visions at the start of each new program in a specialized document called a Broad Agency Announcement (BAA), which are used to generate interest in the broader R&D community. Thus, the vision is formulated before groups are funded because DARPA's funding recipients rely on these BAAs to determine potential solutions.

4 *Ibid.*

Visions at the Program Level

By studying the role of vision within DARPA, this study reveals several new dimensions of vision as related to innovation. One dimension is the level at which a vision operates. The dominant business literature has largely studied vision at the organizational level;[5] at the other end of the literature, several studies have investigated technological visions at the product or project level.[6] Within DARPA, work is broken down at three levels: organizational, program, and project, and the data shows that vision is introduced and functions primarily at the *program* level. Figure 5-2 illustrates the multiple levels of visions that could exist within an organization, and shows how visions at DARPA address the gap between the organizational and project/product levels.

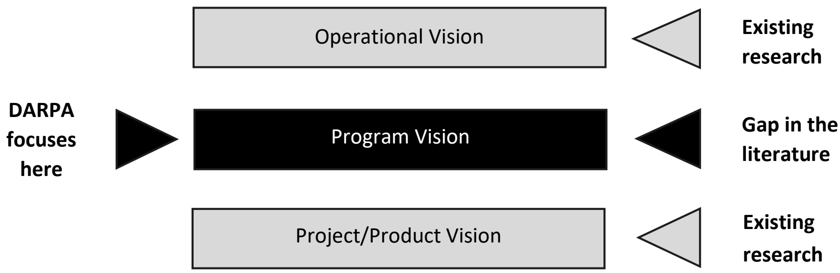

Fig. 5-2 Visions at DARPA operate at the program level. The literature on innovation predominantly discusses technological visions at the organizational level, and several studies have investigated technological visions at the project level. The literature fails to discuss vision at the program level, which is equivalent to the business unit or market level. At DARPA, technological visions function at the program level. (Figure prepared by the author.)

In fact, DARPA lacks a traditional corporate vision, which identifies a set of organizational values and direction for the enterprise. Since its inception in 1958, the agency has not defined (or even reinvented) its long-term goals, aspirations, and values at the organizational level. Instead, DARPA emphasizes visions at the program level, which correlates with a traditional business unit or market focus. Multiple

5 Collins, J. C., and Porras, J. I. (1991). "Organizational Vision and Visionary Organizations", *California Management Review* 34/1: 30–52.

6 Lynn, G. S., and Akgün, A. E. (2001). "Project Visioning: its Components and Impact on New Product Success", *Journal of Product Innovation Management* 18: 374–87.

visions—often totaling over a hundred, depending on the number of program managers actively serving at DARPA—exist in parallel at a given time. Programs serve as new, broad-scale technical initiatives that typically encompass multiple projects, and projects are equivalent to product teams in industry. Again, a DARPA program could be considered equivalent to a business unit or new market category. At DARPA, a program is more of an open-ended question or challenge posed to the R&D community, which might have multiple solutions and product possibilities, and scholars have documented the benefit of a challenge model within an R&D setting.[7]

In addition, visions at the program level allow DARPA program managers to direct multiple projects, multiple teams, and even multiple products over multiple years. Through visions at the program level, DARPA can excite and rally interest across several different technical areas, helping to distribute resources more effectively. Program visions provide a way to organize multiple projects and smaller-scale efforts across a range of funding recipients, who each may interpret the vision differently in application. This approach, in turn, increases the likelihood of a greater diversity of solutions. A program structure also allows for greater flexibility in engendering commitment.

Vision Quality

A second dimension is the quality of the vision. In the literature, few studies focus on technological visions, and most scholars draw on studies of corporate vision. For example, Gary S. Lynn and Ali Akgün describe product visions as a combination of clarity, support, and stability, which are determined relative to the larger organization.[8] While these attributes offer a sense of an ideal vision, they do not provide meaningful guidelines on how to develop a vision, including

7 Bonvillian, W. B. (2006). “Power Play, The DARPA Model and U.S. Energy Policy”, *The American Interest* 2/2, November/December, 39–48, https://www.the-american-interest.com/2006/11/01/power-play/; Bonvillian, W. B. (2009). “The Connected Science Model for Innovation—The DARPA Model”, in *21st Century Innovation Systems for the U.S. and Japan*, ed. S. Nagaoka, M. Kondo, K. Flamm, and C. Wessner. Washington, DC: National Academies Press. 206–37, https://doi.org/10.17226/12194, http://books.nap.edu/openbook.php?record_id=12194&page=206 (Chapter 4 in this volume).

8 Lynn and Akgün. (2001). “Project Visioning”.

the type of vision to create in the technology space. This study shows that technological visions at DARPA have several attributes that are essential to the creation of its visions.

Since its inception, DARPA has socialized a catchphrase known as DARPA Hard. Drawn from the data, a DARPA Hard program vision is characterized as technically challenging, actionable, multidisciplinary, and far-reaching. Taken apart, these attributes can be found discussed in prior studies.

The first attribute—technically challenging—is understood within the operations research and engineering design community as a "wicked problem".[9] A wicked problem is a technically difficult problem that is nearly impossible to solve due to complex interdependencies, a high level of ambiguity, and conflicting interests from stakeholders. Wicked problems cannot be solved through classic experimentation and logic, instead requiring a different and more creative strategy of reasoning. By focusing on these types of problems at DARPA, program managers have ensured that they push the limits of innovation sought, what might be interpreted as "highly radical" innovation according to Abetti's scale.[10] When most definitions of radical innovation argue for market changes, DARPA is pushing for a radical *technology* shift, which then may lead to a radical market shift. Each attempt at creating a new technical solution changes the understanding of the problem in two fundamental ways. First, more information helps to reformulate the initial requirements, and second, every prototype and implementation built advances the state of knowledge overall in the world. In other words, there is no turning back or reverting to the former understanding of the problem. The vision for a DARPA program provides the high-level guidelines to inspire potential funding recipients, and by engaging both more and different groups to respond, DARPA is able to cast a wider net for solutions and likewise accelerate the experimentation process.

This approach helps to drive toward action, and actionable is the second attribute of DARPA Hard. Program visions are intentionally

9 Buchanan, R. (2009). "Thinking about Design: An Historical Perspective", in *Philosophy of Technology and Engineering Sciences*, ed. A. Meijers. Amsterdam, The Netherlands: Elsevier B.V. 409–53, https://doi.org/10.1016/b978-0-444-51667-1.50020-3

10 Abetti, P. A. (2000). "Critical Success Factors for Radical Technological Innovations: A Five Case Study", *Creativity and Innovation Management Journal* 9/4: 208–21, https://doi.org/10.1111/1467-8691.00194

grounded in reality because they are expected to improve and extend the limits of existing technologies. Visions cannot exist as science-fiction fantasy, political rhetoric, or policy scenarios. This attribute is partly captured in earlier research about the reflective practitioner, in which Donald Schön describes how professionals, such as engineers, address problematic situations that are fraught with uncertainty, disorder, and indeterminacy by taking action through real-time cycles of feedback and learning.[11] In DARPA's case, program managers rely on their visions as a way to simulate broader learning in their research networks.

A growing body of research about learning in inter-organizational networks shows that networks facilitate rapid responses. Powell states that, "Whether it is the case that one firm's technological competence has outdistanced the others, or that innovations would be hard to replicate internally, as suggested by the growing reliance on external sources of research and development, network forms of organization represent a fast means of gaining access to know-how that cannot be produced internally".[12]

The third attribute—multidisciplinary—is equally critical to forming the right program visions at DARPA. As many DARPA program managers interviewed for this study noted, they needed to redefine problems outside of usual boundaries, and complex situations required drawing from more than one discipline. Multidisciplinary efforts are not new to government-sponsored R&D and can be evidenced in the rise of systems engineering in the 1950s that supported large scale efforts, such as the Atlas missile program and ARPANET.[13] This type of approach encourages less hierarchical control and more network-based management techniques.

The fourth attribute—far-reaching—is important when creating program visions at DARPA. One part of far-reaching is about having a broad impact in society. Subjects spoke about making a difference in magnitude.

11 Schön, D. (1983). *The Reflective Practitioner: How Professionals Think in Action*. New York, NY: Basic Books.

12 Powell, W. W. (1990). "Neither Market nor Hierarchy: Network Forms of Organization", *Organizational Behavior* 12: 295–336, at 316.

13 Hughes, T. P. (1998). *Rescuing Prometheus: Four Monumental Projects that Changed the Modern World*. New York, NY: Pantheon Books.

DARPA program managers stated that they need to think big in order to have big results. Another aspect of far-reaching is the ability to plan long-term. The importance of planning long-term has its roots in World War II, notably the founding of RAND.[14] This idea of planning for the long term made its way into today's management science through thinkers such as Peter F. Drucker.[15]

The real test of a good vision in R&D is whether others will commit resources to action, which will bring results in the future. DARPA deliberately couples action with future intent. However, the conundrum is that traditional R&D results may not be produced or easy to measure because the extent of far-reaching effects take time and are broadly distributed across society. The attribute of far-reaching is consistent with recent work in foresight engineering, which focuses on long-range technology cycles as part of an organization's ongoing search for innovation opportunities.[16]

Together, these four attributes—technically challenging, actionable, multidisciplinary, and far-reaching—that make up a DARPA Hard program provide a metric that can be instrumented and tested. Based on pioneering work in taxonomies,[17] Figure 5-3 presents a sample classification using a 7-point scale that was used for the quantification of human performance variables, specifically describing human ability for side-to-side equilibrium.[18] This type of scale could be adapted in order to classify each of the four attributes characterizing DARPA Hard. Follow-on studies can further define and test the scale values as related to radical innovation. Ultimately, if other organizations seek to recreate

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14 Campbell, V. (2004). "How RAND Invented the Postwar World", *Invention & Technology* 20/1: 50–59.

15 Drucker, P. F. (1959). "Long-Range Planning: Challenge to Management Science", Management Science 5/3: 238–49; Drucker, P. F. (1973). *Management: Tasks, Responsibilities, Practice.* New York, NY: Harper Colophon.

16 Carleton, T. and Cockayne, W. (2009). "The Power of Prototypes in Foresight Engineering", in *Proceedings of the 17th International Conference on Engineering Design* (ICED'09), ed. M. Norell Bergendahl, M. Grimheden, L. Leifer, P. Skogstad, and U. Lindemann. Stanford, CA: The Design Society. 267–76.

17 Bloom, B. S., ed. (1956). *Taxonomy of Educational Objectives: The Classification of Educational Goals: Handbook I, Cognitive Domain.* New York, NY: Green; Fleishman, E., and Quaintance, M. (1984). *Taxonomies of Human Performance: The Description of Human Tasks.* Orlando, FL: Academic Press.

18 Cockayne W., and Darken, R. (2004). "The Application of Human Ability Requirements to Virtual Environment Interface Design and Evaluation", in *The Handbook of Task Analysis for Human-Computer Interaction*, ed. D. Diaper, and N. Stanton. Mahwah, NJ: Lawrence Erlbaum Associates. 401–21.

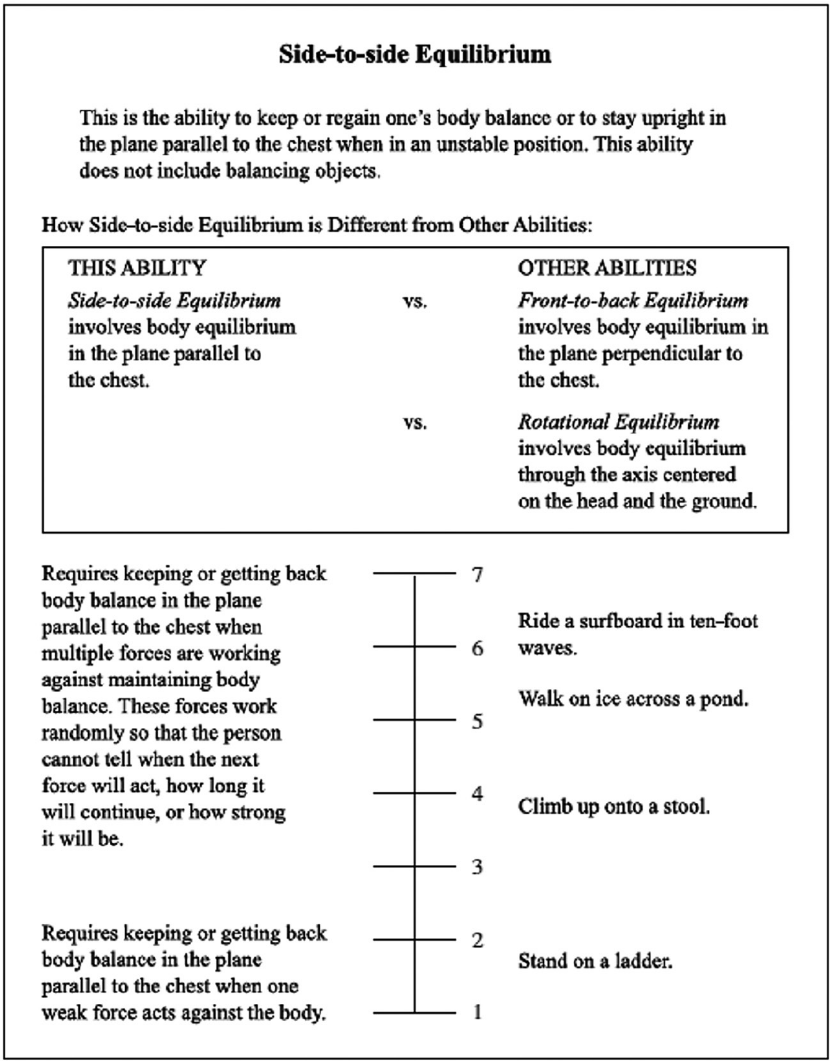

Fig. 5-3 A sample 7-point scale for quantification of human performance variables. A sample 7-point scale, drawn from another study, could be adapted to classify and evaluate each of the four attributes characterizing DARPA Hard. Follow-on studies can define and test the scale values as related to radical innovation. (Figure from William R. Cockayne. (1998). "Two-Handed, Whole-Hand Interaction", Master's thesis, Naval Postgraduate School, Monterey, California. Used here with permission from the author.)

a variant of DARPA Hard, they will benefit from defining and using a clear classification of technological visions.

Visionaries of Technology

A third dimension of vision is the person responsible for fostering it. Visions cannot exist without creators, who must imagine and invent them. Within DARPA, the work on innovation is driven as much by ideas as by individuals. Program managers are hired as technical visionaries, and they are solely responsible for shaping, spearheading, and promoting their respective visions of technology. The project champion is a critically recognized role in innovation, and findings from this study are consistent with literature on this topic.[19] At DARPA, a new program is not confounded with multiple organizational champions; instead, there is a clear relationship in that each program manager builds one vision per program. Figure 5-4 depicts this relationship. However, the DARPA program manager does not operate in isolation. He (or she) is part of a broader ecosystem and network, in which multiple players—both internally and externally to the agency—are engaged to support the formation and execution of a program vision.

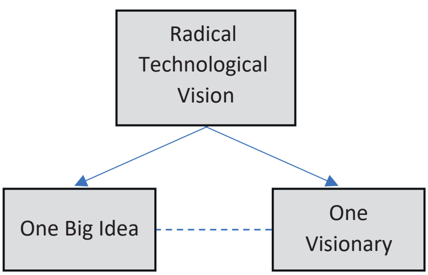

Fig. 5-4 A radical technological vision relies on one big idea and one visionary. At DARPA, a program vision relies on a program manager, who serves as the vision's primary champion internally and externally. Moreover, there is a clear relationship in that each program managers builds one vision per program. (Figure prepared by the author.)

DARPA program managers serve in other innovation roles that have been documented separately in literature. For example, they share

19 Howell, J. M., and Higgins, C. A. (1990). "Champions of Technological Innovation", *Administratively Science Quarterly* 35: 317–41.

some characteristics with *business innovators* because DARPA program managers provide substantial funding, as well as some organizational credibility and access to other resources.[20] Although DARPA program managers do not build and develop their own visions, instead relying on the various funding recipients, they do act as *technical innovators* in other ways.[21] More informed than the usual project champion, DARPA program managers are nearly all technically educated and bring deep expertise from various fields of engineering and science. This background allows them to more effectively understand the given technical problem, as well as advise and guide the technical teams that they sponsor. A growing number of studies discuss the special role of a technical visionary, who combines technical knowledge with project oversight.[22]

DARPA program managers also play the role of technology licenser or technology transfer manager. They are directly responsible for finding potential user groups, typically in the U.S. military services, who might test and ultimately adopt a functional prototype. The final success of DARPA program visions hinges on user adoption.

At DARPA, potential program managers—the champions of new technological visions—are found and recruited through the extended research network. Studies show that as networks mature, they tend to petrify.[23] People prefer to work with familiar connections, which limits network access to new connections. Current program managers will find new program managers based on similar qualities and will continue funding the same relationships. When this happens, an innovation network does not diversify, and the development of new ideas can be potentially severely limited. DARPA has addressed this limitation by deliberately hiring program managers new to the network, who, in turn, bring new visions of technology. Subsequently, the new-to-the-network program manager finds and funds research groups that bring additional new ideas to the network, which helps to refresh institutional thinking and challenge engrained assumptions.

20 Howell and Higgins. (1990). "Champions of Technological Innovation".

21 *Ibid.*

22 Hebda, J. M., Vojak, B. A., Griffin, A., and Price, R. L. (2007). "Motivating Technical Visionaries in Large American Companies", *IEEE Transactions on Engineering Management* 54/3: 433–44; Deschamps, J. (2008). *Innovation Leaders: How Senior Executives Stimulate, Steer and Sustain Innovation*. Hoboken, NJ: Jossey-Bass.

23 Powell. (1990). "Neither Market nor Hierarchy".

Lastly, DARPA is now over fifty years old as an organization, and, historically, the agency has relied on its network for internal job referrals. As the people in DARPA's network have aged, they may not be cultivating as many new relationships with other research groups or also with junior engineers and scientists. Age plays a substantial role in creating new fields, and research shows that younger scientists are more likely to be drawn to a new field than older scientists.[24]

Some scholars have studied how large mature organizations must continually reconfigure their systems of power in order to sustain innovation.[25] Recently, DARPA leadership has recognized the need to recruit younger program managers into its mix. For example, the press observed former agency director Tony Tether "has managed to draw younger researchers into an agency whose stalwart backers are growing greyer every year".[26] However, more research is needed to understand the effects of age on DARPA's ability to foster radical innovation.

The Development of Partial Visions

In the key texts that mention vision, few descriptions are provided about how to generate a vision or develop a partial vision into a complete technological vision.[27] Scholars underscore the importance of having a vision, yet they assume a complete vision. Findings from this study demonstrate that multiple steps are consistently taken by DARPA program managers in order to advance their early ideas and thinking before the complete vision is formed. Figure 5-5 illustrates the actions that must occur before a complete vision is achieved. In addition, while the technological idea drives action, the path to the vision itself is emergent.

This study describes the formation of partial visions via two primary mechanisms, specifically expert workshops and proof-of-concepts, which are used consistently throughout DARPA's history to develop partial visions into clear visions. While details may differ, the objective

24 Rappa, M., and Debackere, K. (1993). "Youth and Scientific Innovation: The Role of Young Scientists in the Development of a New Field", *Minerva* 31/1: 1–20.

25 Dougherty, D., and Hardy, C. (1996). "Sustained Product Innovation in Large, Mature Organizations: Overcoming Innovation-to-Organization Problems", *Academy of Management Journal* 39/5: 1120–53.

26 "A Little Less Disneyland", *Nature* 451: 374 (2008), https://doi.org/10.1038/451374a

27 Roberts. (1987). *Generating Technological Innovation*.

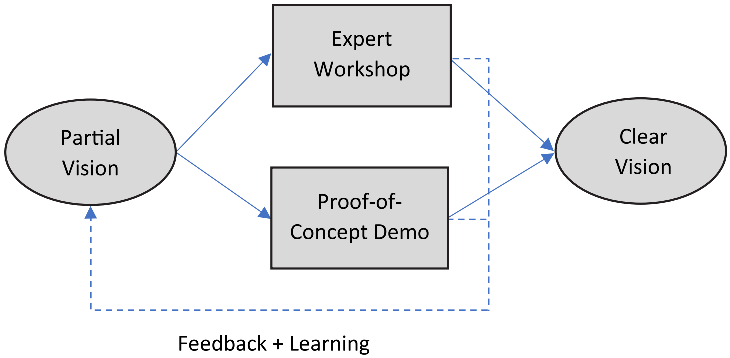

Fig. 5-5 Efforts preceding a complete vision of technology. Earlier actions occur before a complete vision is achieved at DARPA. (Figure prepared by the author.)

is the same between the two mechanisms: to gain more insight into a promising yet incomplete vision. Expert workshops and proof-of-concepts address the people and the idea, respectively. Through expert workshops, each program manager engages his or her network, and the network serves as a way to gain perspective through dialogue among trusted colleagues. In studies about knowledge networks and communities of practice, network members regularly share information through both formal and informal channels,[28] and the DARPA workshops positively exploit the broader knowledge network for the agency. The DARPA workshops are effective because they draw on the collective wisdom for a field, helping DARPA program managers to gain access to the latest knowledge about a particular topic.

If the workshops rely on people, the proof-of-concepts depend on the idea. The objective of the proof-of-concepts is to explore and test the feasibility of an emerging idea. Each proof-of-concept serves as a directed demonstration. Proof-of-concepts are regularly discussed in engineering design research and business studies as a form of prototyping,[29] and specifically, Carleton and Cockayne discuss the

28 Hildreth, P. M., and Kimble, C., eds. (2004). *Knowledge Networks: Innovation Through Communities of Practice*. Hershey, PA: Idea Group Publishing; Powell, W. W., and Grodal, S. (2005). "Networks of Innovators", in *The Oxford Handbook of Innovation*, ed. J. Fagerberg, D. Mowery, and R. R. Nelson. New York, NY: Oxford University Press. 56–85.

29 Schrage, M. (1999). *Serious Play: How the World's Best Companies Simulate to Innovate*. Boston, MA: Harvard Business School Press; Betz, F. (2003). *Managing Technological*

growing role that physical prototypes serve in long-range planning.[30] This study provides new information about the use of proof-of-concepts in vision development as a way to demonstrate feasibility and test early hunches before undertaking a new technical initiative. There is an opportunity to expand on the relationship between prototyping and vision formation.

It is important to note that this combination of expert workshops and proof-of-concepts has provided the primary mechanisms for converting partial visions into full visions at DARPA; no other mechanisms were pursued as long or as reliably, as reported by DARPA program managers and funding recipients. This approach has implications for organizations pursuing radical or disruptive innovation. O'Connor and her colleagues discuss the different experiments that big companies have attempted in order to scout for and generate radical ideas.[31] Some of these experiments resemble the expert workshops at DARPA. IBM has held a large annual R&D event to order to stimulate new ideas internally and identify potential emerging business opportunities. This event has been denoted using multiple names—including idea jams, idea cafes, and deep dives—and while the organizers continually tinker with the process, the event itself remains constant every year. The annual event has led to a high number of opportunities, which in turn have become profitable business lines at IBM.

Learning Radical Innovation Through Socialization

The third finding relates to the culture of innovation at DARPA. Program managers come from a variety of backgrounds. While they have impeccable academic and professional credentials, many lack direct experience with certain innovation skill sets, such as documenting a vision, recruiting and leading others, and technology transfer. Regardless of their background, expectations are high for DARPA program managers to develop and deliver on their program visions quickly.

Innovation: Competitive Advantage from Change. 2nd ed. New York, NY: John Wiley; Moss, L. T. and Atre, S. (2003). *Business Intelligence Roadmap: The Complete Project Lifecycle for Decision-Support Applications*. Boston, MA: Addison-Wesley.

30 Carleton and Cockayne. (2009). "The Power of Prototypes".

31 O'Connor et al. (2008). *Grabbing Lightning*.

In addition, DARPA does not provide formal training in innovation "know how", particularly the skills needed to develop program visions. Is staff training necessary for radical innovation? According to subjects, DARPA has not codified much of its internal procedures historically; so new program managers cannot rely on manuals or similar process guides. Instead, knowing is a matter of participating. At DARPA, subjects reported learning primarily from immersion. From the start, a candidate for a new program manager has to be already embedded in the research community to be considered for recruiting.

Once at DARPA, program managers described learning by doing, particularly by proactively reaching out to colleagues, alumni and other members in the network for advice and resources, as well as by gaining new knowledge from regular field visits.

In many ways, DARPA is a culture of show, not tell. Through a process of socialization, program managers acquire the habits, beliefs, and accumulated knowledge of the organization. In sociology, this period is known as metamorphosis, when a newcomer becomes an established organizational member.[32] How people behave and interact with one another over time shapes an organizational culture, and the data from DARPA is consistent with prior studies about tacit knowledge and informal learning occurring within innovation organizations and communities of practice.

If an organization is to survive, then research shows that stability over time is required, so that one generation of employees transmits the dominant social and cultural patterns to the next generation.[33] In other words, practice is transferred from those who have done it to those who need to do it. At DARPA, this transfer of knowledge occurs through informal conversations, and, given the short contracts of DARPA technical staff, the cycle of generations is rapid. It is remarkable that a knowledge-generating organization over fifty years old, which has resisted lasting knowledge capture, has maintained such a stable set of practices as DARPA has. Based on subject reports, two factors have likely contributed most to the unusual stability of DARPA's culture. First, the

32 Kramer, M. W. (2010). *Organizational Socialization: Joining and Leaving Organizations.* Cambridge, UK: Polity.

33 Alvesson, M. (1995). *Management of Knowledge-Intensive Companies*. New York, NY: Walter de Gruyter.

broader infrastructure supporting DARPA program managers, namely the support staff, provide continuity across leadership turnovers. This support staff functions as an underlying layer of institutional permanence, handling the same routines and project coordination tasks. Second, the agency's network structure supports ongoing learning. For example, even when program managers leave their agency roles officially, they typically stay connected to DARPA in other ways. This connection creates additional channels of knowledge sharing between staff and also ensures that some institutional memory is maintained across staff rotations. New staff rely on the stories and experiences shared within the network in order to prepare themselves at DARPA.

Internal Review of Radical Innovation Ideas

Even with the right person and the right idea, a promising technological vision may not become a new program at DARPA. There is one final test before a Broad Agency Announcement (BAA) is released to the public. A program manager must pitch his vision internally with a small audience for funding approval, and decision-making authority resides namely with the agency director and respective office director. Subject reports demonstrate that DARPA has consistently followed this governance model over the years, actively discouraging larger evaluations in the agency's innovation process. Subjects especially note the benefits of speed, convenience, and flexibility from these small group reviews.

DARPA's model runs counter to the literature and practice of innovation, which discusses consensus-based governance models—such as innovation boards, technology councils, R&D committees, task forces, and stage-gates—as a dominant best practice.[34] These models provide a decision-making framework that help to define evaluation criteria, grant decision-making power, and verify feasibility of a new

34 Bacon, F. R., Jr., and Butler, T. W., Jr. (1973). *Achieving Planned Innovation: A Proven System for Creating Successful New Products and Services.* New York, NY: Simon & Schuster; Hamel, G. (2002). *Leading the Revolution: How to Thrive in Turbulent Times by Making Innovation a Way of Life.* Boston, MA: Harvard Business School Press; Snyder, N. T., and Duarte, D. L. (2003). *Strategic Innovation: Embedding Innovation as a Core Competency in your Organization*. San Francisco, CA: Jossey-Bass; O'Connor et al. (2008). *Grabbing Lightning*; Skarzynski, P., and Gibson, R. (2008). *Innovation to the Core: A Blueprint for Transforming the Way your Company Innovates*. Boston, MA: Harvard Business School Press.

research idea. A growing body of literature has noted that certain models have limitations for radical innovation. Gassmann and von Zedtwitz note:

> In industries or projects where the science or technology push is the dominant driver of innovation, stage-gate processes are too rigid and slow. Innovations that are triggered by a technological invention with unknown market potential need different processes and techniques to succeed.[35]

Overall, innovation studies endorse a strong philosophy that the processes for radical or disruptive innovation must differ from traditional R&D processes in order to be effective within an organization. By deliberately adopting a model of limited, leadership-driven review and following it for over fifty years, DARPA provides empirical support for this belief. Instead of creating large task forces, DARPA relies on its leadership to approve and support the visions. Instead of formally scheduled sessions, DARPA program managers arrange meetings when they feel that their new program visions are ready for funding. Most of corporate R&D, the work of funding agencies, and academic research are actually structured in direct opposition to this approach. Members of the science community, who believe that DARPA provides an enduring and effective model for advancing radical innovation, understand this difference. Penman and Bates write, "Those wishing to emulate the success of DARPA and Bell Labs might consider another important aspect: freedom from the so called 'peer review' that weighs down most National Institutes of Health (NIH) and National Science Foundation efforts".[36]

Conclusion

Four main findings were discussed in relation to the literature review. By describing how visions serve an integral role in DARPA's innovation process, the first finding brings new perspective to innovation studies about the role of visions in radical innovation. In particular, new program

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35 Gassmann, O., and von Zedtwitz, M. (2003). "Innovation Processes in Transnational Corporations", in *The International Handbook on Innovation*, ed. L. V. Shavinina. Oxford, UK: Elsevier Science. 702–14, at 704.

36 Penman, S., and Bates, C. C. (1999). "DARPA in the Spotlight", *Science* 286/5438: 239.

visions must meet the criteria of being DARPA Hard, and this term of art introduces a working metric for technical breakthroughs that are nearly impossible to achieve based on the current state of knowledge and tools. Second, the discovery that expert workshops and proof-of-concepts have been used repeatedly to convert partial visions into complete visions at DARPA shows that activities exist pre-vision and directly influence the formation of technological visions. Third, the discovery that new program managers receive no formal documentation or training for their roles and instead rely on acculturation is consistent with prior research on innovation networks and communities of practice. Finally, by showing that DARPA has a leadership-driven, decision-making model, in which leadership approves a new program vision, the fourth finding introduces contradictory evidence to the dominant literature. These four findings, supported by empirical evidence, add to the current understanding of technological visions and radical innovation research.

References

"A Little Less Disneyland", *Nature* 451: 374 (2008), https://doi.org/10.1038/451374a

Abetti, P. A. (2000). "Critical Success Factors for Radical Technological Innovations: A Five Case Study", *Creativity and Innovation Management Journal* 9/4: 208–21, https://doi.org/10.1111/1467-8691.00194

Alvesson, M. (1995). *Management of Knowledge-Intensive Companies.* New York, NY: Walter de Gruyter.

Aspray, W., and Norberg, A. (1998). *An Interview with J. C. R. Licklider*, 28 October. University of Minnesota, MN: Charles Babbage Institute, Center for the History of Information Processing.

Bacon, F. R., Jr., and Butler, T. W., Jr. (1973). *Achieving Planned Innovation: A Proven System for Creating Successful New Products and Services.* New York, NY: Simon & Schuster.

Basit, T. N. (2003). "Manual or Electronic? The Role of Coding in Qualitative Data Analysis", *Educational Research* 45/2: 143–54, https://doi.org/10.1080/0013188032000133548

Belfiore, M. (2009). *The Department of Mad Scientists: How DARPA is Remaking our World, from the Internet to Artificial Limbs.* New York, NY: Smithsonian Books/HarperCollins.

Betz, F. (2003). *Managing Technological Innovation: Competitive Advantage from Change*. 2nd ed. New York, NY: John Wiley.

Bloom, B. S., ed. (1956). *Taxonomy of Educational Objectives: The Classification of Educational Goals: Handbook I, Cognitive Domain*. New York, NY: Green.

Bonvillian, W. B. (2006). "Power Play, The DARPA Model and U.S. Energy Policy", *The American Interest* 2/2, November/December, 39–48, https://www.the-american-interest.com/2006/11/01/power-play/

Bonvillian, W. B. (2009). "The Connected Science Model for Innovation—The DARPA Model", in *21st Century Innovation Systems for the U.S. and Japan*, ed. S. Nagaoka, M. Kondo, K. Flamm, and C. Wessner. Washington, DC: National Academies Press. 206–37, https://doi.org/10.17226/12194, http://books.nap.edu/openbook.php?record_id=12194&page=206 (Chapter 4 in this volume).

Bryant, A., and Charmaz, K., eds. (2007). *The SAGE Handbook of Grounded Theory*. Los Angeles, CA: Sage Publications, https://doi.org/10.4135/9781848607941

Buchanan, R. (2009). "Thinking about Design: An Historical Perspective", in *Philosophy of Technology and Engineering Sciences*, ed. A. Meijers. Amsterdam, The Netherlands: Elsevier B.V. 409–53, https://doi.org/10.1016/b978-0-444-51667-1.50020-3

Campbell, V. (2004). "How RAND Invented the Postwar World", *Invention & Technology* 20/1: 50–59.

Carleton, T., and Cockayne, W. (2009). "The Power of Prototypes in Foresight Engineering", in *Proceedings of the 17th International Conference on Engineering Design (ICED'09)*, ed. M. Norell Bergendahl, M. Grimheden, L. Leifer, P. Skogstad, and U. Lindemann. Stanford, CA: The Design Society. 267–76.

Chesbrough, H. (2003). *Open Innovation: The New Imperative for Creating and Profiting from Technology*. Boston, MA: Harvard Business School Press.

Christensen, C. M. (1997). *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail*. Boston, MA: Harvard Business School Press.

Christensen, C. M., and Raynor, M. E. (2003). *The Innovator's Solution: Creating and Sustaining Successful Growth.* Boston, MA: Harvard Business School Press, https://doi.org/10.5465/ame.2004.12689164

Christiansen, J. A. (2000). *Building the Innovative Organization: Management Systems that Encourage Innovation.* New York, NY: St. Martin's Press.

Chubin, D. E., and Hackett, E. J. (1990). *Peerless Science: Peer Review and U.S. Science Policy.* Albany, NY: State University of New York Press.

Cockayne, W. R. (2004). "A Study of the Formation of Innovation Ideas in Informal Networks", PhD thesis, Stanford University, Palo Alto.

Cockayne, W. R. (1998). "Two-Handed, Whole-Hand Interaction", Master's thesis, Naval Postgraduate School, Monterey, California.

Cockayne W., and Darken, R. (2004). "The Application of Human Ability Requirements to Virtual Environment Interface Design and Evaluation", in

The Handbook of Task Analysis for Human-Computer Interaction, ed. D. Diaper, and N. Stanton. Mahwah, NJ: Lawrence Erlbaum Associates. 401–21.

Collins, J. C., and Porras, J. I. (1991). "Organizational Vision and Visionary Organizations", *California Management Review* 34/1: 30–52.

Collins, J. C., and Porras, J. I. (1996). "Building your Company's Vision", *Harvard Business* Review 74/4: 65–77.

Collins, J. C., and Porras, J. I. (1997). *Built to Last: Successful Habits of Visionary Companies.* New York, NY: HarperBusiness.

Cooper, R. G. (2001). *Winning at New Products: Accelerating the Process from Idea to Launch*. 3rd ed. Cambridge, MA: Basic Books.

Corbin, J. M., and Strauss, A. (2008). *Basics of Qualitative Research: Techniques and Procedures for Developing Grounded Theory*. 3rd ed. Los Angeles, CA: Sage Publications, https://doi.org/10.4135/9781452230153

Cotterman, R., Fusfeld, A., Henderson, P., Leder, J., Loweth, C., and Metoyer, A. (2009). "Aligning Marketing and Technology to Drive Innovation", *Research Technology Management* 52/5: 14–20, https://doi.org/10.1080/08956308.2009.11657585

Daniel, H.-D. (1993). *Guardians of Science: Fairness and Reliability of Peer Review.* Weinheim, Germany: VCH,

https://onlinelibrary.wiley.com/doi/book/10.1002/3527602208

DARPA. (1998). *DARPA Technology Transition*, http://www.darpa.mil/Docs/transition.pdf

DARPA. (2003). *Strategic Plan*, February, https://upload.wikimedia.org/wikipedia/commons/5/57/DARPA_Strategic_Plan_%282003%29.pdf

DARPA. (2007). *Strategic Plan*, February, https://www.hsdl.org/?view&did=769871

DARPA. (2008). *DARPA: 50 Years of Bridging the Gap*, ed. C. Oldham, A. E. Lopez, R. Carpenter, I. Kalhikina, and M. J. Tully. Arlington, VA: DARPA, https://issuu.com/faircountmedia/docs/darpa50

DARPA. (2008). *Human Resources (HR) Recruitment—Sourcing and Placement of DARPA Program Managers (PMs).* Request for Information, reference number SN08-27, 7 April.

DARPA. (2009). *Department of Defense Fiscal Year (FY) 2010 Budget Estimates, Volume 1—Defense Advanced Research Projects Agency*, May, https://www.darpa.mil/attachments/(2G7)%20Global%20Nav%20-%20About%20Us%20-%20Budget%20-%20Budget%20Entries%20-%20FY2010%20(Approved).pdf

DARPA. (2010). *Broad Agency Announcements*, https://www.darpa.mil/work-with-us/office-wide-broad-agency-announcements

DARPA. (2010). *DARPA Mission*, https://www.darpa.mil/about-us/mission

DARPA. (2010). *Director's Biography*, https://www.darpa.mil/about-us/people

DARPA. (2010). *Offices*, https://www.darpa.mil/about-us/offices

DARPA. (2010). *Technology Transition Team*.

DARPA. (2001). *Broad Area Announcement: Augmented Cognition.* Solicitation Number: DARPA-BAA 01–38. Commerce Business Daily, PSA #2902, 27 July, 2001.

DARPA. (2008). *Broad Area Announcement: Legged Squad Support System*. Solicitation Number: DARPA-BAA-08–71, 24 October.

Defense Acquisition, Technology, and Logistics. (2007). *Joining DARPA as a Program Manager Starts With your Idea*, November.

Defense Science Board. (1999). *Investment Strategy for DARPA*, Storming Media Report No. A014763. Washington, DC: Pentagon Reports.

Dekkers, R. (2005). *(R)evolution: Organizations and the Dynamics of the Environment*. New York, NY: Springer Science+Business Media.

Deschamps, J. (2008). *Innovation Leaders: How Senior Executives Stimulate, Steer and Sustain Innovation*. Hoboken, NJ: Jossey-Bass, https://doi.org/10.1002/9781119208761

de Vaus, D. (2001). *Research Design in Social Research*. Thousand Oaks, CA: Sage Publications.

Dougherty, D., and Hardy, C. (1996). "Sustained Product Innovation in Large, Mature Organizations: Overcoming Innovation-to-Organization Problems", *Academy of Management Journal* 39/5: 1120–53.

Drucker, P. F. (1959). "Long-Range Planning: Challenge to Management Science", *Management Science* 5/3: 238–49.

Drucker, P. F. (1973). *Management: Tasks, Responsibilities, Practice*. New York, NY: Harper Colophon.

Dundon, E. (2002). *The Seeds of Innovation: Cultivating the Synergy that Fosters New Ideas.* New York, NY: AMACOM.

Edelheit, L. S. (2004). "The IRI Medalist's Address: Perspective on GE Research & Development", *Research Technology Management* 47/1: 49–54, https://doi.org/10.1080/08956308.2004.11671608

Ettlie, J. E., Bridges, W. P., and O'Keefe, R. D. (1984). "Organization Strategy and Structural Differences for Radical versus Incremental Innovation", *Management Science* 30/6: 682–95.

Fleishman, E., and Quaintance, M. (1984). *Taxonomies of Human Performance: The Description of Human Tasks.* Orlando, FL: Academic Press.

Fleming, L. (2002). "Finding the Organizational Sources of Technological Breakthroughs: The Story of Hewlett-Packard's Thermal Ink-Jet", *Industrial and Corporate Change* 11/5: 1059–84, https://doi.org/10.1093/icc/11.5.1059

Fuchs, E. R. H. (2010). "Rethinking the Role of the State in Technology Development: DARPA and the Case for Embedded Network Governance", *Research Policy* 39/9: 1133–47, https://doi.org/10.1016/j.respol.2010.07.003 (Chapter 7 in this volume).

Gassmann, O., and von Zedtwitz, M. (2003). "Innovation Processes in Transnational Corporations", in *The International Handbook on Innovation*, ed. L. V. Shavinina. Oxford, UK: Elsevier Science, 702–14.

Glaser, B. G. and Strauss, A. L. (1967). *The Discovery of Grounded Theory.* New York, NY: Aldine.

Goulding, C. (2002). *Grounded Theory: A Practical Guide for Management, Business and Market Researchers.* Thousand Oaks, CA: Sage Publications, https://doi.org/10.4135/9781849209236

Hafner, K., and Lyon, M. (1996). *Where Wizards Stay Up Late: The Origins of the Internet*. New York, NY: Touchstone.

Hamel, G. (2002). *Leading the Revolution: How to Thrive in Turbulent Times by Making Innovation a Way of Life*. Boston, MA: Harvard Business School Press.

Harvard Business Essentials. (2003). *Managing Creativity and Innovation.* Boston, MA: Harvard Business School Press.

Hebda, J. M., Vojak, B. A., Griffin, A., and Price, R. L. (2007). "Motivating Technical Visionaries in Large American Companies", *IEEE Transactions on Engineering Management* 54/3: 433–44, https://doi.org/10.1109/tem.2007.900791

Hildreth, P. M., and Kimble, C., eds. (2004). *Knowledge Networks: Innovation Through Communities of Practice*. Hershey, PA: Idea Group Publishing, https://doi.org/10.4018/978-1-59140-200-8

Hiltzik, M. (1999). *Dealers of Lightning: Xerox PARC and the Dawn of the Computer Age*. New York, NY: HarperBusiness.

Howe, H. E. (1952). "'Space Men' Make College Men Think", *Popular Science* 161/4: 124–27.

House, C. H., and Price, R. L. (2009). *The HP Phenomenon: Innovation and Business Transformation. S*tanford, CA: Stanford Business Books.

Howell, J. M., and Higgins, C. A. (1990). "Champions of Technological Innovation", *Administratively Science Quarterly* 35: 317–41.

Hughes, T. P. (1998). *Rescuing Prometheus: Four Monumental Projects that Changed the Modern World.* New York, NY: Pantheon Books.

Johnson, C. L., and Smith, M. (1989). *Kelly: More than my Share of it All*. Washington, DC: Smithsonian.

Johnson, M. W. (2010). *Seizing the White Space: Business Model Innovation for Growth and Renewal.* Boston, MA: Harvard Business School Press.

Junod, T. (2003). "Science & Industry: DARPA", *Esquire*, 1 December.

Kim, W. C., and Mauborgne, R. (2005). *Blue Ocean Strategy: How to Create Uncontested Market Space and Make Competition Irrelevant.* Boston, MA: Harvard Business School Press.

Kostoff, R. N., Boylan, R., and Simon, G. R. (2004). "Disruptive Technology Roadmaps", *Technological Forecasting and Social Change* 71: 141–59, https://doi.org/10.1016/s0040-1625(03)00048-9

Kramer, M. W. (2010). *Organizational Socialization: Joining and Leaving Organizations.* Cambridge, UK: Polity.

Leheny, R. (2007). *What is a DARPA Program Manager?* Speech Presented at DARPATech, DARPA's 25th Systems and Technology Symposium, Anaheim, CA, 7 August.

Leifer, R., McDermott, C. M., O'Connor, G. C., Peters, L. S., Rice, M. P., and Veryzer, R. W. (2000). *Radical Innovation: How Mature Companies Can Outsmart Upstarts.* Boston, MA: Harvard Business Press.

Levy, S. (2000). *Insanely Great: The Life and Times of Macintosh, the Computer that Changed Everything.* New York, NY: Penguin Books.

Lundquist, G. (2004). "One Point of View: The Missing Ingredients in Corporate Innovation", *Research-Technology Management* 47/5: 11–12, https://doi.org/10.1080/08956308.2004.11671646

Lynham, S. A. (2002). "The General Method of Theory-Building Research in Applied Disciplines", Advances *in Developing Human Resources* 4: 221–41 https://doi.org/10.1177/15222302004003002

Lynn, G. S., and Akgün, A. E. (2001). "Project Visioning: its Components and Impact on New Product Success", *Journal of Product Innovation Management* 18: 374–87, https://doi.org/10.2139/ssrn.2151901

Maccoby, M. (2007). "Developing Research/Technology Leaders", *Research-Technology Management* 50/2: 65–67, https://doi.org/10.1080/08956308.2007.11657432

Malakoff, D. (1999). "Pentagon Agency Thrives on In-Your-Face Science", *Science* 285/5433: 1476–80, https://doi.org/10.1126/science.285.5433.1476

Moss, L. T., and Atre, S. (2003). *Business Intelligence Roadmap: The Complete Project Lifecycle for Decision-Support Applications.* Boston, MA: Addison-Wesley.

National Research Council. (2005). *Government/Industry/Academic Relationships for Technology Development: A Workshop Report.* Steering Committee for Workshops on Issues of Technology Development for Human and Robotic Exploration and Development of Space, Aeronautics and Space Engineering

Board, Division on Engineering and Physical Sciences. Washington, DC: The National Academies Press, https://doi.org/10.17226/11206

Nanus, B. (1992). *Visionary Leadership: Creating a Compelling Sense of Direction for your Organization.* San Francisco, CA: Jossey-Bass.

Norling, P. M., and Statz, R. J. (1998). "How Discontinuous Innovation Really Happens", *Research Technology Management* 41/2: 41–44, https://doi.org/10.1080/08956308.1998.11671208

O'Connor, G. C., Leifer, R., Paulson, A. S., and Peters, L. S. (2008). *Grabbing Lightning: Building a Capability for Breakthrough Innovation.* San Francisco, CA: Jossey-Bass.

O'Connor, G. C., and Rice, M. P. (2001). "Opportunity Recognition and Breakthrough Innovation in Large Established Firms", *California Management Review* 43/20: 95–116, https://doi.org/10.2307/41166077

Page, L. (2009). "Spy Chief to Obama: Let DARPA Fix Economy", *The Register*, 21 January, https://www.theregister.co.uk/2009/01/21/darpa_economy_fix_plan/Pappert, S. (2009). *Succeeding with DARPA/MTO: Tips from an ex-Program Manager*. Proceedings from the 2009 Microsystems Technology Office Symposium, March 2–5.

Penman, S., and Bates, C. C. (1999). "DARPA in the Spotlight", *Science* 286/5438: 239, https://doi.org/10.1126/science.286.5438.239b

Perez, C. (2002). *Technological Revolutions and Financial Capital: The Dynamics of Bubbles and Golden Ages*. Northampton, MA: Edward Elgar, https://doi.org/10.4337/9781781005323.00011

Powell, W. W. (1990). "Neither Market nor Hierarchy: Network Forms of Organization", *Organizational Behavior* 12: 295–336.

Powell, W. W., and Grodal, S. (2005). "Networks of Innovators", in *The Oxford Handbook of Innovation*, ed. J. Fagerberg, D. Mowery, and R. R. Nelson. New York, NY: Oxford University Press. 56–85, https://doi.org/10.1093/oxfordhb/9780199286805.001.0001

Quigley, J. V. (1993). *Vision: How Leaders Develop It, Share It, and Sustain It*. New York, NY: McGraw-Hill.

Quigley, J. V. (1994). "Vision: How Leaders Develop It, Share It, and Sustain It", *Business Horizons* 47/5: 37–41.

Rappa, M., and Debackere, K. (1993). "Youth and Scientific Innovation: The Role of Young Scientists in the Development of a New Field", *Minerva* 31/1: 1–20.

Rhea, D. (2003). "Bringing Clarity to the 'Fuzzy Front End': A Predictable Process for Innovation", in *Design Research: Methods and Perspectives*, ed. B. Laurel. Boston. MA: The MIT Press, 145–54.

Richardson, J. J., Bosma, J., Roosild, S., and Larriva, D. (1999). *A Review of the Technology Reinvestment Project*. Arlington, VA: Potomac Institute for Policy Studies.

Richardson, J. J., Larriva, D. L., and Tennyson, S. L. (2001). *Transitioning DARPA Technology*. Arlington, VA: Potomac Institute for Policy Studies.

Rice, M. P., O'Connor, G. C., Peters, L. S., and Morone, J. G. (1998). "Managing Discontinuous Innovation", Research *Technology Management* 41/3: 52–58.

Roberts, E. B., ed. (1987). *Generating Technological Innovation.* New York, NY: Oxford University Press.

Roland, A., and Shiman, P. (2002). *Strategic Computing: DARPA and the Quest for Machine Intelligence, 1983–93.* Cambridge, MA: The MIT Press.

Schilling, M. A. (2005). *Strategic Management of Technological Innovation*. New York, NY: McGraw-Hill/Irwin.

Schön, D. A. (1983). *The Reflective Practitioner: How Professionals Think in Action*. New York, NY: Basic Books.

Schumpeter, J. (1942). *Capitalism, Socialism, and Democracy.* New York, NY: Harper & Row.

Schrage, M. (1999). *Serious Play: How the World's Best Companies Simulate to Innovate.* Boston, MA: Harvard Business School Press.

Siedman, I. (2006). *Interviewing as Qualitative Research: A Guide for Researchers in Education and the Social Sciences.* New York, NY: Teachers College Press.

Sigismund, C. G. (2000). *Champions of Silicon Valley: Visionary Thinking from Today's Technology Pioneers*. New York, NY: John Wiley.

Smith, P. G., and Reinertsen, D. G. (1998). Developing Products in Half the Time: New Rules, New Tools. 2nd ed. New York, NY: John Wiley.

Snyder, N. T., and Duarte, D. L. (2003). *Strategic Innovation: Embedding Innovation as a Core Competency in your Organization*. San Francisco, CA: Jossey-Bass.

Stringer, R. (2000). "How to Manage Radical Innovation", *California Management Review* 42/4: 70–88, https://doi.org/10.2307/41166054

Skarzynski, P., and Gibson, R. (2008). *Innovation to the Core: A Blueprint for Transforming the Way your Company Innovates*. Boston, MA: Harvard Business School Press.

Tennenhouse, D. (2004). "Intel's Open Collaborative Model of Industry-University Research", *Research Technology Management* 47/4: 19–26, https://doi.org/10.1080/08956308.2004.11671637

Tether, T. (2005). *Multidisciplinary Research*. Presentation at the Committee on Science, United States House of Representatives, 12 May.

Tornatzky, L. G., Fleischer, M., and Chakrabarti, A. K. (1990). *The Processes of Technological Innovation.* Lexington, MA: Lexington Books.

Tzeng, C. (2009). "A Review of Contemporary Innovation Literature: A Schumpeterian Perspective", *Innovation: Management, Policy & Practice* 11: 373–94, https://doi.org/10.5172/impp.11.3.373

United States Department of Defense. (2008). *DOD's Financial Management Regulation (Publication No. DOD 7000.14-R), Volume 2B, Chapter 5 (Research, Development and Evaluation Appropriations).* Washington, DC: U.S. Government Printing Office, https://comptroller.defense.gov/portals/45/documents/fmr/archive/02barch/02b_05_dec10.pdf

Urban Dictionary. (2010). *DARPA hard*, https://www.urbandictionary.com/define.php?term=DARPA%20hard

Van Atta, R., Lippitz, M., et al. (2003). *Transformation and Transition, DARPA's Role in Fostering a Revolution in Military Affairs*. *Volume 1.* Alexandria, VA: Institute for Defense Analyses, https://doi.org/10.21236/ada422835, https://fas.org/irp/agency/dod/idarma.pdf

Van Atta, R. H., Cook, A., et al. (2003). *Transformation and Transition: DARPA's Role in Fostering an Emerging Revolution in Military Affairs. Volume 2.* Washington, DC: U.S. Government Printing Office, https://doi.org/10.21236/ada422835 , https://apps.dtic.mil/dtic/tr/fulltext/u2/a422835.pdf

Van Atta, R. (2008). "Fifty Years of Innovation and Discovery", in *DARPA, 50 Years of Bridging the Gap*, ed. C. Oldham, A. E. Lopez, R. Carpenter, I. Kalhikina, and M. J. Tully. Arlington, VA: DARPA. 20–29, https://issuu.com/faircountmedia/docs/darpa50 (Chapter 2 in this volume).

Van de Ven, A. H., Angles, H. L., and Poole, M. S. (2000). *Research on the Management of Innovation: The Minnesota Studies.* New York, NY: Oxford University Press.

Van de Ven, A. H., Polley, D. E., Garud, R., and Venkataraman, S. (1999). *The Innovation Journey*. New York, NY: Oxford University Press.

Vojak, B. A., Griffin, A., Price, R. L., and Perlov, K. (2006). "Characteristics of Technical Visionaries as Perceived by American and British Industrial Physicists", *R&D Management* 36/1: 17–26, https://doi.org/10.1111/j.1467-9310.2005.00412.x

Waldrop, M. M. (2001). *The Dream Machine: J. C. R. Licklider and the Revolution that Made Computing Personal*. New York, NY: Viking Press.

Watts, R. M. (2001). "Commercializing Discontinuous Innovations", *Research-Technology Management* 44/6: 26–31, https://doi.org/10.1080/08956308.2001.11671461

Weinberger, S. (2006). *Imaginary Weapons: A Journey through the Pentagon's Scientific Underworld.* New York, NY: Nation Books.