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A DHS SKUNKWORKS PROJECT: DEFINING AND ADDRESSING HOMELAND SECURITY GRAND CHALLENGES

by

Calvin J. Bowman

December 2016

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What global grand challenges do we face today that will have an impact on the homeland security landscape twenty-five years from now? Today, a grand challenge is intended as a call-to-action for a given field, to find the potential solution for a moonshot problem. This thesis recommends potential methods and organizational capacity requirements for Department of Homeland Security (DHS) science and technology (S&T) based on a focused comparison of three cases: XPRIZE, Defense Advanced Research Projects Agency (DARPA), and DHS S&T. This research shows that both XPRIZE and DARPA have a consistent record of innovation and disruption that have transformed contemporary life through, for example, the internet, space travel, cloud computing, GPS, artificial intelligence, virtual reality, and satellite imagery. However, DHS S&T has an uneven history and uninspiring track record of using research and development to deliver results. Through a contemporary application of smart practices used by XPRIZE and DARPA, DHS can better prepare for today's shifting technological threat environment. DHS' current approach to grand challenges is local and linear when it should be global and innovative. Better defining moonshot problems will lay the foundation for S&T to adopt pioneering strategies and to harness the massive potential of the crowd. These strategies will further drive innovation, the cornerstone to solving tomorrow's grand challenges.

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A DHS SKUNKWORKS PROJECT: DEFINING AND ADDRESSING HOMELAND SECURITY GRAND CHALLENGES

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ABSTRACT

What global grand challenges do we face today that will have an impact on the homeland security landscape twenty-five years from now? Today, a grand challenge is intended as a call-to-action for a given field, to find the potential solution for a moonshot problem. This thesis recommends potential methods and organizational capacity requirements for Department of Homeland Security (DHS) science and technology (S&T) based on a focused comparison of three cases: XPRIZE, Defense Advanced Research Projects Agency (DARPA), and DHS S&T. This research shows that both XPRIZE and DARPA have a consistent record of innovation and disruption that have transformed contemporary life through, for example, the internet, space travel, cloud computing, GPS, artificial intelligence, virtual reality, and satellite imagery. However, DHS S&T has an uneven history and uninspiring track record of using research and development to deliver results. Through a contemporary application of smart practices used by XPRIZE and DARPA, DHS can better prepare for today's shifting technological threat environment. DHS' current approach to grand challenges is local and linear when it should be global and innovative. Better defining moonshot problems will lay the foundation for S&T to adopt pioneering strategies and to harness the massive potential of the crowd. These strategies will further drive innovation, the cornerstone to solving tomorrow's grand challenges.

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TABLE OF CONTENTS

LIST OF FIGURES

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LIST OF ACRONYMS AND ABBREVIATIONS

AI	artificial intelligence
CHDS	Center for Homeland Defense and Security
DARPA	Defense Advanced Research Projects Agency
DHS	Department of Homeland Security
DOD	Department of Defense
FEMA	Federal Emergency Management Agency
GAO	Government Accountability Office
HGP	Human Genome Project
HSE	homeland security enterprise
IoT	internet of things
MTP	massive transformational purpose
NPS	Naval Postgraduate School
R&D	research and development
SFI	Strategic Foresight Initiative
S&T	Science and Technology Directorate

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EXECUTIVE SUMMARY

This thesis analyzes the current and future capacity of the Department of Homeland Security's (DHS') Science and Technology Directorate (S&T) to define and address homeland security grand challenges. The method of analysis is a structured focused comparison of three case studies: XPRIZE, Defense Advanced Research Projects Agency (DARPA), and DHS S&T. Results of the research show that only through a thorough reconsideration of the S&T approach can DHS fulfill its mission of delivering innovative results that outpace the speed of evolving threats. Specifically, S&T needs to invest in long-term projects that will address potential legacy events twenty-five years in the future.

The thesis is divided into three major sections. The first two focus on the private sector's XPRIZE and the public sector's DARPA. These models are relevant for several reasons. First, both have a consistent record of innovation and disruption that have transformed contemporary life through, for example, the internet, space travel, cloud computing, GPS, artificial intelligence, virtual reality, and satellite imagery. Second, both groups are viewed as the high-water mark for defining and solving grand challenges. The third section of this thesis identifies areas in which DHS S&T has experienced success and failure relative to its research and development (R&D) mission of delivering solutions to the homeland security enterprise. In terms of areas for improvement, DHS lacks a strategic department-wide policy for defining and reporting on R&D activities, and S&T in particular relies heavily on internal focus groups, dismisses ideas that do not align with its administration goals, and does not invest in true moonshot challenges.

This thesis offers recommendations to DHS S&T that could encourage innovative methods for solving grand challenges. First, it proposes a use-inspired basic research methodology that addresses the needs of today's homeland security environment while also considering the long-term grand challenges that could be realized in twenty to thirty years. Doing so could reduce the nation's risk profile and long-term vulnerabilities, better preparing the United States for previously unimagined threats. Second, this thesis advocates trust, autonomy, and independence as crucial elements to allow problem

solvers to achieve visionary breakthroughs. These traits, as a collective, have proven to be the lifeblood of organizations that create investments in technology now for capabilities used tomorrow. Third, this thesis proposes harnessing the intellect of the crowd through a visioneering methodology. With so many new minds coming online and so many advances to communication platforms, DHS has a unique opportunity to reshape how it addresses moonshot problems. Additionally, these new minds can access a greater breadth of information, thereby enhancing their contribution to the problem solving process.

Finally, this thesis identifies further research opportunities related to the risk, time, and cost of changing DHS' approach to solving grand challenges. Transitioning these endeavors from the laboratory into the market poses formidable challenges. Like the innovative technologies created by XPRIZE and DARPA, the solution to a given problem is not the end of a project, but just the beginning. For DHS to develop disruptive technologies and successfully bring them to market, its leaders must understand the potential risks, cost implications, and schedule restraints inherent to the projects they undertake. As Clayton Christensen writes, "disruptive technologies have fluid futures, as in, it is impossible to know what they will disrupt once matured."[1] To solve the world's most critical problems, we must be willing to take risks and let our inspiration drive transformative change.

[1] Clayton Christensen, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* (Watertown, MA: Harvard Business Review Press, 1997).

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DEDICATION

I dedicate this thesis to:

My parents: Per Anne Frank, “Parents can only give good advice or put them on the right paths, but the final forming of a person’s character lies in their own hands.”

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I. INTRODUCTION

A. RESEARCH QUESTION

This thesis answers the question: How can the Department of Homeland Security (DHS) create an institutional capacity to define and address homeland security grand challenges?

B. PROBLEM STATEMENT

A grand challenge is a narrow, short-lived process for a problem that cannot be easily solved. It is intended as a call-to-action for a given field, to find the potential solution for a hard-to-solve problem. Brooks, Leach, Lucas, and Millstone state that a grand challenge approach leads by setting specific and time-bound goals, and inviting applicants with optimal combinations of interdisciplinary expertise and institutional capacity to compete in open competitions to develop potential solutions to a particular problem.[1] These problems we are attempting to find solutions for are long-term global issues and trends driving change in our societies and markets.

Evolving issues having global impacts have necessitated the model behind grand challenges for centuries. Dating back over 300 years ago, 1,550 sailors aboard four warships of the British Royal Navy wrecked off the Isles of Scilly due to navigators' inability to calculate their positions. The Scilly naval disaster of 1707 motivated the British government to form the Commissioners for the Discovery of the Longitude at Sea, to offer a reward for playing a "vital role in the development of navigation, astronomy, instrument design and world navigation."[2]

Today, a grand challenge can also more broadly be explained as the potential solution that solves a "problem that significantly impacts the welfare or future progress of

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[1] Sally Brooks et al., *Silver Bullets, Grand Challenges and the New Philanthropy* (Brighton, UK: STEPS Centre, 2009), 4, http://steps-centre.org/anewmanifesto/manifesto_2010/clusters/cluster3/Philanthropy.pdf.

[2] Peter Johnson, "The Board of Longitude 1714–1828," J*ournal of the British Astronomical Association* 99, no. 2 (1989): 63.

humanity."[3] According to Fu, Lu, and Lu, research and development (R&D), "contests are often sponsored by governments, firms, nonprofit organizations, and even wealthy individuals, to mobilize focused effort towards various valuable missions."[4] Sponsors and organizers come to the table with their respective plans. According to Lompel, Jha, and Bholla, "these agendas shape the competitions' declared goals and map the process that selects final winners."[5]

This thesis focuses on defining homeland security grand challenges and identifying what capacities within the homeland security enterprise (HSE) are needed to create homeland security grand challenges that play a vital role within DHS. This thesis is about building new capacities to reach new levels and finding solutions to problems that have not been realized. It does not present any easy answers because there are none.

C. LITERATURE REVIEW

1. Introduction

This literature review focuses on three key areas: grand challenges, capacity building, and the current status of the DHS grand challenge process. The research that analyzes grand challenges follows three significant trends closely correlated to the grand challenge process itself and are paramount in facilitating action and improvement within DHS's mission of finding "methods and solutions for the critical needs of the HSE."[6] These three trends can be categorized as grand challenge definition, grand challenge actors, and grand challenge design. This review focuses on three components of capacity building: how capacity is defined, how capacity is measured, and how capacity is created.

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[3] Taryn Williams, "The X PRIZE Design Process…EXPOSED," neXt PRIZE, June 10, 2010, para. 6, http://nextprize.xprize.org/2010_06_01_archive.html.

[4] Qiang Fu, Jingfeng Lu, and Yuanzhu Lu, "Incentivizing R&D: Prize or Subsidies?," *International Journal of Industrial Organization* 30, no. 1 (January 2012): 68, doi: 10.1016/j.ijindorg.2011.05.005.

[5] Joseph Lampel, Pushckar P. Jha, and Ajay Bhalla, "Test-Driving the Future: How Design Competitions Are Changing Innovation," *The Academy of Management Perspectives* 26, no. 2 (May 2012): 73, doi: 10.5465/amp.2010.0068.

[6] Department of Homeland Security, *Strategic Plan 2015–2019: Science and Technology Directorate* (Washington, DC: Department of Homeland Security, 2015), 3, http://www.dhs.gov/sites/default/files/publications/ST_Strategic_Plan_2015_508.pdf.

Finally, the review summarizes the current framework of the DHS Science and Technology Directorate (S&T) in doing grand challenges.

2. What Is a Grand Challenge?

XPRIZE is a non-profit organization and global leader that designs and manages public, large-scale, incentivized prize competitions intended to encourage technological development. The XPRIZE focuses the impact of grand challenges in five areas: learning, exploration, energy and environment, global development, and life sciences.[7] The XPRIZE Foundation establishes that, at its core, a grand challenge is a problem-solving activity that sets "audacious yet achievable goals that address a complex problem in which the solution significantly impacts the welfare or future progress of humanity."[8]

The White House's Office of Science and Technology Policy has recognized the significance and success of leveraging awards with innovative solutions, adding that grand challenges "harness science, technology, and innovation to solve important national or global problems and that have the potential to capture the public's imagination."[9]

Notably, grand challenges in the regulatory domain have become a priority with the creation of President Obama's Strategy for American Innovation. Agencies such as the Department of Defense (DOD), the Department of Energy (DOE), and DHS have all used a grand challenge methodology in their efforts to harness innovation to address national priorities in areas such as defense, energy, and security. Thomas Kalil, deputy director for policy for the White House Office of Science and Technology Policy and senior advisor for science, technology, and innovation for the National Economic

[7] "Global Leaders Compete to Create the Next XPRIZE," XPRIZE Foundation, April 23, 2012, http://www.xprize.org/press-release/global-leaders-compete-create-next-xprize.

[8] Williams, "X PRIZE Design Process," sec. "Design Process," 1.

[9] "21st Century Grand Challenges," White House, para. 1, accessed October 7, 2015, https://www.whitehouse.gov/administration/eop/ostp/grand-challenges.

Council, notes that "there is no universally accepted definition of what constitutes a grand challenge."[10]

However, Kalil recognizes that grand challenges follow five specific attributes. First, they have major impacts in domains of national priority. Next, grand challenges are ambitious but achievable. Third, they are intrinsically motivating. Fourth, according to Kalil, grand challenges should have "measurable targets for success and timing of completion."[11] And finally, Kalil notes that "grand challenges can help drive and harness innovation and advances in science and technology."[12]

Perhaps one of the most successful applications of government-sponsored prize competitions is the grand challenges set forth by the DOD's Defense Advanced Research Projects Agency (DARPA). Spanning over fifty years, and now with a current budget of almost $3 billion, DARPA defines grand challenges as narrow, short-lived problem-solving activities in which a sponsor provides an atypical incentive that is awarded to the declared winner who best demonstrates a solution to a typically hard-to-solve/hard-to-define problem. A grand challenge sponsor can be a government agency, private institution, association/professional organization, or philanthropist. Types of atypical incentives include recognition, reputation, cash, and special status in the field's given community. Finally, winners are determined by a clear, precisely defined set of criteria.

a. Grand Challenge Organizers, Actors, and Beneficiaries

According to Fu, Lu, and Lu, "R&D contests are often sponsored by governments, firms, nonprofit organizations, and even wealthy individuals, to mobilize focused effort towards various valuable missions."[13] Sponsors, such as the Bill and Melinda Gates Foundation, "bring together funding and research partners throughout the grand challenges network," supporting grand challenges focused on global health

[10] Tom Kalil, " The Grand Challenges of the 21st Century" (prepared remarks, Information Technology and Innovation Foundation in Washington, DC, April 12, 2012), 3, https://www.whitehouse.gov/sites/default/files/microsites/ostp/grandchallenges-speech-04122012.pdf.

[11] Ibid.

[12] Ibid.

[13] Fu, Lu, and Lu, "Incentivizing R&D," 67.

issues.[14] Additionally, over the past decade the United States has authorized the funding of grand challenges to encourage innovation within areas of government searching for innovative solutions. One recent example is NASA's Asteroid Grand Challenge, which is focuses on "finding all asteroid threats to human populations and knowing what to do about them."[15] This grand challenge was spurred when President Obama called for NASA to increase its focus on identifying and mitigating space debris that could have both domestic and global ramifications.[16] Another recent example of a problem using this method is the U.S. Agency for International Development's (USAID) grand challenge to find solutions for the Zika virus. The project dubbed Combating Zika and Future Threats: A Grand Challenge for Development called for "innovators around the world to submit groundbreaking ideas to enhance our ability to respond to the current Zika outbreak."[17]

Innovators attempting to solve these problems are an expansive collection of citizens and academic institutions, as well as government and non-government organizations from around the globe. These competitions are hugely popular, and the participants they attract are also supported by the mainstream media and academic communities.[18] According to the Organization for Economic Co-operation and Development, grand challenges can empower new players and "non-governmental organizations, private, often philanthropic, foundations and social entrepreneurs which often are driven by non-profit motives can play a significant role in catalysing innovation to solve social problems that are insufficiently addressed by governments or the market."[19]

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[14] "Grand Challenges Annual Meeting Videos," accessed December 14, 2016, http://grandchallenges.org/videos.

[15] "What Is the Asteroid Grand Challenge?," NASA, March 15, 2015, para. 1, https://www.nasa.gov/feature/what-is-the-asteroid-grand-challenge.

[16] Ibid.

[17] "Combating Zika and Future Threats: A Grand Challenge for Development," U.S. Agency for International Development, accessed July 4, 2016, https://www.usaid.gov/grandchallenges/zika.

[18] Yehuda Koren, "The BellKor Solution to the Netflix Grand Prize," Netflix, August 2009, http://www.netflixprize.com/assets/GrandPrize2009_BPC_BellKor.pdf.

[19] OECD, *The OECD Innovation Strategy: Getting a Head Start on Tomorrow* (Paris: OECD, 2010), 182, doi: 10.1787/9789264083479-en.

The Aspen Institute's Strategic Advisory Council further promulgates a framework for prize competitions that designs "a prize competition that identifies innovations that encourage future-mindedness in capital markets and longer-term thinking and acting."[20] However, Luciano Kay states that "entrants are generally attracted by the non-monetary benefits of participation (e.g., reputation, visibility, opportunity to participate in technology development and accomplish other personal and organizational goals) and the potential market value of the technologies involved in competitions."[21] However, he continues, while prize money does play a role in attracting participants, it "is not as important as other prize incentives, yet it is still important to position and disseminate the idea of the prize."[22]

b. Grand Challenge Design

The design for grand challenges can vary, but there are several specific traits these competitions follow. A sponsor—such as a government agency, private institution, professional organization, or philanthropist—provides an atypical incentive of recognition, reputation, cash, or special status that is awarded to the declared winner, as determined by a clear and precisely defined criteria. This winner is usually the individual or group that best demonstrates a solution to a typically hard-to-solve problem.

According to Lampel, Jha, and Bhalla, these problems "shape the competitions' declared goals and map the process that selects final winners."[23] However, Kuhlmann and Rip recognize that the building blocks of a grand challenge "have to do with the necessary long-term perspective, and with the recognition that addressing grand

[20] "Aspen Institute for Business and Society," Adessy, para. 2, accessed December 14, 2016, http://www.adessyassociates.com/aspen-business.php.

[21] Luciano Kay, *How Do Prizes Induce Innovation? Learning from the Google Lunar X-PRIZE* (Atlanta: Georgia Institute of Technology, August 2011), xix, https://smartech.gatech.edu/bitstream/handle/1853/41193/Kay_Luciano_201108_phd.pdf.

[22] Ibid.

[23] Lampel, Jha, and Bhalla, "Test-Driving the Future," 73.

challenges through innovation has to work with a more complex notion of innovation than is usual."[24]

3. Grand Challenges and Capacity Building in DHS

According to Nancy Suski, director of the Emergency Preparedness and Response Portfolio for S&T, "a significant portion of the federal government's resources for research and development was (sic) consolidated under the agency's Science and Technology Directorate."[25] As a result, the Obama administration and Congress passed the America COMPETES Act, which granted federal agencies "broad authority to conduct prize competitions to spur innovation, solve long-term problems, and advance their core missions."[26] The DHS secretary delegated the Department's America COMPETES Act prize authority to DHS's under secretary for science and technology, which tasked DHS' S&T with "researching and organizing scientific, engineering, and technological resources into technological tools to help protect the homeland."[27] In turn, S&T will "leverage this newly delegated authority to support the Department's Research and Development strategy through a competitive awards program that stimulates innovation and advances the Department's mission while also supporting the Homeland Security Enterprise (HSE)."[28]

In March 2015, DHS S&T introduced the InnoPrize Program. It was created to assist DHS in "planning and executing prize competitions that enable a transparent and

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[24] Stefan Kuhlmann and Arie Rip, *The Challenge of Addressing Grand Challenges* (Enschede, Netherlands: University of Twente, January 2014), 3, https://ec.europa.eu/research/innovation-union/pdf/expert-groups/The_challenge_of_addressing_Grand_Challenges.pdf.

[25] Patricia Jones Kershaw, *Creating a Disaster Resilient America: Grand Challenges in Science and Technology* (Washington, DC: National Academies Press, 2005), 10, http://www.nap.edu/catalog/11274.

[26] Office of Science and Technology Policy, *Implementation of Federal Prize Authority: Fiscal Year 2012 Progress Report* (Washington, DC: White House, December 2013), 5, https://www.whitehouse.gov/sites/default/files/microsites/ostp/competes_prizesreport_dec-2013.pdf.

[27] "Frequently Asked Questions: The America COMPETES Act and DHS Prize Authority," Department of Homeland Security, sec. "How will this prize authority be implemented in the Department?," accessed July 7, 2016, https://www.dhs.gov/frequently-asked-questions.

[28] Ibid.

fresh approach to operational challenges, problem solving, and spurring innovation."[29] As called for in the president's Strategy for American Innovation, the InnoPrize competition "provides all agencies with the broad authority to conduct prize competitions … in order to stimulate innovation, solve tough problems, and advance their agencies' core missions."[30]

However, though S&T does have authority to conduct grand challenges, former Under Secretary for DHS S&T Tara O'Toole has admitted difficulty in achieving the goals of the competitions.[31] As noted by Dean Kamen to the Homeland Security Science and Technology Advisory Committee, "grand challenges have worked well within industry but it takes time and energy and is a budget challenge."[32]

D. RESEARCH DESIGN

Primarily, this thesis attempts to analyze DHS' capacity to define and address grand challenges within the bounds of the HSE. The assertion is that homeland security grand challenges are not precisely and elaborately defined and that DHS does not exhibit the capacity to create innovative solutions to solve these problems.

This thesis is a structured, focused comparison of three case studies that attempt to solve moonshot problems using contemporary methods to spur innovative solutions. The first two sections focus on an analysis of two case studies: the private sector's XPRIZE and the public sector's DARPA. Both groups are viewed as the high-water mark of grand challenges. These models are relevant to study for several reasons. First, both have a consistent record of innovation and disruption that have transformed contemporary life through, for example, the internet, space travel, cloud computing, GPS,

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[29] "Department of Homeland Security," Challenge.gov, sec. "More Information," accessed July 7, 2016, https://www.challenge.gov/agency/department-of-homeland-security/.

[30] Tom Kalil and Robynn Strum, "Congress Grants Broad Prize Authority to All Federal Agencies," White House, para. 1, 7, December 21, 2010, https://www.whitehouse.gov/blog/2010/12/21/congress-grants-broad-prize-authority-all-federal-agencies.

[31] "Department of Homeland Security (DHS) Science and Technology Directorate (S&T) Homeland Security Science and Technology Advisory Committee (HSSTAC) Minutes," Department of Homeland Security, accessed December 11, 2016, https://www.dhs.gov/sites/default/files/publications/hsstac_meeting_sep2012_minutes_508.pdf.

[32] Ibid., 8.

artificial intelligence, speech recognition, and satellite imagery. Additionally, both excel at attracting the top "'performers'—individuals or teams drawn from universities, companies of all sizes, labs, government partners, and nonprofits" to participate in solving the problem.[33] Often, these disruptive innovations have gone on to create a host of multibillion-dollar industries.

In the third section, this thesis uses Heilmeier's Catechism—a set of questions developed and used by DARPA—to analyze the trends and smart practices currently in practice by DHS. The case study approach in the first two sections provides structure and symmetry as a baseline for analysis. In turn, the analysis is further enhanced in the third section by cross-referencing the information from the two case studies against Heilmeier's Catechism. Specifically, the third section asks the following questions: What are you trying to do, how is it done today, and what is new in your approach? The research intends to provide a roadmap for DHS to examine how grand challenges are defined and addressed within its enterprise. Creating this capacity could play a vital role in the long-term approach to the homeland security mission.

To help identify a framework and culture of innovation that addresses homeland security problems of the future, this thesis analyzes successful R&D methods used by XPRIZE and DARPA. Identifying these successes allows this thesis to do the following:

- Establish common language and definitions of grand challenges, including who does them and how they are done.
- Identify which capacities an organization must possess to perform grand challenges successfully
- Suggest a method that can be adopted by DHS to formalize and enhance its R&D capabilities to address homeland security grand challenges.
- Recommend the next steps for further research that could not be accomplished within the scope of this thesis

The research used to identify and analyze the case studies is culled from internet sources, academic publications, and peer-reviewed journals. Further, government records

[33] Regina E. Dugan and Kaigham J. Gabriel, "'Special Forces' Innovation: How DARPA Attacks Problems," *Harvard Business Review*, October 2013, para. 2, https://hbr.org/2013/10/special-forces-innovation-how-darpa-attacks-problems.

such as Government Accountability Office (GAO) reports and congressional testimony, as well as literature produced by DARPA and XPRIZE, were also instrumental in constructing the case studies. These documents helped identify definitions, organizational capacities, policies, and contributions to the field.

Finally, it was expected that research would uncover some unanticipated themes that impact the grand challenge process. A grand challenge methodology may not apply to every homeland security problem. Therefore, this thesis suggests new methods and organizational capacity requirements for DHS to consider when defining and addressing homeland security grand challenges. However, the opportunities for continuing research and contributions to the literature are abundant. This thesis provides researchers with a general outline on the limitations of this paper and what inquiry and analysis can be further explored.

II. CASE STUDY: XPRIZE GRAND CHALLENGES

> At XPRIZE, failure is not a bad thing; it's part of the process.
>
> —Peter Diamandis
> Founder and Chairman, XPRIZE Foundation

Today we live in a world that is undergoing change at an exponential pace. We used to live in a world that was very local and linear. The events that affected us were typically within a day's walk, and events that happened on the other side of the planet did not have an impact on our lives. Understanding that most people think linearly, it could be difficult to conceptualize the massive difference in scale between the two methods of thought. As an example, imagine yourself standing in the back of a classroom. In the front of the room is the door. You're about thirty paces away from that door, and if you took thirty steps, you would be standing outside of the classroom. Now take those thirty linear steps, and turn them into exponential steps and you are over 3 billion feet away from the back of that classroom and have traversed the planet twenty-six times.[34]

XPRIZE thinks exponentially. In 1995, Peter Diamandis created the XPRIZE under the premise that "there is no problem we cannot take on and slay with the right combination of people, technology, and capital."[35] Today, the mission of an XPRIZE carries that philosophy by identifying the national or global crises, market failures, and opportunities for which solutions are thought to be either out of reach or just plain impossible. Four core pillars create the framework by which the XPRIZE Foundation can define, stimulate, solve, and optimize grand challenges that face our world today. Through these identifiers, XPRIZE designs and operates incentivized prize competitions to drive radical breakthroughs to find solutions to these hard-to-solve problems.[36]

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[34] Peter H. Diamandis, "The Difference between Linear and Exponential Thinking," Big Think, May 23, 2013, http://bigthink.com/in-their-own-words/the-difference-between-linear-and-exponential-thinking.

[35] *Visioneer: The Peter Diamandis Story*, documentary film, directed by Nick Nanton (2015; Winter Park, FL: Celebrity Films).

[36] "2014 Annual Report," XPRIZE.

XPRIZE designs its future roadmap to achieve a massive transformational purpose (MTP) of bringing about radical breakthroughs for the benefit of humanity.[37] An MTP is the higher aspirational purpose of an organization within a specified domain. For the XPRIZE, they define what those grand challenges are and identify if they are prizable by harnessing the power of the crowd.

For example, the once groundbreaking photography company Eastman Kodak was founded in the 1800s, and has a mission statement stating:

> We provide—directly and through partnerships with other innovative companies—hardware, software, consumables and services to customers in graphic arts, commercial print, publishing, packaging, electronic displays, entertainment and commercial films, and consumer products markets. With our world-class R&D capabilities, innovative solutions portfolio and highly trusted brand, Kodak is helping customers around the globe to sustainably grow their own businesses and enjoy their lives.[38]

Overcome by digital competition, Kodak filed for bankruptcy in January 2012 and today is used as an example of an organization unwilling to adapt to market breakthroughs. Inversely, consider Instagram, the global social image-sharing platform that shares more than 95 million photos shared every day. The MTP of this organization that has existed for less than one decade reflects an aspirational and inspirational MTP to "Capture the World's Moments."[39] It is more than just about one single person or one photo. It is a global proclamation of possibilities that can be attained.

A. FAILURE AND ACHIEVABILITY—THE MOONSHOT TEST

For a hard-to-solve problem to be considered a "grand challenge," it must identify the potential achievability and market application of the problem, as well as any possible failures. This is called the "moonshot test." The term "moonshot" is derived from the Apollo 11 space flight project, which landed the first human on the moon in 1969. When

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[37] Salim Ismail, Michael S. Malone, and Yuri van Geest, *Exponential Organizations: Why New Organizations Are Ten Times Better, Faster, and Cheaper than Yours (and What to Do about it)* (New York: Diversion Books, Kindle Edition, 2014), Kindle locations 685–686.

[38] "Our Company," Kodak, para. 1, accessed September 23, 2016, http://www.kodak.com/ek/US/en/corp/aboutus/our_company/default.htm.

[39] "Instagram," accessed September 23, 2016, https://www.instagram.com/.

President Kennedy delivered his challenge to the nation in 1961, he set the audacious goal of "landing a man on the moon and returning him safely to the earth," with the equally impossible timeline of "before this decade is out."[40] In an instant, a new cliché entered the lexicon. If we can put a man on the moon, the saying went, then we can achieve anything.

More recently, the term moonshot has been used by Google and is defined as an "ambitious, exploratory, and ground-breaking" project.[41] It defines a large problem with a proposed radical solution that looks for "a technology breakthrough that exists today," giving stakeholders hope that the solution is possible "even if its final form is five to ten years away and obscured over the horizon."[42] Similarly, the significant problem must have a previous market failure. As Peter Diamandis, founder of the XPRIZE Foundation, explains, it must be a problem area and there must be "something that's keeping this area stuck and not moving forward."[43]

The XPRIZE Foundation established audacious yet achievable goals, created a large monetary prize, and without discrimination challenged any person, group, or organization to be the first to solve that problem within an established timeframe. Most importantly, the successful design of the competition would rely on satisfying the primary criteria that there had been a market failure within the specified problem. If the problem were experiencing organic growth, the integrity and justification of the XPRIZE philosophy would be considered compromised. The Archon XPRIZE is a good example of this.

Regarding large-scale prize competitions, the Archon XPRIZE advertised one of the largest monetary awards and had the potential to have one of the most significant global impacts in proactive, preventative, and personalized medical care the healthcare

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[40] "Apollo 11 Moon Landing," John F. Kennedy Presidential Library and Museum, epigraph, accessed September 23, 2016, https://www.jfklibrary.org/JFK/JFK-Legacy/NASA-Moon-Landing.aspx.

[41] *WhatIs*, s.v. "Moonshot," last modified April 2014, http://whatis.techtarget.com/definition/moonshot.

[42] "What We Do," X, para. 1, accessed July 14, 2016, https://x.company/about.

[43] "How to Design a Prize Competition," Pendulum in Action, accessed July 9, 2016, http://www.penduluminaction.com/design-prize-competition/.

industry has ever experienced. More important than the monetary value of the grand challenge, however, was its goal of capturing the imagination of the public to spur innovation in the field of genome sequencing. Above all, this grand challenge would accelerate the rate of positive change that could provide researchers with data to protect against disease and valuable clues to enhance health and longevity.

What would eventually serve as the inspiration for the Archon XPRIZE competition, the Human Genome Project (HGP) was an international, collaborative research program whose goal was "the complete mapping and understanding of all the genes of human beings. All our genes together are known as our 'genome.'"[44] In 1990, when the HGP launched, researchers estimated that the entire project would take at least fifteen years at the cost of about $6 billion. Seven years after the initial launch of the project, still, only one percent of the genome had been sequenced, and the project was a projected to be 650 years behind schedule.

However, after another four years of research, the sequence of the entire genome's 3 billion base pairs was 90 percent complete, and in 2001, its results were published in the International Human Genome Sequencing Consortium.[45] Craig Venter's groundbreaking approach ultimately took a full year to sequence a single human genome at an astonishing cost of approximately $2.7 billion.[46] In his White House announcement at the culmination of the project, President Bill Clinton said, "Without a doubt, this is the most important, most wondrous map ever produced by humankind."[47] However, while success was achieved in completing the full sequence, the moonshot of radically

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[44] "An Overview of the Human Genome Project," National Human Genome Research Institute, para. 1, accessed August 23, 2016, https://www.genome.gov/12011238/an-overview-of-the-human-genome-project/.

[45] Ibid.

[46] "The Human Genome Project Completion: Frequently Asked Questions," National Human Genome Research Institute, accessed September 1, 2016, https://www.genome.gov/11006943/human-genome-project-completion-frequently-asked-questions/.

[47] White House, "Remarks Made by the President, Prime Minister Tony Blair of England (via satellite), Dr. Francis Collins, Director of the National Human Genome Research Institute, and Dr. Craig Venter, President and Chief Scientific Officer, Celera Genomics Corporation, on the Completion of the First Survey of the Entire Human Genome Project," National Human Genome Research Institute, para. 5, June 26, 2000, https://www.genome.gov/10001356/.

transforming the medical utility of genomics technologies had not been accomplished rapidly and economically.

Almost twenty years since the launch of the original HGP, it still took over one year to sequence a single human genome with a price tag exceeding $10 million. The project on its own was massive, but the amount of time it took and the cost to map an entire sequence was not transformative. The breakthrough to impact over one billion people had still not been recognized. As a result, the XPRIZE Foundation announced the launch of the Archon XPRIZE competition to "create an open forum to the worldwide community of genetics and beyond, to help further define appropriate standards for measuring the quality of whole human genome sequencing as well as create an international consensus on a standard with the creation of the Validation Protocol."[48]

What had been missed by scientists and researchers was that over the years, according to the XPRIZE Foundation, technology performance issues in human genome mapping were "being solved at a rate that outpaced all technological and economic expectations," because of Moore's law.[49]

Moore's Law projected that "computing would dramatically increase in power and decrease in relative cost, at an exponential pace."[50] As shown in Figure 1, applying Moore's Law to the HGP demonstrates the cost to sequence a genome diverging dramatically around 2008, falling from almost $10 million to close to $1,000 in 2015. Private companies such as Illumina and Life Technologies recognized the opportunity to capitalize on this slow-to-market industry and, in doing so, the inherent competition provided the stimulus needed to advance the research and drive down the costs.

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[48] "Archon Genomics Overview," XPRIZE Foundation, para. 3, accessed December 11, 2016, http://genomics.xprize.org/about/overview.

[49] Ibid.; Ismail, Malone, and van Geest, *Exponential Organizations*; Grant Campany, "Cancellation of the Archon Genomics XPRIZE: A Public Debate," March 27, 2014, sec. 1, http://genomics.xprize.org/news/blog/cancellation-of-archon-genomics-xprize-public-debate.

[50] "50 Years of Moore's Law," Intel, heading, accessed October 22, 2016, http://www.intel.com/content/www/us/en/silicon-innovations/moores-law-technology.html; R. R. Schaller, "Moore's Law: Past, Present and Future," *IEEE Spectrum* 34, no. 6 (June 1997): 52–59, doi: 10.1109/6.591665.

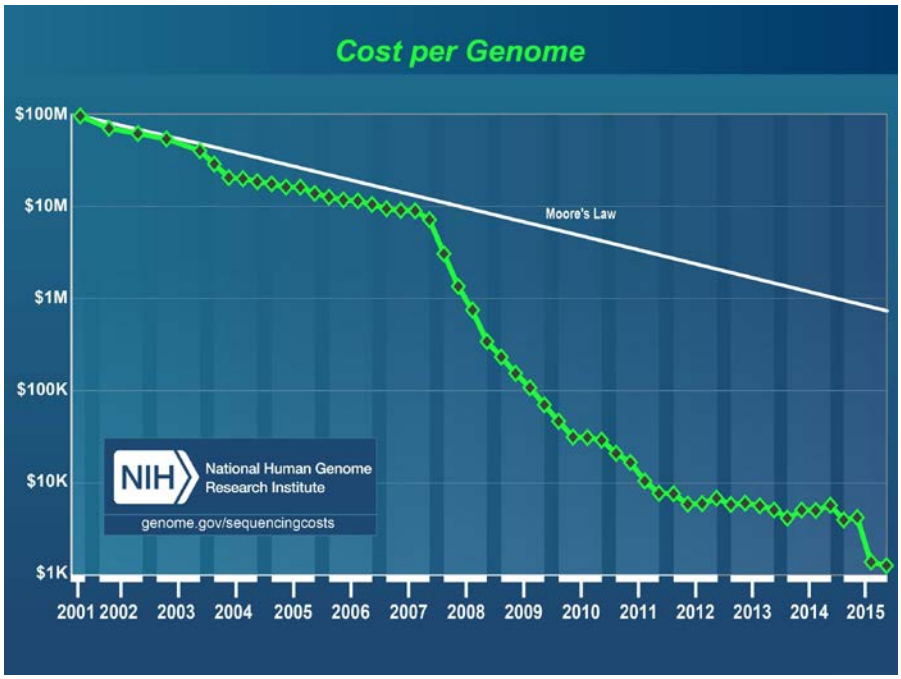

Figure 1. Moore's Law Applied to the Human Genome Project[51]

"An XPRIZE is successful only when it creates or catalyzes an industry by addressing key market failures that prevent innovation in a given field."[52] Over the next decade, the ability to map our genes will be a more integral component of our medical care.[53] As a result of the rapid and organic growth in the field of geometrics, the competition was not incentivizing the technological changes for which it was intended and, in 2013, the Archon XPRIZE became the first and only XPRIZE competition to be canceled.[54] The failure of the XPRIZE competition was not a failure to find a solution to the problem (they did); it was a failure in that a large-scale prize competition such as the XPRIZE was no longer useful as the catalyst to bring the utility to market.

[51] Source: "The Cost of Sequencing a Human Genome," National Human Genome Research Institute, Figure 1, last modified July 6, 2016, https://www.genome.gov/sequencingcosts/.

[52] Campany, "Cancellation of the Archon Genomics XPRIZE," sec. 1.

[53] Meg Tirrell, "Unlocking My Genome: Was it Worth it?," CNBC, December 1, 2015, http://www.cnbc.com/2015/12/10/unlocking-my-genome-was-it-worth-it.html.

[54] "Archon Genomics XPRIZE," accessed October 19, 2016, http://genomics.xprize.org/.

The cancellation of such a respected prize competition illustrated the significance of the moonshot test and the role a market failure plays in identifying a grand challenge. In 2006, the Archon Genomics XPRIZE focused on failures in the fields of "sequencing, such as poor accuracy, high cost, low quality, and long processing times of genomic sequencing technologies."[55] However, according to the XPRIZE Archon website, "over the seven-year life of the Archon Genomics XPRIZE, these technology performance issues were being solved at a rate that outpaced all technological and economic expectations."[56] By 2013, the private sector was solving this grand challenge outside the bounds of the competition.[57] While the Archon XPRIZE met certain criteria required of a grand challenge, ultimately the problem was no longer stuck, and its market application had organically grown.

B. WHO DETERMINES THE FUTURE?—THE XPRIZE ECOSYSTEM

1. Visioneers

The second core pillar of XPRIZE is identifying the human capital that will define the problem, finance the prize, and design the parameters under which the challenge will operate. This section focuses on two main components of the XPRIZE ecosystem—the visioneers and the visioneering process.

Visionary leaders capture the imagination of not only the scientific community, but also the population at large, to stimulate action toward a specifically identified moonshot. The XPRIZE challenge was imagined by Peter Diamandis, an aerospace engineer and molecular geneticist who earned undergraduate and graduate degrees from MIT and an M.D. from Harvard Medical School. Early in his career, as a tool of encouragement from a colleague to complete his pilot's license, Diamandis was given a copy of the 1954 Pulitzer Prize–winning book, *The Spirit of St. Louis*, penned by famed pilot Charles Lindbergh. The book chronicled Lindbergh's account of the Orteig Prize for

[55] Campany, "Cancellation of the Archon Genomics XPRIZE," sec. 1.

[56] Ibid.

[57] Ibid.

the first plane to fly nonstop from New York to Paris.[58] Investments being made by people attempting to win the $25,000 prize competition, observed Diamandis, were close to sixteen times the value of the prize being offered.[59] This return on investment and ability to create innovative solutions to grand challenges became the catalyst for what would become known as an XPRIZE.

At a four-day "build a rocket" brainstorming retreat for rocket scientists and space lovers, Diamandis disseminated a draft he had been working on titled "Spaceflight Prize Strategy." In it, he laid out the early foundations for what would become the Ansari XPRIZE, stating:

> There is a strong technology available which helps humans in achieving difficult, sometimes seemingly impossible feats, this technology is a forcing function which helps to focus the whole of human ingenuity at the same well articulated goal. … This concept, the forcing function, this technology, is the competitive "Prize." Not prizes for spelling bees or prizes for a lifetime achievement, but prizes which lay out impossible goals and tempt man to take great strides forward. Prizes such as those which were set out to the aeronautical world for speed, distance, endurance, etc. Prizes which brought forward adventurers, dreamers, and doers. Prizes such as the $ 25,000 Orteig Prize. Where no government filled the need and no immediate profit could fill the bill, the Orteig Prize stimulated multiple different attempts. Where $ 25,000 was offered, nearly $ 400,000 was spent to win the prize—because it was there to be won.[60]

The first XPRIZE grand challenge imagined by Diamandis in 1996 remained faithful to the spirit of his original inspiration for these challenges. To catalyze a new industry of space tourism, Diamandis launched the $10 million XPRIZE. Following high-watermark achievements by NASA through the '60s and '70s space program, America's excitement for the exploration of space began to wane. In his 2011 essay, *Innovation Starvation*, author Neal Stephenson states, "I worry that our inability to match the achievements of the 1960s space program might be symptomatic of a general failure of

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[58] Charles A. Lindbergh, *The Spirit of St. Louis* (New York: Scribner, 2003).

[59] "Raymond Orteig-$25,000 Prize," Charles Lindbergh, accessed September 21, 2016, http://www.charleslindbergh.com/plane/orteig.asp.

[60] Julian Guthrie, *How to Make a Spaceship: A Band of Renegades, an Epic Race, and the Birth of Private Spaceflight* (London: Penguin, Kindle Edition), 131.

our society to get big things done."[61] Until now, writers such as Stephenson and Jules Verne were among the very few who had imagined that space tourism could be a reality beyond the pages of science fiction. It was through these lenses that Diamandis recognized the market failures of space exploration, and his philosophy for solving problems became the cornerstone of the first XPRIZE grand challenge.

The Ansari XPRIZE ignited a space exploration revolution, inspired international collaboration and competition, and drove regulatory reform. Diamandis envisioned creating a grand challenge that would challenge "teams from around the world to build a reliable, reusable, privately financed, manned spaceship capable of carrying three people to 100 kilometers above the Earth's surface twice within two weeks."[62] However, any investment toward space tourism came with two assumptions: it was too dangerous and too expensive.[63] Further, it was against Federal Aviation Administration regulations for any private entity to attempt to do so. To highlight this market failure in space exploration, it is critical to recognize that in an almost nine-year span, from 1961 through 1969, NASA had developed and flown seven different manned launch systems, yet over the next forty-four years, there were only three.[64]

Twenty-six teams from seven countries invested over $100 million competing in the Ansari XPRIZE Grand Challenge. However, by investing in the prize, sponsors automatically invest in the efficiency of the competition and only pay the winning team for actual results. Realizing that the XPRIZE grand challenge was able to leverage a ten-to-one ratio of the prize purse, the Ansari Foundation signed on as the main sponsor.

XPRIZE sponsors are visionaries who support efforts to find innovative solutions to global problems. This group of philanthropists actively engaged XPRIZE Foundation leadership on strategic topics and fueled the capacity of the prize competitions by enhancing the monetary incentives. The sponsors also work closely with the Foundation

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[61] Neal Stephenson, "Innovation Starvation," *World Policy Journal* 28, no. 3 (Fall 2011): 12.

[62] "Mojave Aerospace Ventures Wins the Competition that Started it All," XPRIZE Foundation, sec. "Competition," accessed September 8, 2016, http://ansari.xprize.org/teams.

[63] "Fact Sheet—Commercial Space Transportation," Federal Aviation Administration, June 28, 2010, http://www.faa.gov/news/fact_sheets/news_story.cfm?newsId=11559.

[64] *Visioneer*, narrative by aerospace engineer Burt Rutan, 00:02:45.

to identify strategic partners and opportunities. The fundamental effectiveness of a challenge can be undermined from the outset if the focus for the grand challenge is not precisely and elaborately defined. Therefore, a collaborative team of staff members focuses on the organizational management of a challenge and on the capacities needed to achieve a result successfully.

While the prize award for the Ansari XPRIZE was $10 million, the winning team invested more than double that amount, putting in over $20 million to build the winning design. Through their investment, the Ansari family was able to harness the power of the crowd to validate the market while leveraging their initial seed money with an exponential return on investment of ten to one. Before the Ansari XPRIZE, Diamandis noted that "few investors seriously considered the market of commercial spaceflight."[65] Space exploration has traditionally been seen as a role occupied by NASA, and, as a consequence, progress and innovation in the space exploration field, both public and private, were limited and non-existent, respectively. By creating a grand challenge to break the bottleneck, an initial $10 million investment ultimately resulted in over $1 billion in newly invested money in commercial space exploration and tourism.[66]

Sponsorship of an XPRIZE, however, is not focused as much on the return of the monetary investment as much as it is on highlighting an even greater general benefit. The advancement of knowledge in the private aerospace industry through the competition was exponential. It gives the sponsor a new perspective on what is to come in the industry and gives them the foresight to pivot their current market positions based on the exponential changes witnessed through these competitions. Benefits of participation can outweigh the monetary gains by providing a potential market value to not only the sponsor, but the participants as well. Academic reputation, visibility, and the opportunity to participate in technology developments are all leveraged as additional and potentially even more attractive incentives than the advertised monetary prize. By opening the competition to anyone (a crowdsourcing methodology), Diamandis was able to harness the power of the

[65] Peter Diamandis and Steven Kotler, *Bold: How to Go Big, Create Wealth and Impact the World* (New York: Simon and Schuster, 2016), 246.

[66] Ibid.

crowd to spark innovation in a market that had long been stagnant in the government and non-existent in the private sector.

As a result of the XPRIZE grand challenge, commercial space travel has become an entirely new industry. Today, many of the world's leading philanthropic entrepreneurs support major space projects. Billionaires such as Jeff Bezos (Blue Origin), Elon Musk (SpaceX), Richard Branson (Virgin Galactic), and Larry Page and Sergey Brin (Google Lunar XPRIZE) have all made substantial investments in private space exploration as a direct result of the Ansari XPRIZE.[67] These captains of industry who are placing big bets on space travel are the same minds being asked to play a role in mapping the blueprint of incentivized prize competitions and determining the course of our future.

2. Visioneering

As Diamandis created a renewed interest in the evolving concept of prize awards to solve problems, XPRIZE was also evolving its approach to identify and define these problems. In 2011, the XPRIZE Foundation launched an annual gathering called the Visioneering Conference. This meeting of the minds brings together "people from around the world, top benefactors, CEOs, heads of industry, heads of government," and many other forward thinkers to imagine and create the future.[68] In Diamandis' words, "we debate and discuss what the problems should be that we could solve."[69]

Having managed to harness the power of the crowd to solve some of the world's most complex problems, the XPRIZE Foundation was now leveraging the power of the crowd to identify and define those problems. The visioneers that have been selected to design the next generation of potential XPRIZEs are composed of "bold innovators, prominent scientists, engineers and entrepreneurs who are passionate about creating

[67] Doug Messier, "Number of Billionaires Investing in Space Projects Grows at Parabolic Arc," Parabolic Arc, March 3, 2015, http://www.parabolicarc.com/2015/03/03/billionaires-investing-space-projects-grows/.

[68] Tim Stevens, "The Minds behind XPRIZE: The Making of the Next Visionary Challenge," sec. "Visioneering," Engadget, May 10, 2013, https://www.engadget.com/2013/05/10/inside-xprize-visioneering/.

[69] Ibid.

exponential impact across a portfolio of grand challenge areas: cancer, ALS, empathy, water, nutrition, housing, and avatars."[70]

The XPRIZE grand challenge undergoes a multi-step process in which the visioneers define and design the next XPRIZE grand challenge. But what are the rules? The process of defining problems facing humanity and designing prize competitions to solve them is called visioneering. This visioneering process allows an individual to identify multiple issue areas in which he or she would like to participate, followed by a transition to explore real-life market failures in those areas. An XPRIZE cannot be won by making something 5% cheaper or 2% faster. The XPRIZE is fundamentally about enabling something to happen that most people said cannot be done.

The grand challenge design establishes the framework and describes who can participate and the grand challenge timeline, and formalizes a measurable goal in finding breakthrough solutions to the problem. As previously indicated, the fundamental effectiveness of a challenge can be undermined if the focus for the grand challenge is not precisely defined. Therefore, sponsors and the visioneering team work together throughout a visioneering summit to establish a fundamental framework to create the principles of the grand challenge, typically to include the organizational management of a challenge and the capacities needed to achieve a result successfully.

The goal of the visioneering summit is to brainstorm the next grand challenge contest. The multi-day conference examines current market failures around the globe and establishes broad categories to provide structure and focus to this highly curated selection of individuals. It aims to tackle hard-to-solve problems in areas that have been grouped into a number of predefined tracks. These critical global issues are generally focused "in the areas of science and technology, the environment, education and humanitarian advances."[71]

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[70] "XPRIZE Launches New Visioneering Model for Evaluating and Selecting the Next XPRIZE Competition," XPRIZE Foundation, August 16, 2016, http://www.xprize.org/press-release/xprize-launches-new-visioneering-model-evaluating-and-selecting-next-xprize.

[71] Ibid., sec. "About the Roddenberry Foundation."

Over multiple days, the visioneering teams slice the problems into their barest elements, analyzing the current market failures and asking what impact this issue would have if it could be solved. Because of the group dynamic and diversity within the teams, these problems are analyzed from varying points of view, allowing for the ideas to be challenged, dissected, analyzed, and rigorously defined into a formal composition for what could be an XPRIZE competition.

After the initial stages of brainstorming and vetting out ideas, the entire visioneering conference is brought together to vote on the different ideas. Collectively, this community will ultimately determine which concept(s) will be selected as the next global XPRIZE competition.[72] During this critical component of the conference, the number of sponsors wishing to support the XPRIZE mission often continues to increase. As a result of this increase in input, for an XPRIZE to create the buzz to generate excitement, addressing the signal-to-noise ratio is crucial. "With a world full of problems in need of attention, the decision of which to throw the foundation's collective might behind is of vital importance."[73]

C. THE XPRIZE COMPETITION—DEVELOPMENT AND EXECUTION

The purpose of this thesis is to explore how homeland security grand challenges can be defined and to identify what capacities are needed to create a process for executing grand challenges. However, it is important to look beyond the first two sections of this chapter to understand how those methodologies play out over the course of the prize competition. Not doing so would be likened to giving instructions on how to build a large piece of furniture without providing an image of the final product. The last two sections of this chapter provide brief insight into two components of the XPRIZE grand challenge: competition structure and optimization of the results for the global market.

[72] "Visioneers Evaluation Criteria," XPRIZE Foundation, accessed October 19, 2016, http://www.xprize.org/visioneers/evaluation-criteria.

[73] Stevens, "The Minds behind XPRIZE," sec. "Competitions."

On a whiteboard in a small conference room filled with rocket scientists, Peter Diamandis scribed, "Small teams can do big things."[74] Nearly seventy-five years after Charles Lindbergh won the $25,000 Orteig Prize for flying his aircraft nonstop from New York to Paris, Diamandis announced the Ansari XPRIZE competition. Eligible entries were to demonstrate a compelling application to the specified field, creating a new outcome, demonstration, or solution to the grand challenge of building a spaceship that could carry three people into sub-orbit and 100 kilometers above the earth's surface, twice in two weeks.[75]

In her book, *How to Make a Spaceship*, Julian Guthrie articulates the logical rules for the award as presented by Diamandis:

> The prize must involve a human feat with a level of danger and drama that would capture the interest of the public. The prize must involve a feat in which the public could someday imagine themselves participating. The prize must involve competitors racing against time and each other. The prize must be sufficiently lucrative to entice a number of competitors and must be well advertised.[76]

Competition guidelines lay out requirements, implementation plans, and rules as established by the XPRIZE Foundation.[77] These directives and milestones are strictly and tightly defined so that the moonshot problem is being solved without teams compromising the integrity of the challenge to win the money. As a friend of Peter Diamandis once told him, "the 'enemy' of the incentive prize was the 'smart aleck grad student' who met the conditions of the prize without achieving the breakthrough spirit of the prize."[78]

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[74] Guthrie, *How to Make a Spaceship*, 125.

[75] "Ansari XPRIZE," accessed December 11, 2016, http://ansari.xprize.org/.

[76] Guthrie, *How to Make a Spaceship*, chapter 10.

[77] XPRIZE, *IBM Watson Artificial Intelligence XPRIZE competition Guidelines*, Version 1 (Culver City, CA: XPRIZE, 2016), http://ai.xprize.org/sites/default/files/ibm_watson_ai_xprize_guidelines_v1_2016-06-23.pdf.

[78] Guthrie, *How to Make a Spaceship*, 127.

1. Competition Plan

Astronaut Byron Lichtenberg, an early co-founder of the XPRIZE Foundation, once said, "Without a target, you will miss it every time."[79] Incentivized prize competitions offer creative entrepreneurs a "target to shoot for and a goal to achieve."[80] While each XPRIZE grand challenge competition uses a set of criteria unique to the challenge, all have a common framework to serve as guiding principles throughout the XPRIZE enterprise. The structure follows four components that bound the competition: registration, competition plan, competition rounds, and judging and scoring.

The competition plan allows teams to outline their technical approach, team composition and background, budget overview, and timeline for developing the entry components. This overview captures the fundamental ways the team will be competitive and how they will be able to deliver a compelling and innovative entry that will fall within the constraints of the competition. Finally, according to the guidelines developed for the IBM Watson XPRIZE, the competition plan should identify the scope, originality, applicability, test methods, and metrics in order to "measure to performance of the solution."[81] Providing a competition plan is useful for both the entrant and the judging committee as it gives the entrants a benchmark to be measured by the standards they set and the milestones they need to achieve their goal. Finally, the competition plan should include a detailed explanation as to how their entry is in compliance with regulatory requirements and provide any copies of permit applications, and permits received, risk management plans, material safety data sheets, environmental impact assessments, or other pertinent documentation as needed.[82]

2. Competition Rounds

The insurmountable problems that the XPRIZEs have identified are not solved over one week. These moonshot problems take years to plan and develop solutions

[79] Diamandis and Kotler. *Bold*, 114.

[80] Ibid.

[81] XPRIZE, *IBM Watson AI XPRIZE*, 3.

[82] Ibid.

toward, and require teams to design benchmarks, test applications meticulously, and demonstrate success under the rules and regulations of the competition. The timeline for each competition varies based on the challenge. For example, the Shell Ocean Discovery XPRIZE is three years long, with two rounds of judging occurring in years two and three. This competition aims to discover and map the world's oceans with "improved autonomy, faster speeds, and the ability to explore at significant depths."[83]

However, the $30 million Google Lunar XPRIZE competition to "foster a new space economy of innovation and entrepreneurship through low-cost, efficient access to the Moon" was launched in 2007 and has a deadline for a secured launch date by December 2017.[84] This ten-year competition went through multiple deadline extensions since the original 2012 date, at which point "no team [appeared] that close to mounting a reasonable bid to win it."[85] The difference, however, between the Lunar X PRIZE and the Ocean Discovery X PRIZE is a function of the schedules teams need to have a vehicle ready to fly. That includes getting a launch contract and starting to develop hardware for the mission. These technical issues need to be addressed and processed so the team can be ready to launch before the prize expires.

The "degree of difficulty" of X PRIZEs is designed so that they are "nominally won in a 3 to 8 year time period. If a prize is won in less than three years, it was probably too easy; if it takes longer than 8 years to win, most people will lose their interest."[86]

An important note to make regarding the competition rounds is the caveat of a "wildcard" round that was introduced through the IBM Watson AI XPRIZE. This round incentivized innovative approaches to addressing humanity's grand challenges with

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[83] "Shell Ocean Discovery XPRIZE: FAQ," XPRIZE Foundation, sec. 11, accessed December 11, 2016, http://oceandiscovery.xprize.org/about/faq.

[84] "Google Lunar XPRIZE: Guidelines," XPRIZE Foundation, para. 1, accessed October 7, 2015, http://lunar.xprize.org/about/guidelines.

[85] Jeff Foust, "The Google Lunar X PRIZE at Five: Can it Still Be Won?," The Space Review, October 1, 2012, para. 3, http://www.thespacereview.com/article/2164/1.

[86] Peter H. Diamandis, *Using Incentive Prizes to Drive Creativity, Innovation and Breakthroughs* (Culver City, CA: XPRIZE Foundation, 2009), 9, https://ocw.mit.edu/courses/engineering-systems-division/esd-172j-x-prize-workshop-grand-challenges-in-energy-fall-2009/readings/MITESD_172JF09_Diamandis.pdf.

artificial intelligence (AI) through AI–human collaboration. Many of these moonshot problems rely on technology that is emerging at an exponential pace, which means that new discoveries will organically evolve and develop during this phase. The requirements for teams attempting to enter the competition through the wildcard round are strictly defined. Therefore, according to the competition guidelines, teams "must not only show a complete competition plan but also show that their plan incorporates radical new advances that were not available at the start of the competition."[87]

Finally, every XPRIZE competition demands the need of specific yet flexible deadlines to encourage innovation at a pace that recognizes the urgent demand of the potential solution. As Diamandis opines, establishing milestones and a competition deadline "means that you can incentivize rapid breakthroughs much more quickly than traditional mechanisms might."[88] It took Diamandis eight years to harness the power of the crowd to demonstrate the viability of commercial space travel—a feat never accomplished by any other government or private entity.

3. Judging and Scoring

Each team vying for an XPRIZE will undoubtedly take its approach to design and functionality for its proposed solution. However, because the goal part of the XPRIZE competition is to find a solution to a grand challenge, teams must meet or exceed all minimum requirements and are evaluated based on their compliance with the guidelines and rules established by the XPRIZE Foundation.

The judging panel comprises highly qualified and impartial individuals selected by the XPRIZE Foundation and reviewed by a scientific advisory board that will, "assist with the establishment of qualifications for prospective judges, approve the judging panel, assist with development of judging criteria, and provide input toward the

[87] XPRIZE Foundation, *IBM Watson AI XPRIZE*, 6.

[88] Peter Diamandis, "Solving Your Challenge with Incentive Competitions," *Forbes*, July 7, 2014, http://www.forbes.com/sites/peterdiamandis/2014/07/07/solving-your-challenge-with-incentive-competitions/#7e2093665a60.

development of final competition guidelines."[89] Competition judges have sole authority to award or not award a prize, contingent upon the rules and regulations created by that same body.

Finally, it is important to note that judges and the prize development team are very open to changes to the guidelines throughout the competition. The XPRIZE "Community" component of their website offers an open and active forum for XPRIZE staff, competition participants, and anyone else interested in discussions on any of the active competitions as well as topics unrelated to the current grand challenges.[90] The forum community user statistics boast thousands of users posting hundreds of topics, with each subject receiving between hundreds to several thousand page views and replies. This community allows both XPRIZE Foundation members (including the visioneers and prize design teams) and external stakeholders (competition registrants and the general population) to monitor, in real-time, competition questions, discussions, challenges, and progress.

D. OPTIMIZING FOR AN EMERGING MARKET

A properly imagined XPRIZE "should be designed so that after the purse is awarded, it is not the end, but the beginning of a new industry."[91] The Ansari XPRIZE established a growing market, with investments from a number of the world's leading philanthropic entrepreneurs who are directly supporting major space projects and making substantial investments in private space exploration as a direct result of the competition.[92] According to a white paper written by Diamandis, innovation is the catalyst in driving breakthroughs, and "these innovations need to be marketable and deployed."[93] With the advances in space travel, genomics, healthcare, and transportation,

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[89] XPRIZE Foundation, *Qualcomm Tricorder XPRIZE Competition Guidelines* (Culver City, CA: XPRIZE Foundation, 2016), 8, http://tricorder.xprize.org/sites/default/files/qtxp_guidelines_v30_02-23-16.pdf.

[90] "XPRIZE Community," XPRIZE, accessed October 3, 2016, http://forum.xprize.org/.

[91] Diamandis, *Using Incentive Prizes*, 11.

[92] Messier, "Number of Billionaires Investing in Space Projects."

[93] Diamandis, *Using Incentive Prizes*, 11.

among other challenges, many of our known systems and processes are about to be upended.

Ideally, to create both successful "real-world" deployment as well as technological innovation, a properly constructed XPRIZE demonstrates a capability that market demand will encourage the continued development and deployment through advanced market commitments. Scaled Composites' SpaceShipOne, the winning entry of the Ansari XPRIZE built by Burt Rutan and backed by Microsoft co-founder Paul Allen, formed a joint venture with Virgin Galactic in 2005 to create a bigger rocket ship that could carry not just a pilot, but also passengers. Following this successful partnership, Scaled was sold to the global security company Northrop Grumman. In 2014, Northrop Grumman, with Scaled Composites and Virgin Galactic, began development and preliminary design plans for DARPA's Experimental Spaceplane XS-1 program.

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III. CASE STUDY: GRAND CHALLENGES DARPA

If you don't invent the internet, you get a B.

—Matt Hepburn
Biological Technology Office Program Manager

On October 4, 1957, the world's first artificial satellite, the Sputnik 1, was launched by the Soviet Union to help solve a defined range of scientific problems.[94] This "inevitable stage in the development of rocket technology" became the catalyst in the space race between the Soviet Union and the United States.[95] Moreover, it was perceived that the Soviet Union held technological superiority over the United States. Concerned that the United States was falling behind in technological achievements, "especially in the technologies of war fighting and defense," President Eisenhower created DARPA in 1958 to rival the threat posed by its Cold War adversary.[96] DARPA's mission was simple and straightforward: to make crucial investments in breakthrough technologies for national security.[97] The Soviet Union's technological capabilities caught the United States by surprise, and from that point on, the global power made a commitment that "it would be the initiator and not the victim of strategic technological surprises."[98]

Today, the United States faces an evolving military landscape riddled with surprise and shifting technological threat environments. Those environments have created a demand within our military infrastructure to create an organization whose sole mission is to imagine and develop innovative solutions to unforeseen problems. As a result, DARPA has pioneered technologies that have transformed industries outside of the

94 "Creation of the First Artificial Satellites," Molniya Research & Industrial Corporation, accessed October 4, 2016, http://www.buran.ru/htm/gud%2017.htm.

95 Ibid., para. 3.

96 "Innovation at DARPA," Defense Advanced Research Projects Agency (DARPA), July 2016, 1, http://www.darpa.mil/attachments/DARPA_Innovation_2016.pdf.

97 "About DARPA," accessed November 4, 2015, http://www.darpa.mil/about-us/about-darpa.

98 Ibid., para. 2.

military industrial base, including areas of public health, society, and culture.[99] However, DARPA maintains a track record of providing a unique capability to the DOD and the broader U.S. community—one that is focused on advancing technological innovation. The development of cutting-edge technology as the solution to problems of national security ensures that the United States remains vigilant and maintains an aggressive approach of avoidance to any technological surprise. Further, its broader charter establishes that it develop "technologies that the Military Services and Departments were not able or willing to develop."[100] Examples include Arpanet (the internet), GPS, and autonomous vehicles. The immediate value of these projects was not readily apparent, nor did the projects meet the objectives or mission areas of any one service.

Like XPRIZE, DARPA works within an ecosystem of academic, corporate, and governmental partners to pioneer groundbreaking and transformative innovation. A 2001 report dedicated to DARPA projects noted that "the commercial and government organizations (were) created to improve, manage, and apply DARPA-supported technologies, some of which have continued to set industry-wide protocols."[101] Notably, while XPRIZE relies solely on incentivized prize competitions to solve moonshot problems, DARPA follows three core elements critical to solving these problems: mission, culture, and organization. These three elements allow DARPA to increase our national security profile through pivotal investments in breakthrough technologies, by bridging the gap between basic and applied research. This chapter provides an analysis of each of these three critical aspects and identifies the key practices that have led to a track record of successful innovation within a restrictive government environment.

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[99] Annie Jacobson, *The Pentagon's Brain: An Uncensored History of DARPA, America's Top-Secret Military Research Agency* (Boston: Little, Brown and Company, 2015, Kindle edition).

[100] Richard Van Atta, Sidney Reed, and Seymour Deitchman, *DARPA Technical Accomplishments Volume I* (Alexandria, VA: Institute for Defense Analyses, February 1990), 1.

[101] James Richardson, Diane Larriva, and Stephanie Tennyson, *Transitioning DARPA Technology* (Arlington, VA: DARPA, May 2001), v.

A. THE DARPA ECOSYSTEM—PREVENTING SURPRISE BY CREATING SURPRISE

Chapter II analyzed the methodology of the XPRIZE and its single-track approach of using incentivized prize competitions to solve a grand challenge. However, DARPA is first and foremost a projects agency and takes a multi-pronged approach in how problems are defined and addressed. Though their methods differ, their goals are very similar: to set ambitious objectives that focus on "new possibilities created by scientific advances and projects that are focused on solving long-standing problems through new scientific development."[102]

One of the earliest and most disruptive DARPA projects was the organization's work on stealth technologies. For over thirty years, our defense industrial base has developed superior technology that has allowed our military to maintain air dominance. During the height of the Cold War, evidence showed that U.S. aircraft and their onboard equipment were vulnerable to detection and attack by enhanced air-defense missile systems developed by our adversaries. This conflict led DARPA to develop a program with the aim of enhancing our capabilities in stealth technology. In other words, to develop a low-altitude invisible plane.

In 1975, the Air Vehicle Observables workshop produced a study that revealed the extent of the vulnerabilities of U.S. aircraft to exposure and attack by our adversaries.[103] Based on the study and support from the Office of the Secretary of Defense, the DOD, and the United States Air Force, DARPA initiated the Have Blue program. This program laid the foundations for development of a number of flying combat planes vital to the success of conflicts in Iraq, Afghanistan, and Libya, to name a few. Since the breakthrough of stealth technologies, DARPA and our defense industrial base have seen their utility applied to "a wide range of weapon systems and military platforms, among them missiles, helicopters, ground vehicles and ships."[104]

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[102] Dugan and Kaigham, "Special Forces Innovation," sec. "Identifying Projects."

[103] "HAVE BLUE and the Origin of Stealth Technology," DARPA, accessed October 7, 2016, http://www.darpa.mil/about-us/timeline/have-blue.

[104] Ibid., para. 4.

While an ecosystem of military-centric stakeholders worked together to kick off the stealth revolution and many other programs so vital to today's national security, DARPA has since come to harness the power of the crowd. DARPA has created a grand challenge prize-based competition model to create innovative technological products that impact not only our military operations, but also how the future landscape of our normal routines is designed and performed.[105] DARPA's projects, by design, are characteristically futuristic; they aim for disruptive change that transforms industry. To create a product that is a game-changer, the ideas are typically considered impossible, and oftentimes too unrealistic for organizations to invest financial and human capital to attempt.

However, science fiction novels are filled with what at one time were far-fetched ideas that seemed realistic only in the pages of the books they inhabited. In a story published in *Wonder Stories* in 1935 called "The Living Machine," science fiction writer David H. Keller wrote:

> Old people began to cross the continent in their own cars. Young people found the driverless car admirable for petting. The blind for the first time were safe. Parents found they could more safely send their children to school in the new car than in the old cars with a chauffeur.[106]

By design, DARPA is not a risk-averse organization. It looks for ideas and problems that are not problems of today, but problems that could be fifteen to twenty years away. Further, considerate considers only projects that are not being performed in the current market. If other government organizations are attempting to solve a specific problem, then that problem is not for DARPA to solve. From this perspective, using science fiction novels as inspiration does not seem so far-fetched. For example, the United States for years had experienced breakthrough developments in the fields of autopilot in the aviation industry and autonomous vacuum cleaners for our homes. However, the expansion of this technology into ground-based vehicles had done little to

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[105] Ian Maddock, "DARPA's Stealth Revolution," in DARPA: *50 Years of Bridging the Gap*, 152–154 (Arlington, VA: DARPA, 2008), http://www.darpa.mil/attachments/(2O24)%20Global%20Nav%20-%20About%20Us%20-%20History%20-%20Resources%20-%2050th%20-%20Stealth%20(Approved).pdf.

[106] David H. Keller, "The Living Machine," *Wonder Stories*, May 1935, 1464–1473.

move from the pages of science fiction into our reality. For years, countries such as Japan, Germany, and Italy had been pioneering dynamic technologies for driverless cars.[107] In 2003, DARPA Director Dr. Tether convened a roundtable discussion with the under secretary of defense for acquisition, technology, and logistics; commandant of the U.S. Marine Corps; and the commanding general of the U.S. Army Training and Doctrine Command. The purpose was to brainstorm potential methods for creating innovation for autonomous ground vehicles. When the group adjourned, it was determined that a grand challenge prize competition should be considered a strong option and that "developing a strong robotics technology base in the United States was unanimously regarded as an area of strategic importance to DOD."[108]

Following the release of a report on prize competitions done by the National Academy of Engineering, and consultation with military leaders, "DARPA determined the prize authority granted by Congress should be used to accelerate the development of autonomous ground vehicles."[109] In 2003, DARPA authorized this first-of-its-kind challenge: a $1 million prize competition to spur unmanned ground vehicle navigation. The immediate benchmark was to navigate a 142-mile course that ran across the desert autonomously. As stated by Congress in the National Defense Authorization Act for Fiscal Year 2001, "It shall be a goal of the Armed Forces to achieve the fielding of unmanned, remotely controlled technology such that … by 2015, one-third of the operational ground combat vehicles are unmanned."[110]

The competition was anticipated to experience rapid and transformational changes in the multiple areas of technology addressed by the grand challenge. Examples of these technologies included autonomous operations, which would no longer require a command uplink to operate, greater adaptability so that systems could navigate multiple

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[107] Ernst D. Dickmanns, "Dynamic Machine Vision," accessed December 12, 2016, http://www.dyna-vision.de/.

[108] DARPA, *Report to Congress: DARPA Prize Authority Fiscal year 2005* (Washington, DC: Department of Defense, 2006), 1, http://archive.darpa.mil/grandchallenge/docs/Grand_Challenge_2005_Report_to_Congress.pdf.

[109] Ibid.

[110] *National Defense Authorization, Fiscal Year 2001*, Pub. L. 106-398, 114 Stat. 1654A–38 (2000), sec. 220(a), http://www.dod.mil/dodgc/olc/docs/2001NDAA.pdf.

terrain environments, and a level of velocity that could keep up with manned vehicles. The perception within the military industrial base could be shifted based upon a successful demonstration of the technology that fully autonomous vehicles could be implemented in a combat environment.

However, if the primary goal of the grand challenge was to create new technologies within the combat environment, immense additional value would soon be realized through attracting and energizing a broad community of participants not previously associated with DOD programs or projects. Leveraging the crowd would ignite fresh insights on the autonomous vehicle problem. Unlike all other DARPA programs until that point, this prize competition would embrace a crowdsourcing methodology. This is in direct contrast to outsourcing the work, which awarded contracts to a single or small contingency of very large corporations such as Lockheed Martin for the Have Blue program. DARPA's first grand challenge competition created a "community of innovators, engineers, students, programmers, off-road racers, backyard mechanics, inventors and dreamers who came together to make history by trying to solve a tough technical problem," said Lieutenant Colonel Scott Wadle, DARPA's liaison to the U.S. Marine Corps.[111]

B. ORGANIZATION—HYBRID RESEARCH METHODS

DARPA's success has been credited to three major elements: setting ambitious goals, creating temporary project teams, and owning a culture of independence. The first element has been discussed in the first two sections of this chapter. This section analyzes the design of the DARPA organization and culture framed around two mission areas: steady-state operations and grand challenge competitions. The first uses an outsourcing methodology, while the latter leverages a crowdsourcing methodology for defining and addressing complex problems within the military's technological environment.

A fundamental reason for DARPA's success is, in part, its ability to integrate new scientific or technological discovery with real-time application. DARPA takes on

111 "The DARPA Grand Challenge: Ten Years Later," DARPA, March 13, 2014, para. 4, http://www.darpa.mil/news-events/2014-03-13.

moonshot scientific projects that seek a fundamental understanding of the scientific problem, while also providing the military with practical solutions. The model DARPA uses has been formalized by political scientist Donald E. Stokes as Pasteur's quadrant.

Pasteur's quadrant, shown in Figure 2, is a model of scientific study developed by Louis Pasteur as a hybrid between pure basic research and pure applied research. According to the National Science Foundation, pure basic research "is performed without thought of practical ends … and results in general knowledge and understanding of nature and its laws."[112] Pure applied research looks to provide complete answers to practical problems.[113] Pasteur classified his method of "use-inspired basic research," which sought a fundamental understanding of scientific problems while also having a practical use for society, or in the case of DARPA, an immediate or long-term military application.

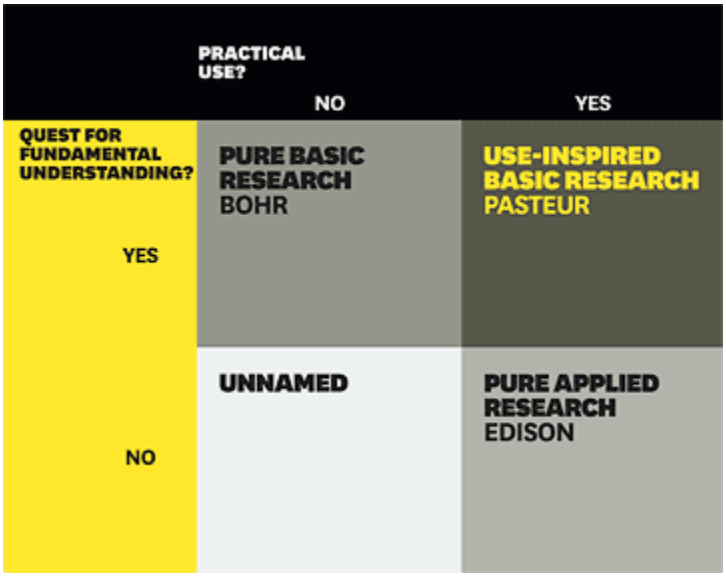

Figure 2. Pasteur's Quadrant[114]

[112] National Science Foundation, "What Is Basic Research?," in *The Third Annual Report of the National Science Foundation* (Washington, DC: National Science Foundation, 1953), 38, https://www.nsf.gov/pubs/1953/annualreports/ar_1953_sec6.pdf.

[113] Ibid.

[114] Source: Donald E. Stokes, *Pasteur's Quadrant: Basic Science and Technological Innovation* (Washington, DC: Brookings Institution, 1997).

DARPA's model of use-inspired basic research has developed a new compact between science and government. The work in Pasteur's quadrant results in discoveries that may not be suitable for every organization interested in that area. For example, findings could disrupt the current business model and destroy an existing organization if its research results are not in line with the organizational mission. Embracing unintended results could provide a new way of thinking or a future blueprint for creating new solutions not originally considered. The DARPA model is not fixed. Instead, it uses dedicated and flexible teams that are more poised to prevent surprise by creating it; moreover, if you do not create the surprise, someone else will.[115]

Another strength of DARPA's organizational approach is that legacies are created by the problems that are solved rather than the length of an employee's tenure; it is a place that offers problem-solvers a unique opportunity to collaborate on seemingly impossible challenges. The average lifespan for employment at DARPA is typically about four years and, as noted in a 2016 DARPA Innovation Report, "a short tenure means that people come to the agency to get something done, not build a career."[116] DARPA is staffed by approximately 220 people, 150 of whom are program managers. Employees are not permanently employed by the organization. Instead, they are given a chance to explore radical ideas for a fixed amount of time.

In an organization where ideas are at least as important as practical action, and where innovation is frequently valued more than continuity, former DARPA Director George Heilmeier was brought on to DARPA to "revitalize" the agency by "hitting hard on basic research projects and big projects that could make a difference."[117] Basic research and projects that could make a difference fell right in line with the agency's method of use-inspired basic research. However, to select and prioritize projects, DARPA needed a metric to assess the value of each proposal's output.[118] Almost immediately,

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[115] Dugan and Kaigham, "Special Forces Innovation."

[116] "Innovation at DARPA," 3.

[117] Richard Van Atta, Sidney Reed, and Seymour Deitchman, *DARPA Technical Accomplishments Volume II* (Alexandria, VA: Institute for Defense Analyses, April 1991), 9-12.

[118] "The Heilmeier Catechism," DARPA, accessed October 19, 2016, http://www.darpa.mil/work-with-us/heilmeier-catechism.

Heilmeier developed a series of questions—referred to as the "Heilmeier Catechism"—to evaluate these research programs.[119] The questions are as follows:

- What are you trying to do? Articulate your objectives using absolutely no jargon.
- How is it done today, and what are the limits of current practice?
- What is new in your approach and why do you think it will be successful?
- Who cares? If you succeed, what difference will it make?
- What are the risks?
- How much will it cost?
- How long will it take?
- What are the mid-term and final "exams" to check for success?[120]

However, it is not DARPA engineers sitting in a laboratory designing the technology or transformative solution. There are no DARPA labs. A great deal of the R&D is outsourced to contractors, allowing for the decentralization of the production design.[121] This method allows the project managers to procure the best and brightest in their given field, regardless of the bureaucratic challenges it would typically take to procure these services. In turn, this process typically results in breakthrough solutions and transformative technological innovation unmatched in any other government sector of R&D.

The nucleus of a project team is traditionally organized around three components: the DARPA project manager, the private industry program manager, and the service contracting agent championing the project. DARPA's philosophy embraces risk as a driver to achieving advantageous and breakthrough technologies.[122] At DARPA, project

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[119] Ibid.

[120] "Heilmeier's Catechism," University of California San Diego, accessed October 22, 2016, http://cseweb.ucsd.edu/~ddahlstr/misc/heilmeier.html.

[121] Richardson, Larriva, and Tennyson, *Transitioning DARPA Technology*.

[122] The Heilmeier Catechism," DARPA.

managers oversee over 250 R&D programs.[123] Project nominations are developed out of an understanding of needs based on input from the services and participants to the research agency. Innovation is not achieved in a silo, but rather by military, governmental, academic, and non-governmental organizations proposing radical new ideas. According to DARPA, this robust innovation ecosystem "relies on diverse performers from throughout this ecosystem to apply multidisciplinary approaches to both advance knowledge through basic research and create innovative technologies that address current and predicted practical problems through applied research."[124] DARPA publicizes funding opportunities primarily by posting Broad Agency Announcements (BAAs) that formally solicit proposals tied to program-specific areas of research and development. Additionally, DARPA maintains an "office-wide" BAA, allowing potential project managers to solicit projects that may fall outside of DARPA's current priorities, but that the proposer feels could be valuable to national security.[125]

DARPA's stealth program team, for instance, included experts in technologies such as "unique fly-by-wire flight control system[s], aeroelastic tailoring on a thin, forward swept, supercritical wing, and the use of close-coupled canards or foreplanes for pitch control."[126] They were employed at Lockheed, Grumman, Rockwell, and other large companies, as well as government labs such as the Air Force Flight Dynamics Laboratory. Within this ecosystem of stakeholders, DARPA has created a new special forces–type of model for innovation.[127] It is unconventional, fast, and very effective.

C. CULTURE—TRUST, AUTONOMY, AND INDEPENDENCE

The DARPA special forces model is unique in the environment of government and military systems. Over time, other agencies such, as DHS's Homeland Security

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[123] DARPA, *Breakthrough Technologies for National Security* (Arlington, VA: DARPA, March 2015), 3, http://www.darpa.mil/attachments/DARPA2015.pdf.

[124] "Opportunities," DARPA, para. 1, accessed December 12, 2016, http://www.darpa.mil/work-with-us/opportunities.

[125] Ibid.

[126] Van Atta, Reed, and Deitchman, *DARPA Technical Accomplishments Volume II*, 11-1.

[127] Dugan and Kaigham, "Special Forces Innovation."

Advanced Research Projects Agency (HSARPA) and the Department of Energy's Advanced Research Projects Agency – Energy (ARPA-E), have attempted to replicate DARPA's culture with varying degrees of success. A driving factor of that outcome is DARPA's exceptional culture of trust, autonomy, and independence. These traits, as a collective, are crucial as the lifeblood of a DARPA network that allows problem solvers to achieve technological superiority.

Trust, as defined by renowned psychologist Erik Erikson, is "an essential truthfulness of others as well as a fundamental sense of one's own trustworthiness."[128] Throughout their lifespan, Erikson identified that individuals go through a series of eight stages of what he called psychosocial development. This comprehensive psychoanalytic theory can be used as an efficient tool to demonstrate the critical features in each of DARPA's three traits, beginning with trust.[129]

In the case of DARPA, trust must be established between the agency and the DOD, with both providing a sense of mutual assurance that their basic needs will be met. For DARPA, that basic need is a safe environment in which both sides are faithful to the values and goals of the organization and the terms of their working relationship.[130] According to Donald Ingber, a professor of bioengineering at Harvard Medical School, DARPA "is the only place that understands that true revolutionary leaps require that you not always know where you're going."[131] Much of DARPA's success has been attributed to its researchers having the freedom to investigate moonshot projects without looking over their shoulders. If the agency operated like many other R&D components that observe strict regulatory oversight, then it would likely grow into an organization that could not sustain the autonomy credited for much of its success. Phrased differently,

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128 Erik H. Erikson, *Identity: Youth and Crisis* (New York: W. W. Norton, 1968), 96.

129 Ibid.

130 "Innovation at DARPA."

131 "DARPA's Amazing Inventions," *Men's Journal*, para. 1, accessed October 30, 2016, http://www.mensjournal.com/expert-advice/darpas-greatest-inventions-20140108.

according to Microsystems Technology Office Director Chappell, "Get the best people, then trust them."[132]

One of the most important aspects of trust within DARPA is its tolerance of failure. If the goal is to be more imaginative and more ambitious than your adversary, then the threshold for failure must increase. At DARPA, ideas are more likely to be rejected because they are too risk averse, not because they are too ambitious. DARPA Information Innovation Office Director John Launchbury stated, "If none of our programs fail, we are not stretching far enough."[133]

As DARPA researchers begin to gain more trust from the institutions that fund them, they begin to develop a sense of autonomy that they can control their actions and act in their environment to get results. No longer is the approach hierarchical. This decentralized structure allows research topics to generate from program managers, potential program managers, and anyone else who is passionate about advancing a moonshot idea. Inversely, if the organization is denied the opportunity to act on its environment, doubt and mistrust begin to surface, leading to a decline in the ability and confidence that are needed to approach these complex and almost impossible-to-solve problems. If trust is a precondition required to gain autonomy, then autonomy is the precursor to the ultimate goal of independence.

As DARPA has displayed a high rate of success through the development of disruptive technologies in the fields of detection, unmanned systems, computing, and robotics, the agency has reached more mature stages of the psychosocial development process. It now has the capacity to initiate activities and assert control over its own environment and output to external forces. According to Erikson, initiative and independence occur when one allows exploration within limits and then supports this choice.[134] DARPA displays this trait by taking on projects that may not be ready for development or implementation by one of the service branches. DARPA's culture of

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[132] "Innovation at DARPA," 5.

[133] Ibid., 6.

[134] Erikson, *Identity*, 96.

independence allows it to look beyond immediate needs and over the horizon to prevent surprise by creating the surprise.

It is important to recognize that pursuing unproven and unknown technology is a risky venture. For example, the United States Air Force and several private firms turned down the opportunity to develop stealth technology further, as the evidence was theoretically based and not applied research.[135] However, DARPA "agreed to take on a risky venture, and succeeded in producing an aircraft which has demonstrated significant technical accomplishments."[136] DARPA's venturesome culture of trust, autonomy, and independence is the main driver behind its massive success, which relies on creating investments in technology now for capabilities used tomorrow.

D. TRANSITION STRATEGY

DARPA's transition record provides a fundamental, though inexact, record of successful product development. Tracking DARPA's transition record is an especially critical method for identifying how success can be measured if the DARPA model is applied, at least in part, in other government sectors. According to a technology report chronicling its transition record, DARPA relies on "organizational and operational characteristics and policies, and the environment under which the Agency operates."[137] DARPA's organizational characteristics—its mission, strategy, and operations—reflect its ability to create new technologies and insert them into new or existing markets through scientific development. As shown in Figure 3, DARPA has developed a range of solutions that could be classified in one of four quadrants. However, it may take several years to insert the technology into the market, depending on its scope. Although this integration requires synergy between collaborators and partners to support transition activities, project managers play the biggest role in advocating for the insertion of their projects.

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[135] Dugan and Kaigham, "Special Forces Innovation."

[136] Van Atta, Reed, and Deitchman, *DARPA Technical Accomplishments Volume II*, 11-13.

[137] Richardson, Larriva, and Tennyson, *Transitioning DARPA Technology*, 33.

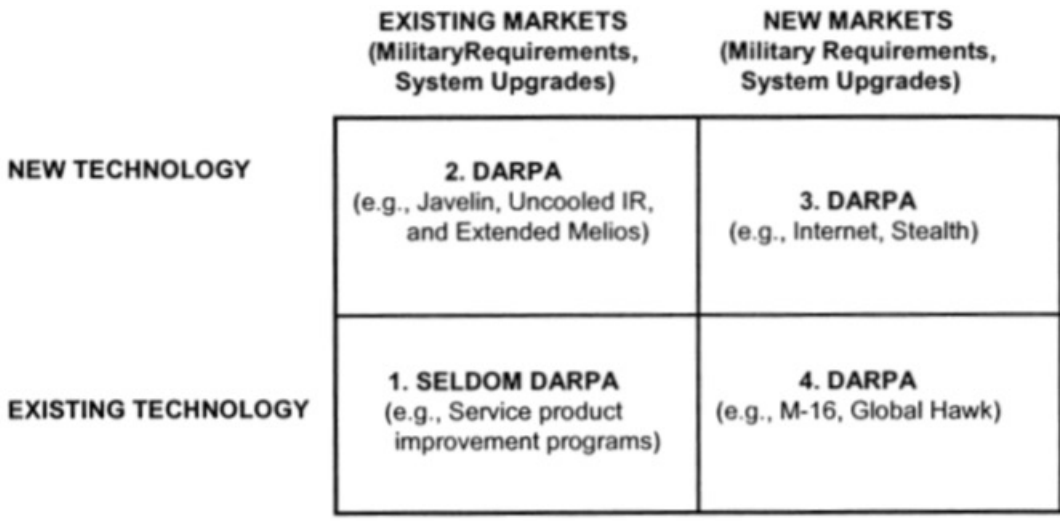

Figure 3. Market/Technology Chart[138]

Project managers, perhaps more than any single proponent of a project, have a responsibility to transition their successful developments from prototype to commercial production and use. The greatest innovations will never change the world if they are never used, and, according to DARPA Program Manager Trent DePersi, "A principal role for the program manager is to persist in selling and transitioning his product. Without persistence the system will pass over even the best technology."[139] Transition planning is a function of the project managers, and shepherding a project from its inception stage through insertion is a critical element. The *Transitioning DARPA Technology Report* ("The Report:) highlights three paths and five strategies for a project manager to recognize the most optimal pathway to insertion.[140]

The three transition paths reflected in The Report are DARPA-to-Service Acquisition, DARPA-to-Industry-to-Service Acquisition, and DARPA-to-Service S&T. Each pathway reflects a specific mechanism designed to bring a developed product to a specified service or consumer of the military industrial base.[141] To identify the optimal

[138] Source: Ibid., 36.

[139] Richardson, Larriva, and Tennyson, *Transitioning DARPA Technology*, 23, footnote 16.

[140] Ibid.

[141] Ibid.

pathway, project managers and stakeholders review several core strategies related to insertion of the technology such as prototype demonstration, customer pull, technology push, or dual use. These strategies recognize stakeholder demand and application evolution, as well as applications that meet the demands of the military and commercial marketplaces. Ultimately, The Report recognizes that "these strategies were used to push the products along essentially all transition paths, although … some are more applicable to a particular path."[142]

DARPA's transition record can be assessed from many perspectives, and determining the performance of an R&D organization with the mission and culture of DARPA is not an exact science. The Report outlined four perspectives that can serve as criteria that "together describe DARPA's transition performance and affect the standards of success under which it should be judged."[143] These four criteria are as follows:

- Total number of products transitions to the military services by DARPA;
- Rate of transition, in terms of transitions per number of program initiated;
- Quality of products; and
- Other factors that affect transition.[144]

DARPA's product transition rate provides valuable information regarding its past successes and potential for success in the future. Through DARPA's organizational characteristics, transition pathways, and robust partnerships, researchers have concluded that "the Agency's transition performance has been impressive."[145] Serving as the primary R&D agency for the DOD, DARPA has experienced both massive successes and failures. However, DARPA's characteristics, strategies, and pathways should not be considered mutually exclusive nor as limitations; rather, they should serve as guidelines to allow for its continued evolution.

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[142] Ibid., 31.

[143] Ibid., viii.

[144] Ibid.

[145] Ibid.

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IV. ANALYSIS AND RECOMMENDATIONS FOR DHS

Imagination is not a gift usually associated with bureaucracies.

—The 9/11 Commission Report

A. WHAT ARE YOU TRYING TO DO?

This chapter evaluates the Department of Homeland Security's current approach to defining and addressing grand challenges using DARPA's Heilmeier's Catechism as a framework for analysis. It is broken down into two main sections: how grand challenges are defined and approached today by DHS and what considerations can be made to adopt smart practices to create a new blueprint for DHS S&T.

B. HOW IS IT DONE TODAY?

In 2003, Congress authorized the creation of DHS' S&T to "deliver effective and innovative insight, methods and solutions for the critical needs of the Homeland Security Enterprise."[146] Mission needs evolve rapidly and the creation of the S&T showed DHS' commitment toward technology that plays a prominent role in today's threat and risk environment. However, S&T has an uneven history and uninspiring track record of using R&D to deliver results that bridge "capability gaps at a pace that mirrors the speed of life."[147] As recently as 2014, a GAO report criticized DHS for not developing a strategic plan to streamline who is leading R&D efforts across the agency.[148] Agencies within DHS with an R&D mission include the Domestic Nuclear Detection Office and the U.S.

146 "About S&T," DHS, accessed December 13, 2016, https://www.dhs.gov/science-and-technology/about-st.

147 "Operational and Support Components," DHS, last modified June 28, 2016, http://www.dhs.gov/components-directorates-and-offices; "About S&T," DHS.

148 David C. Maurer, *Department of Homeland Security: Actions Needed to Strengthen Management of Research and Development* (GAO-14-865T) (Washington, DC: Government Accountability Office, 2014), http://trid.trb.org/view.aspx?id=1322722.

Coast Guard.[149] Additionally, the GAO report stated that "DHS did not have a department-wide policy defining R&D or guidance directing components how to report all R&D activities."[150]

This section is divided into two parts. The first focues on how DHS currently defines and addresses homeland security grand challenges. Recently, DHS and its S&T have recognized their role in understanding threats that will define the homeland security landscape over the next twenty to thirty years. Following its 2015 Strategic Plan, S&T has instituted methodical changes that reflect how they define and address an increasingly complex homeland security environment. Some areas have shown early success while others display a capacity for improvement. The second part of this section compares how DHS approaches grand challenges versus how it is done by XPRIZE and DARPA. This section highlights S&T's current methods for defining and engaging in homeland security grand challenges. While it remains too early to judge the results of this evolution as a success or failure, there are major areas that can be analyzed through the lenses of the two case studies in this thesis.

Threats evolve rapidly in today's ever-changing environment. Tragic events that continue to sweep through our nation have made homeland security the signature national issue during the first two decades of the 21st century.[151] Today, DHS invests substantial time, as well as human and financial capital, to address overall preparedness, particularly in the areas of preventing terrorism, securing and managing our borders, enforcing and administering immigration laws, safeguarding cyberspace, and strengthening our preparedness and resilience capabilities.[152] More recently, S&T has created a strategy

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149 "Transformational and Applied Research Directorate," DHS, last modified August 21, 2015, https://www.dhs.gov/transformational-and-applied-research-directorate; "Acquisition Directorate: Research, Development, Test and Evaluation," United States Coast Guard, last modified November 18, 2016, http://www.uscg.mil/acquisition/rdc/.

150 Maurer, *Actions Needed to Strengthen Management of R&D*, 5.

151 National Academy of Public Administration, *Department of Homeland Security Science and Technology Directorate Developing Technology to Protect America* (Washington, DC: National Academy of Public Administration, 2009), http://www.napawash.org/pc_management_studies/DHS_ST/DHS_ST_Directorate_June_2009.pdf.

152 "2014 Quadrennial Homeland Security Review (QHSR)," DHS, last modified August 10, 2015, http://www.dhs.gov/publication/2014-quadrennial-homeland-security-review-qhsr.

that involves three steps to define homeland security challenges: internal brainstorming, crowdsourcing, and cross-referencing potential goals against current doctrine and policy.

Creating innovative solutions to address grand homeland security gaps requires thinking about these problems differently. In terms of DHS' approach to R&D, its S&T profile is primarily focused on using the pure applied research method—carrying out the goal of solving a practical problem or answering a specific question. Traditionally, DHS has gravitated toward a more applied focus than other agencies supporting pure basic research. The organization has supported open solicitations to provide applicable solutions for programs such as the First Responders Group, Chemical Biological Defense Division, Explosives Division, and the Cyber Security Division.[153]

In 2014, DHS conceptualized five visionary goals that would serve as the strategic direction to ensure future resiliency and security, and it also developed a three-step approach to establishing these goals. First, DHS "established an internal focus group comprised of S&T employees to brainstorm visionary ideas."[154] These goals, molded by internal focus groups of S&T divisions and employees, aimed twenty to thirty years out to project what the homeland security landscape would look like while also "developing innovative solutions, while increasing efficiencies, and empowering stakeholders to capitalize on technological advancements."[155] The five S&T visionary goals identified in the 2015–2019 strategic plan are as follows:

- Screening at Speed: Security that Matches the Pace of Life
- Trusted Cyber Future: Protecting Privacy, Commerce, and Community
- Enable the Decision Maker: Actionable Information at the Speed of Thought
- Responder of the Future: Protected, Connected, and Fully Aware

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153 "Guide to FY 2017 Research Funding at the Department of Homeland Security," University of Southern California, March 2, 2016, https://research.usc.edu/files/2011/05/Guide-to-FY2017-DHS-Research-Funding.pdf.

154 Science and Technology Directorate, *Strategic Plan 2015–2019* (Washington, DC: Department of Homeland Security, April 2015), 12, https://www.dhs.gov/sites/default/files/publications/st/ST_Strategic_Plan_2015_508.pdf.

155 "Visionary Goals," DHS, sec. "Operational + Strategic Focus," accessed October 24, 2016, https://www.dhs.gov/science-and-technology/visionary-goals.

- Resilient Communities: Disaster-Proofing Society[156]

These visionary goals reflect DHS' renewed commitment to identifying problems that are homeland security–focused and acknowledging their fundamental impact on society. However, DHS and its components are but one entity of the HSE. Developing an appreciation for how complex homeland security problems can impact the landscape beyond DHS requires participation from a diverse network of stakeholders beyond the scope of S&T.

Recognizing the need for broader community engagement to provide feedback to strengthen the visionary goals, S&T created mechanisms to enhance public solicitation and debate. Research funding and online engagement with external stakeholders represent its efforts to enlist and embrace support from non-traditional sources. First, research projects are funded through a variety of programs within S&T such as through the Long-Range Broad Agency Announcement, Small Business Innovation Research, and Applied Research/Technology Development Solicitations, in addition to its APEX projects. As the primary R&D arm of DHS, S&T offers "standing, open invitation for researchers and scientists to contribute their best ideas that address DHS capability gaps."[157] However, though S&T is defined as the primary DHS organization for R&D activities, several other DHS components also carry out R&D activities. Additionally, according to a 2012 GAO report, "several other DHS components also funded R&D and activities related to R&D."[158] These R&D programs have the potential to identify opportunities for advancement and close gaps using applied technology solutions within the homeland security mission space.[159]

To communicate these gaps with the public at large, S&T created a platform called the "DHS S&T National Conversation." The online portal allows registered users to share their insights on specific S&T efforts. According to the website, the National

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156 Science and Technology Directorate, *Strategic Plan 2015–2019*; "Visionary Goals."

157 "Visionary Goals," DHS, sec. "Operational + Strategic Focus."

158 Congressional Research Service, *Federal Research and Development Funding* (CRS Report No. R44516) (Washington, DC: Congressional Research Service), 49.

159 "FY 2017 Research Funding at DHS," University of Southern California.

Conversation "is intended to bring together everyone to play a role in shaping the future of homeland security technology … [and] understand the homeland security market, apply innovation, and create outcomes that will help keep us all safer while minimizing disruption to the pace of daily life."[160] Promoting engagement across non-traditional stakeholder boundaries to define and address homeland security problems allows DHS to recognize previously unimagined solutions. However, the voice of the broader community may or may not be as useful if their input does not align with current administration goals.

DHS cross-references the goals established by S&T against current doctrine and policies that provide the final layer of reference for defining homeland security grand challenges. In 2014, DHS Secretary Jeh Johnson issued a memo titled "Strengthening Departmental Unity of Effort" to "better understand the broad and complex DHS mission space and empower DHS Components to effectively execute their operations."[161] Pursuant to this memo, S&T outlined these visionary goals in its strategic plan to better unify staff and strengthen its departmental effort. Further, policies and priorities of the White House as well as the 2014 Quadrennial Homeland Security Review were used to lend legitimacy and buy-in to these goals.[162] This last step in DHS' three-step approach represents the culmination of defining homeland security grand challenges. As a result, DHS can shift the focus to closing domestic national security gaps by creating force multiplying solutions to address high-priority needs.

As of 2015, S&T has extended its goals beyond defining the grand challenges identified within the HSE and now seeks to create solutions that can be implemented across all DHS mission areas and components. To this end, it has created programs incorporating the visionary goals that will support current operational needs. Currently, there are eight Apex programs underway:

- Apex Air Entry/Exit Re-engineering

[160] Reginald Brothers, "S&T's Visionary Goals: Make Your Voice Heard," DHS, August 25, 2014, https://www.dhs.gov/blog/2014/08/25/sts-visionary-goals-make-your-voice-heard.

[161] Jeh Johnson, "Strengthening Departmental Unity of Effort," DHS, April 22, 2014, http://www.hlswatch.com/wp-content/uploads/2014/04/DHSUnityOfEffort.pdf.

[162] Brothers, "S&T's Visionary Goals."

- Apex Border Situational Awareness
- Apex Real-Time Biothreat Awareness
- Apex Flood Awareness
- Apex Next Generation Cyber Infrastructure
- Apex Screening at Speed
- Apex Next Generation First Responder
- Apex Border Enforcement Analytics Program [163]

However, there are both similarities and stark contrasts between how the S&T defines, designs, and solves grand challenges and how this process is done by XPRIZE and DARPA. Though the three steps used by S&T to define and address homeland security grand challenges partially mirror the practices of XPRIZE and DARPA, more often they reflect a departure from these methods. S&T relies on focus groups of S&T employees to define grand challenges and create visionary goals in multiple areas related to the defense of the homeland. For example, in the cyber security mission area, Apex Next Generation Cyber Infrastructure addresses functional gaps to the financial sector, such as

- Dynamic Defense: internal and external configurations
- Network Characterization: anomaly detection to incidents
- Malware Detection: detect and prevent malware code
- Software Assurance: searching for software defects
- Insider Threat: detect exfiltration by internal sources[164]

These S&T projects, however, fall short of passing the moonshot test if they are measured against the smart practices outlined by XPRIZE and DARPA. XPRIZE creates audacious yet achievable goals, and the organization is successful because of its ability to create solutions that galvanize further innovation in a given field. Similarly, DARPA

[163] "Apex Programs," DHS, accessed July 26, 2016, https://www.dhs.gov/science-and-technology/apex-programs.

[164] "Protecting the Nation's Cyber Infrastructure," DHS, accessed October 25, 2016, https://www.dhs.gov/science-and-technology/apex-ngci.

invests in projects that are unique to the market, whether within or outside the military industrial base. If the major components of the project are already being advanced by another organization or are experiencing organic growth in the industry, they will likely not be targeted for investment by DARPA. One example of how DHS inadequately defines key components is the S&Ts Next Generation Cyber Infrastructure program. This program tackles critical problems that require attention, but these problems do not satisfy the basic requirements of a grand challenge.

Since its creation in 2002, S&T has been inconsistent in achieving impactful solutions and has been challenging to manage. Though it offers opportunities for participation from private-sector organizations, government laboratories, federally funded research centers, and academic institutions, its lack of coordination has created a control issue resulting in DHS' inability to properly track R&D projects. According to a 2015 statement for the Consolidated Appropriations Act, "The Department lacks a mechanism for capturing and understanding research and development (R&D) activities conducted across DHS, as well as coordinating R&D to reflect departmental priorities."[165] This assessment of current R&D activities establishes two critical observations: DHS has made progress in creating a partnership philosophy, but it still lacks department-wide policies to address homeland security grand challenges.

Further, S&T's crowdsourcing approach is commendable in its understanding of the dynamic force of harnessing the power of the crowd; however, this online portal, while robust and accessible, has been under-accessed and overlooked as a tool to produce results. On the other hand, XPRIZE leverages the crowd in several ways—first by defining the problem through a visioneering network, and second, and more in line with the approach used by S&T, through the XPRIZE Community forum. This online community boasts thousands of users engaged daily across hundreds of topics and categories, allowing XPRIZE to understand real-time dynamic shifts in trends and developments through specified areas of a grand challenge. In turn, this online discussion

[165] Congressional Record, December 17, 2015, p. H10162.

allows problem solvers the opportunity to pivot their approaches and to potentially identify a breakthrough solution.

Finally, while S&T's third stage of cross-referencing allows DHS to ensure compatibility with current policy and strategies, this approach could compromise the integrity of a project by undermining its potential value.[166] DARPA's work in Pasteur's quadrant results in discoveries that could disrupt the current business models. However, DHS is willing to negate potential unintended results by dismissing ideas that are not in line with current doctrine. While synergy within the DHS mission environment is admirable for department-wide strategies, organizations interested in innovative solutions must be willing to establish a culture of autonomy to ensure that the basic principles of their scientific endeavors are met. Further, being flexible to embrace strategic foresight—regardless of whether or not the potential outcome falls outside the scope of immediate homeland security needs—could result in unconventional outcomes that could someday match an unconventional threat environment.

However relevant and visionary, these goals have garnered inadequate attention over the first thirteen years of S&T's history. This gap is also recognized at DHS as a whole, and according to Christian Beckner, the deputy director of the Center for Cyber and Homeland Security at The George Washington University, "What has been missing in the last decade has been a sustained and institutionalized set of processes."[167] This symptom can also be applied to S&T's approach to grand challenges. Smart practices identified through the XPRIZE and DARPA case studies provide a blueprint for how DHS could define and approach grand challenges over the next five years.

C. WHAT IS NEW IN YOUR APPROACH?

Nobel Prize–winning physicist Niels Bohr is often attributed as saying, "Prediction is very difficult, especially about the future."[168] When an organization such

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166 Johnson, "Strengthening Departmental Unity of Effort."

167 Christian Beckner, "New DHS Secretary Tackles 'Unity of Effort,'" Homeland Security Watch, April 23, 2014, http://www.hlswatch.com/2014/04/23/new-dhs-secretary-tackles-unity-of-effort/.

168 *Wikipedia*, s.v. "Niels Bohr," last modified December 6, 2016, https://en.wikiquote.org/wiki/Niels_Bohr.

as XPRIZE or DARPA sets an audacious goal of solving a problem that will change the world, it is attempting to predict the future and make those predictions self-fulfilled prophecies. These organizations set out to create exponential change that will have lasting impacts beyond our domain of influence. While DHS may not yet create breakthrough technologies that have such far-reaching implications, it can adopt methods currently used by XPRIZE and DARPA to advance its organizational capacity to define and prioritize grand challenges.

Over the past ten years, S&T has lacked the capacity to define and address homeland security grand challenges, partially because of its failure to develop a strategic plan to coordinate R&D tasks across the enterprise. A 2014 GAO report cited that while DHS had made progress in streamlining efforts, "the department's R&D efforts were fragmented and overlapping, a fact that increased the risk of unnecessary duplication."[169] To create harmony across all components, DHS should develop a system for defining, coordinating, and tracking all R&D activities under S&T. This calculated decision would allow DHS to fully take advantage of opportunities to mine project ideas from sources throughout the entire HSE and avoid following the hive mind, which "minimizes the chance of outside perspectives being introduced."[170] Developing a coordinated strategy would help not only rigorously define who oversees R&D but also provide the foundation for determining which methods are used to identify these activities.

It is important to establish a method of research that addresses the needs of today's homeland security environment while also considering the long-term grand challenges that could be realized in twenty to thirty years. Other governmental agencies have successfully used Pasteur's quadrant as a model of scientific study for R&D activities. According to Dr. Dudley Childress, director of prosthetic research at VA Medical Center, opportunities through use-inspired research "can be increased by pure basic research and existing technology can be advanced by purely applied R&D."[171] Use-

[169] GAO, *DHS Actions Needed to Strengthen Management of R&D*, sec. "What GAO Found," para. 2.

[170] James E. Ricciuti, "Groupthink: A Significant Threat to the Homeland Security of the United States" (master's thesis, Naval Postgraduate School, 2014), abstract.

[171] Dudley S. Childress, "Working in Pasteur's Quadrant," U.S. Department of Veterans Affairs, para. 5, last modified February 1, 1999, http://www.rehab.research.va.gov/jour/99/36/1/child-ed.htm.

inspired basic research provides a fundamental understanding of the scientific problem, and the practical uses are both immediate and long term.

Building a capacity to create innovative solutions through a culture of trust, autonomy, and independence has been recognized as crucial to allowing problem solvers to achieve visionary breakthroughs. DHS has experienced consistent failure in creating an environment suitable for encouraging and facilitating the dynamic level of imagination and creativity achieved at DARPA and XPRIZE. This thesis advocates implementing a visioneering method as a department-wide opportunity to embrace and engage the entire HSE, including employees, private-sector organizations, government laboratories, federally funded research centers, and academic institutions. At XPRIZE, creating a visioneering strategy by curating a selective group of diverse individuals resulted in defining the world's most complex and grand challenges. Creating this capacity within DHS would provide several beneficial outcomes.

First, DHS leaders could fulfill an organizational goal within their unity of effort mission by investing in professional development and stewardship of current and future DHS employees. This pathway also offers benefits to the specific DHS component for its contributions toward addressing long-term problems. Additionally, DHS as a whole would cultivate non-traditional sources to help explore, define, and address complex problems, consistent with smart practices at XPRIZE that have a track record of success.

Harnessing the intellect of so many unique new minds could further develop a diverse inventory of ideas to reshape how S&T defines and addresses moonshot problems. However, creating an environment suitable for channeling these ideas into a cohesive and organized method would not be possible without qualified guidance to cultivate these ideas. XPRIZE was successful by holding multiday visioneering workshops. Similarly, DHS can strengthen its capacity to define moonshot problems by providing a foundation of academic and practitioner-based expertise to lead homeland security visioneering workshops. One example of an organization currently funded by DHS and housed in a military institution is the Center for Homeland Defense and Security (CHDS). Based out of the Naval Postgraduate School (NPS), CHDS' focus on leadership development and educating how public safety officials view "an increasingly

complex world and homeland security mission" could provide a foundation for a dynamic and diverse source of subject-matter experts.[172] Because NPS currently offers a variety of academic and practitioner-based programs, CHDS could offer the institutional capacity to provide mission guidance and personnel, serving as the incubator to transform visionary ideas into tightly defined grand challenges.

Adopting a visioneering methodology could also renew interest in existing research and institutional knowledge already being driven by DHS to define these homeland security grand challenges. For example, the Federal Emergency Management Agency's (FEMA) Strategic Foresight Initiative (SFI) was launched in 2010 to provide the HSE with a transformative and enduring foresight capacity.[173] The SFI team created three groupings of drivers of change that would "have real potential to reshape the context within which [DHS] will operate."[174] These drivers are social and technological, environmental, and economic and political. However, while they appear all encompassing, they do not provide a blueprint for which projects should be tasked within the homeland security mission space. Instead, they provide an overview of the uncertainties that define and motivate potential future environments. The SFI drivers are the basis from which specific grand challenges or hard-to-solve problems can be defined and addressed by a network of homeland security visioneers. Within the right creative environment, visioneers can begin to convert these broad drivers into tightly defined projects that will impact the homeland security landscape.

D. WHAT ARE THE RISKS? HOW MUCH WILL IT COST? HOW LONG WILL IT TAKE?

This thesis focuses on two overarching questions: How does DHS define and address homeland security grand challenges, and what smart practices can be culled to

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[172] "About CHDS," Center for Homeland Defense and Security, accessed October 27, 2016, https://www.chds.us/c/about-chds.

[173] Federal Emergency Management Agency (FEMA), *Crisis Response and Disaster Resilience 2030: Forging Strategic Action in an Age of Uncertainty* (Washington, DC: DHS, January 2012), https://www.fema.gov/media-library-data/20130726-1816-25045-5167/sfi_report_13.jan.2012_final.docx.pdf.

[174] Ibid., i.

provide DHS with a new framework to define and address these problems? However, further research opportunities remain to investigate these critical questions. This section provides a starting point to explore these elements further and answer key questions raised by this thesis.

Like the innovative technologies created by XPRIZE and DARPA, the solution to a problem is not the end of a project, but just the beginning. Both organizations catapult new technologies and insert them into new or emerging markets. For DHS to develop disruptive technologies and successfully bring them to market, its leaders must understand the potential risks, cost implications, and schedule restraints inherent to the projects they undertake. In project management studies, these challenges are often referred to as the project management triangle, or triple constraint: scope, cost, and time. As illustrated in Figure 4, these constraints are interdependent of one another, and altering one will have a cascading effect on the other two. Moreover, all three elements are pulled together by one common force: project success.[175] While these identifiers are easily defined, they are difficult to quantify.

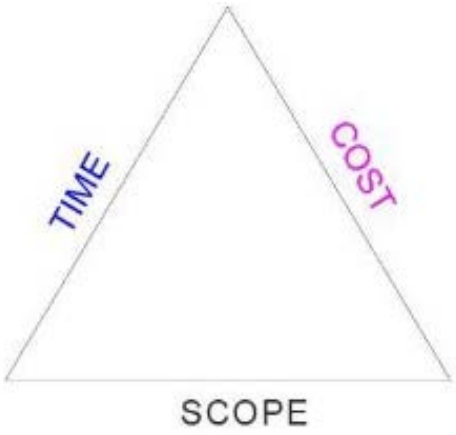

Figure 4. Project Management Triangle[176]

[175] Zaeem Ahmad Siddiqui, "Triple Constraint Theory / Project Management Triangle (PMT)," LinkedIn, May 16, 2015, https://www.linkedin.com/pulse/triple-constraint-theory-project-management-triangle-pmt-siddiqui.

[176] Source: Ibid.

Understanding that risk plays a factor in project completion allows for its inclusion as an element of scope. Scope is defined as "the functional elements that, when completed, make up the end deliverable for the project."[177] The risk factor, then, for DHS is project failure. Renewed investment toward a strategic foresight capacity to enhance our ability to address events twenty to thirty years away is an approach that may not provide an immediate return on investment. DHS policymakers must recognize that the solutions being developed today may not result in solving current problems. Moreover, the types of moonshot problems being addressed will likely result in disruptive change. Attempting this type of change leads to failure as often as it leads to success. If DHS is more interested in minimizing risk, then maintaining its current approach of incremental change may be the most prudent course of action. However, if DHS is willing to tolerate potential failures, the rewards will likely exponentially increase.

Time is a critical element at both XPRIZE and DARPA. These organizations define moonshot problems, leverage them with prize money, and challenge anyone to solve them within a tightly defined deadline. XPRIZE cites the degree of difficulty as a main driver behind establishing deadlines to its prize competitions. If a grand challenge is solved in a relatively short amount of time, the standards defining it as a moonshot problem are not high enough. Inversely, if it takes too long to solve, most people lose interest in the problem. Similarly, DARPA motivates innovation by creating temporary project teams. These teams are composed of high-caliber contractors or academics looking to solve a problem, not build a career. These individuals are motivated to urgently create innovative solutions within the time constraints of a fixed contract. This model may be most effective because it pressures problem-solvers to achieve what they set out to do, or risk termination of the project.

Of the three elements that make up the project management triangle, cost may be the most challenging to evaluate. When DARPA accepts proposals for projects, it does not establish a predetermined amount; rather, the organization requires an application that

[177] Tom Tsongas, "Scope, Time and Cost—Managing the Triple Constraint," *Program Success*, para. 5, May 2, 2011, https://programsuccess.wordpress.com/2011/05/02/scope-time-and-cost-managing-the-triple-constraint/.

justifies how much investment will be allocated to a given project. The application describes the project and budget, and DARPA funds projects based on rigorous scrutinization of the scope of work and the projected length of time to complete the project. S&T's fiscal year 2016 budget of $646 million demands a framework that meticulously defines the most important homeland security grand challenges.

Only through a thorough reconsideration of the S&T approach can DHS fulfill its mission of delivering innovative results that outpace the speed of evolving threats. R&D throughout DHS must be streamlined but also expanded to embrace personnel from across the enterprise. Further, policymakers must understand that the impetus for reform often occurs when there has been an unimaginable homeland security catastrophe. DHS was created out of the tragic events of 9/11. Hurricanes Katrina and Sandy, as well as the Orlando Nightclub shootings, have also contributed to changes in policy and doctrine. These legacy events provide DHS with an immediate snapshot of our country's current capacity to protect, mitigate, respond to, and recover from a catastrophic event. S&T needs to invest in long-term projects that will address potential legacy events twenty-five years in the future.

E. IN A WORLD OF GRAND CHALLENGES, OPTIMISM ABOUNDS

The world we live in has its set of problems. Immigration reform, evolving terrorist threats, and climate change are just a few of the global grand challenges facing the world today. If you narrow the challenges down by geographic area, you will likely discover that these sets of problems still exist in most parts of the world. In the United States, these challenges are very real and ostensibly increasing. Shifting demographics caused by globalization have reached the forefront of political and societal discourse. An unprecedented number of mass casualty incidents by both domestic and foreign actors lead nightly newscasts. Extreme weather patterns such as hurricanes, winter storms, flooding, and fires engulf the entire nation. However, the underpinning of every grand challenge has one common thread weaved through its complex fiber: optimism.

At its core, every grand challenge holds a basic belief that the future can be better than the past. Making a case for optimism in the 21st century is a challenge itself;

however, these drivers of change provide an opportunity for us to shape a new future based on our actions. Over the years, solutions to grand challenges have provided a glimpse into the extraordinary power researchers can have on the long-term trends impacting humanity. For example, FEMA's Strategic Foresight Initiative white paper, "Technological Development and Dependency," offers insight into the long-term ramifications of technology growth and its impacts on the HSE.[178] As technology continues advancing at an exponential pace and becomes increasingly accessible, the problems that specialized researchers require twenty-five years to solve may be solved more democratically and rapidly, and at less cost. Advances in robotics and drones, virtual and augmented reality, artificial intelligence, and the growth of the internet of things (IoT) will provide the HSE with new vulnerabilities and new opportunities.

Exponential growth in technology will present the HSE with bold and innovative new ways to address grand challenges. Advances in robotics and drones could open a new frontier for how emergency officials conduct response operations. For example, the life-risking task of a search and rescue team could be offset by a swarm of drones, pre-loaded with floor plans to navigate structurally unsound or collapsed buildings to search for survivors. As another example, virtual reality could augment expensive field training by providing powerful tools for learning hard and soft skills.[179] Finally, the IoT will have a direct impact on border, transportation, port, and maritime security, as well as the protection of critical infrastructure.[180] As Peter Diamandis has explained, "Imagine a world rapidly approaching a trillion sensor economy where the IoT enables a data-driven future in which you can know anything you want, anytime you want, anywhere you want.

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[178] "Technological Development and Dependency: Long-Term Trends and Drivers and Their Implications for Emergency Management," Strategic Foresight Initiative, May 2011, https://www.fema.gov/pdf/about/programs/oppa/technology_dev_%20paper.pdf.

[179] James R. Lint, "Virtual Reality Applications for the Military and Homeland Security," In Homeland Security, December 1, 2016, http://inhomelandsecurity.com/virtual-reality-military/.

[180] Marc Pearl, "How the Internet of Things Could Transform Homeland Security," *Federal Times*, April 19, 2016, http://www.federaltimes.com/articles/how-the-Internet-of-things-could-transform-homeland-security.

A world of instant, high-bandwidth communications and near perfect information."[181] The potential for our emergency response protocols is limited only by imagination.

Defining and addressing a grand challenge and creating disruptive change is only achieved when leaders are ambitious and audacious enough to depart from the trends of its market analysis and client demands. Leaders who invest organizational resources into long-term market opportunities have the foresight to take action today within the context of tomorrow. As Clayton Christensen writes, "disruptive technologies have fluid futures, as in, it is impossible to know what they will disrupt once matured."[182] DHS' current approach to grand challenges is local and linear when it should be global and innovative, harnessing the massive potential of the crowd to solve moonshot problems in previously unimagined ways. To solve the world's most critical problems, we must be willing to take risks and let our inspiration drive transformative change.

[181] Peter H. Diamandis, "Sensors & Convergence (Part 1)," *Tech Blog*, sec. "Networks and Sensors—Context," accessed December 13, 2016, http://www.diamandis.com/blog/sensors-convergence-part-1.

[182] Clayton Christensen, *The Innovator's Dilemma: When New Technologies Cause Great Firms to Fail* (Watertown, MA: Harvard Business Review Press, 1997).

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