AFRL-AFOSR-VA-TR-2018-0402

Air Force 2030 Science & Technology Organizational and Process Study at Northwestern University

Jay Walsh
NORTHWESTERN UNIVERSITY

10/05/2018
Final Report

DISTRIBUTION A: Distribution approved for public release.

Air Force Research Laboratory
AF Office Of Scientific Research (AFOSR)/ RTB2
Arlington, Virginia 22203
Air Force Materiel Command

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE *(DD-MM-YYYY)*: 28-09-2018

2. REPORT TYPE: FINAL

3. DATES COVERED *(From - To)*: 01-03-2018 - 28-09-2018

4. TITLE AND SUBTITLE
Northwestern University AFRL Science & Technology 2030 Initiative Business Organization and Process Study

5a. CONTRACT NUMBER

5b. GRANT NUMBER
FA9550-18-1-0302

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
Walsh, Joseph, T.; Cao, Jian; Dhar, Lisa; Kumar, Prem; Lippitz, Michael, J.; Loffler, Alicia; Moore, Nicole; Sawhney, Mohanbir; Werwath, Mark, W.; Wolcott, Robert, C.; Yehiely, Fruma

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
NORTHWESTERN UNIVERSITY
633 CLARK ST EVANSTON
EVANSTON IL 60208-0001

8. PERFORMING ORGANIZATION REPORT NUMBER
201809-NU01

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
USAF, AFRL DUNS 143574726
AF OFFICE OF SCIENTIFIC RESEARCH
875 NORTH RANDOLPH STREET, RM 3112
ARLINGTON VA 22203-1954
JULIA A. CARRICO 7036966564

10. SPONSOR/MONITOR'S ACRONYM(S)
AFRL

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
unrestricted

13. SUPPLEMENTARY NOTES

14. ABSTRACT
As part of the United States Air Force (USAF) “Science and Technology (S&T) Strategy 2030” study, this report presents the Northwestern University team’s findings and recommendations on business processes and organizational structures that have proven effective at promoting, supporting, and managing early stage research. The recommendations are organized around four themes, which were informed by: (1) interviews with AFRL personnel during an on-site visit to Wright-Patterson Air Force Base, (2) a workshop composed of internal/external expert discussions, and (3) the expertise and experience of the study team.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19b. TELEPHONE NUMBER *(Include area code)*
unclassified	unclassified	unclassified		64	Dr. Joseph Walsh / 847-491-3485

DISTRIBUTION A: Distribution approved for public release.

INSTRUCTIONS FOR COMPLETING SF 298

1. REPORT DATE. Full publication date, including day, month, if available. Must cite at least the year and be Year 2000 compliant, e.g. 30-06-1998; xx-06-1998; xx-xx-1998.

2. REPORT TYPE. State the type of report, such as final, technical, interim, memorandum, master's thesis, progress, quarterly, research, special, group study, etc.

3. DATE COVERED. Indicate the time during which the work was performed and the report was written, e.g., Jun 1997 - Jun 1998; 1-10 Jun 1996; May - Nov 1998; Nov 1998.

4. TITLE. Enter title and subtitle with volume number and part number, if applicable. On classified documents, enter the title classification in parentheses.

5a. CONTRACT NUMBER. Enter all contract numbers as they appear in the report, e.g. F33315-86-C-5169.

5b. GRANT NUMBER. Enter all grant numbers as they appear in the report. e.g. AFOSR-82-1234.

5c. PROGRAM ELEMENT NUMBER. Enter all program element numbers as they appear in the report, e.g. 61101A.

5e. TASK NUMBER. Enter all task numbers as they appear in the report, e.g. 05; RF0330201; T4112.

5f. WORK UNIT NUMBER. Enter all work unit numbers as they appear in the report, e.g. 001; AFAPL30480105.

6. AUTHOR(S). Enter name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. The form of entry is the last name, first name, middle initial, and additional qualifiers separated by commas, e.g. Smith, Richard, J, Jr.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES). Self-explanatory.

8. PERFORMING ORGANIZATION REPORT NUMBER. Enter all unique alphanumeric report numbers assigned by the performing organization, e.g. BRL-1234; AFWL-TR-85-4017-Vol-21-PT-2.

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES). Enter the name and address of the organization(s) financially responsible for and monitoring the work.

10. SPONSOR/MONITOR'S ACRONYM(S). Enter, if available, e.g. BRL, ARDEC, NADC.

11. SPONSOR/MONITOR'S REPORT NUMBER(S). Enter report number as assigned by the sponsoring/ monitoring agency, if available, e.g. BRL-TR-829; -215.

12. DISTRIBUTION/AVAILABILITY STATEMENT. Use agency-mandated availability statements to indicate the public availability or distribution limitations of the report. If additional limitations/ restrictions or special markings are indicated, follow agency authorization procedures, e.g. RD/FRD, PROPIN, ITAR, etc. Include copyright information.

13. SUPPLEMENTARY NOTES. Enter information not included elsewhere such as: prepared in cooperation with; translation of; report supersedes; old edition number, etc.

14. ABSTRACT. A brief (approximately 200 words) factual summary of the most significant information.

15. SUBJECT TERMS. Key words or phrases identifying major concepts in the report.

16. SECURITY CLASSIFICATION. Enter security classification in accordance with security classification regulations, e.g. U, C, S, etc. If this form contains classified information, stamp classification level on the top and bottom of this page.

17. LIMITATION OF ABSTRACT. This block must be completed to assign a distribution limitation to the abstract. Enter UU (Unclassified Unlimited) or SAR (Same as Report). An entry in this block is necessary if the abstract is to be limited.

REPORT

AFRL SCIENCE & TECHNOLOGY 2030 INITIATIVE

BUSINESS ORGANIZATION & PROCESS STUDY

Grant / AFRL FA9550-18-1-0302
Principal Investigator / Jay T. Walsh

NORTHWESTERN UNIVERSITY
EVANSTON, IL
SEPTEMBER 28, 2018

UNCLASSIFIED

Northwestern

This material is based upon work supported by the
Air Force Office of Scientific Research
under award number FA9550-18-1-0302

FINAL TECHNICAL REPORT

AIR FORCE SCIENCE & TECHNOLOGY 2030 INITIATIVE

BUSINESS ORGANIZATION & PROCESS STUDY

AFRL FA9550-18-1-0302

NORTHWESTERN UNIVERSITY
EVANSTON, IL
SEPTEMBER 28, 2018

STUDY PRINCIPAL INVESTIGATOR

Jay T. Walsh // Vice President for Research, Northwestern University

CO-INVESTIGATORS

Jian Cao // Associate Vice President for Research
Lisa Dhar // Director, New Business Ventures for Engineering, Innovation & New Ventures (INVO)
Prem Kumar // Professor, Electrical Engineering and Computer Science
Michael J. Lippitz // Principal, Clareo
Alicia Loffler // Associate Provost, Innovation & New Ventures (INVO)
Nicole M. Moore // Director, Office of Research Development
Mohanbir S. Sawhney // Clinical Professor, Marketing
Mark W. Werwath // Clinical Associate Professor, Industrial Engineering and Management Sciences
Robert C. Wolcott // Clinical Professor, Innovation & Entrepreneurship, Kellogg at Northwestern
Fruma Yehiely // Associate Vice President for Research

LIST OF PARTICIPANTS

Nicholas Angeloni // Director, Strategic Planning and Coordination, Office for Research, Northwestern
Iqbal Arshad // Senior Vice President, Mobile Products, Lenovo
Suzanne Bell // Professor, Industrial & Organizational Psychology, DePaul University
James Bellingham // Director, Center for Marine Robotics, Woods Hole Oceanographic Institute
Pushpalatha Bhat // Senior Scientist, Particle Physics Division, Fermilab
Kent Bostick // Deputy Director, National Security Programs, Argonne National Laboratory
Jim Bray // Director, Corporate Engagement, Northwestern
Karen Cielo // Senior Associate Director, Office of Research Development, Northwestern
Tim Collins // Chief Technology Officer, RF IDeas, Inc.
Paul Collopy // Professor, Industrial & Systems Engineering and Engineering Management, University of Alabama
Clark Cooper // Senior Advisor for Science, Directorate for Mathematical and Physical Sciences, National Science Foundation
Thomas Day // Founder, Invent2026
Frank Donnelly // Strategic Advisor, Financial Management, Air Force Research Laboratory

Mitra Dutta // Vice Chancellor for Research, University of Illinois at Chicago
Gabi Edgerton // Technical Writer, Red Pen Scientific, Inc.
Dan Friend // Senior Army Fellow, Kellogg at Northwestern
Jay Harrison // Chief Innovation Officer, Army Futures Command Task Force, US Army
Gretchen Jordan // Principal, 360 Innovation LLC
Luciano Kay // Research Associate, Institute for Social, Behavioral, and Economic Research, University of California Santa Barbara
Steven Lauver // Deputy Director, A8XP Innovation Branch, US Air Force
Peggy Matson // Director & Clinical Professor, Graduate Studies in Engineering Management and Project Management, Washington University in St. Louis
Megan McConnell // Program Assistant, Office of Research Development, Northwestern
Rebecca McNaughton // Assistant Director, Office of Research Development, Northwestern
Robert Mittman // Founder, Facilitation | Foresight | Strategy
Kirt Moser // Deputy Director, Center for Rapid Innovation, Air Force Research Laboratory
Ruth Moser // Director, Sensors Directorate, Air Force Research Laboratory
David Rosen // CEO & Founder, TechX Foundry
Rudyard Sadleir // Business Development Executive, Argonne National Laboratory
Bill Seng // Manager, AS&T Portfolio Deputy/Assurance, Sandia National Laboratories
Ned Smith // Associate Professor, Management and Organizations, Kellogg at Northwestern
Michael Stroscio // Professor, Electrical & Computer Engineering, Bioengineering, and Physics, University of Illinois at Chicago
Mark Tschopp // Regional Director, ARL-Central, Army Research Laboratory
Anthony Weeks // Graphic Recorder, Five Elements Consulting Group
Gerald Whittaker // Strategy Consultant, Scoop & Associates, LTD / Air Force Research Laboratory, Phillips Research Site at Kirtland, NM
Brian Zuckerman // Research Staff Member, Science and Technology Policy Institute, Institute for Defense Analyses

EXECUTIVE SUMMARY

Background & Methodology

As part of the United States Air Force (USAF) "Science and Technology (S&T) Strategy 2030" study, this report presents the Northwestern University (NU) team's findings and recommendations on business processes and organizational structures that have proven effective at promoting, supporting, and managing early stage research. The recommendations are organized around the four themes listed below, which were informed by: (1) interviews with AFRL personnel during an on-site visit to Wright-Patterson Air Force Base, (2) a workshop composed of internal/external expert discussions, and (3) the expertise and experience of the NU study team.

- *Identifying Research Areas* and adjusting as S&T evolve and new goals/missions emerge.
- *Measuring Return on Investment* (ROI) in diverse research fields and project types.
- *Optimizing Organization Structure* (governance, leadership, and recruitment) to facilitate agility and support innovation.
- *Optimizing S&T Strategy* based on mission, opportunities, and resources.

A Call for Change

USAF Site Visit. USAF personnel emphasized the need for flexibility to establish and adjust the S&T portfolio in response to changing technology and missions. Challenges include insufficient communication and program coordination, absence of standardized project evaluation criteria, unclear high-level strategy, and suboptimal personnel recruitment.

Identifying Research Areas. The competitiveness of the USAF relies on accurately identifying early stage research areas that align with strategic goals and readily evolve in response to scientific progress and discovery (as well as new goals). The NU team recommends an integrated approach that blends 3 models: (1) a <u>problem-focused</u> model that supports applied research directly aligned with well-specified challenges; (2) a <u>discovery-based</u> model that supports exploratory projects in new fields relevant to the USAF mission; and (3) a <u>challenge current thinking</u> model based on fostering an organizational culture that questions assumptions to identify new directions of potentially breakthrough research.

Measuring Return on Investment. Novel or emerging technologies will not always have clear applications, and the "value" of a given technology may be differently assessed by funders versus users. The NU team recommends <u>a broad approach to measuring ROI</u> using metrics from leading research institutions. Metrics should accommodate technologies developed in response to a requirement (problem-focused research), as well as those developed in anticipation of future needs or those that have no clear current application (discovery-based research). In addition, such metrics, must consider the impact of the technology on resource and personnel pipelines. Relevant models identified include overall S&T strategy assessment, key performance indicators, and contribution analysis.

Optimizing Organization Structure. Organization structures can simplify access to knowledge and intelligence, help attract and engage a world-class workforce, and enhance synergy among various efforts. Structures should be selected based on different project types, goals, and objectives and may overlay the existing organization structure and foundation. The NU team identified 3 models that each encourage innovation in different ways: (1) the <u>challenge-driven teams</u> model, in which groups are assembled with a clear purpose or strategic direction; (2) the <u>enabler</u> model, in which leadership directly supports entrepreneurial efforts by employees; and (3) the <u>affinity networks</u> model, in which virtual organizations are created via a shared immersive or inspirational experience to establish connections and valuable collaborations.

Optimizing S&T Strategy. The overall S&T strategy for USAF requires an interconnected approach that allows for the continuous reevaluation of future needs and identification of weaknesses, disruptive opportunities, and threats. The NU team identified 3 strategic approaches that can be applied in combination to achieve USAF goals: (1) trend mapping to define the future landscape of needs and influences; (2) backcasting to develop a roadmap that proactively moves towards a desired future; and (3) establishing and supporting institutionalized dissent (i.e., "red teams") aimed at identifying risks and guarding against group-think.

The identified models for each theme fall into 4 broad, cross-cutting ideas:

1. Problem-focused approaches should be used to develop a roadmap that proactively moves towards a desired future. These approaches support applied research that is directly aligned with well-defined challenges, and should be implemented with (among other methods) challenge-driven teams and, where appropriate, backcasting.
2. Discovery-based approaches should be used to support exploratory projects in new fields relevant to the USAF mission, using trend mapping as needed to define the future landscape of needs and influences and, as appropriate, creating and leveraging affinity networks.
3. Challenge current thinking approaches should be used to foster an organizational culture that questions assumptions. These approaches should include red teams aimed at identifying risks. Supporting entrepreneurial efforts by employees, i.e., the enabler model, can play an important role in changing the organizational culture by creating an outlet for ideas that are out of the scope of existing programs.
4. Broad approaches to measuring ROI, based on metrics from leading research institutions, should be used to support decision making in all of the above approaches. ROI models must cover not only outcomes but also general innovation capabilities, including people (research talent), tools, patents, and knowledge communities/networks.

Transformational Necessities

Collectively, these various models and approaches support 3 overriding, mutually reinforcing objectives for USAF:

- Remove obstacles that stifle innovation. Specific recommendations include: lightening the touch of programmatic oversight, streamlining and improving contracting and external partnerships, and enhancing linkages with commercial venturing mechanisms like accelerators and incubators.
- Be a learning organization. Specific recommendations include: encouraging an environment of psychological safety through programs offering incentives and recognition, implementing sunsetting mechanisms to standardize the ways programs are evaluated over time and to support institutional "unlearning" of inhibitory standard practices, and developing narratives that trace breakthroughs back to basic research.
- Attract the best people. Specific recommendations include: increasing diversity through enhanced outward facing communication and networking efforts, funding people rather than projects to facilitate long-term relationships with high-performing researchers, offering graduate education fellowships in exchange for a commitment to serve within USAF research organizations, and bringing USAF research organization to the talent via urban outposts or similar efforts.

Removing obstacles to innovation and proactively implementing structures and processes that facilitate continuous learning will help USAF attract the best people—those most likely to drive innovative outcomes and breakthrough and sustain a learning, agile culture. The team recognizes that USAF may be implementing aspects of these models already.

TABLE OF CONTENTS

Page intentionally left blank

1. INTRODUCTION AND STUDY METHODOLOGY

1.1 Overview and Objectives

In September 2017, Secretary of the Air Force Heather Wilson announced inception of the "Science and Technology (S&T) Strategy 2030" study aimed at updating US Air Force (USAF) methods for conducting research and development to meet projected security challenges. Northwestern University (NU) participated by identifying appropriate business processes and structures to manage organizations like the Air Force Research Laboratory (AFRL), based on interviews with USAF personnel on site at Wright-Patterson Air Force Base, a workshop composed of internal/external expert discussions, and the expertise and experience of the NU study team.

The NU study focused on 4 themes identified by the AFRL, as applied to early stage research:

- *Identifying Research Areas* and adjusting as S&T evolve and new goals/missions emerge.
- *Measuring Return on Investment* (ROI) in diverse research fields and project types.
- *Optimizing Organization Structure* (governance, leadership, and recruitment) to facilitate agility and support innovation.
- *Optimizing S&T Strategy* based on mission, opportunities, and resources.

1.2 Definition of Terms

The USAF tasking for this study asked for input on processes and organizational structures to support **early-stage research**. In the Department of Defense (DOD), these early stages are categorized as Budget Activity 1 (BA1), BA2, and BA3. BA1 (sometimes denoted as 6.1) is referred to as "basic research". BA1 research is defined by DOD as "systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and/or observable facts without specific applications…in mind."[1] BA2 (or 6.2) is "applied research" for the "systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met." BA3 ("advanced technology development") is about the "development and integration (of technology)…for field experiments and tests." "Science and Technology" (S&T), as defined by the US government, includes BA1, BA2, and BA3.

Within the context of S&T research, we use the term **innovation** to refer to research results that are groundbreaking, unexpected, novel, or that otherwise advance knowledge beyond existing paradigms.[2] Innovation is key to maintaining a competitive edge to best respond to future needs. This study focused on practices that support *innovative early-stage research.* Therefore, this report's use of the term innovation is distinct from its definition in a commercial context (i.e., the creation of value, not just invention/discovery).

Ensuring a high level of **agility** at the institutional level became a cross-cutting theme of our discussions. Within this context, agility refers to the ability to rapidly and effectively respond to a changing landscape, recognizing emerging factors that suggest a shift in course and then having the flexibility to devote resourced attention to support the new direction.

Our recommendations focus on **models** that describe effective business processes and/or organizational structures that work to promote agility or innovativeness. The models—drawn largely from the private

[1] DOD Financial Management Regulation, DOD 7000.14-R, Vol 2B, Ch 5.
[2] Elsewhere in the literature such innovation might be referred to as "radical" or "breakthrough" to distinguish it from "incremental" or "sustaining" innovations that represent extensions and refinements of known approaches and understandings that fit existing organizational divisions.

sector—are meant to serve as examples that can be adapted to the AFRL context as part of a portfolio of strategies to achieve USAF goals. We recognize the USAF may already be implementing aspects of these models.

This report summarizes the findings into 2 areas “A Call for Change” and “Transformational Necessities” as requested by the USAF. **A Call for Change** includes examples of business processes and organizational structures best suited to managing early-stage research and rapidly adopt technologies. **Transformational Necessities** are practices necessary to adopt the systems/processes laid out in these examples.

1.3 Site Visit

Seven members of the NU study team, divided into 2 groups, interviewed 28 USAF personnel at Wright-Patterson Air Force Base on April 9, 2018 (See Appendix A for agenda and participants). Interviewees identified several strengths and challenges in each of the 4 thematic areas, and these were discussed at weekly meetings with the broader NU study team and during the workshop to help identify and prioritize recommendations within the four thematic areas.

1.4 Workshop Methodology

On June 1 and June 2, 2018, the NU team convened 45 participants with diverse backgrounds and expertise from the academic, commercial, and government sectors (see Appendix B for workshop agenda). Participants were chosen based on their academic expertise, professional background and experience, specialized knowledge of DOD and other federal research enterprises, and a commitment to assisting the USAF to identify key ideas, concepts, and approaches for managing early stage research and exploiting the rapidly changing S&T landscape.

The group was charged with generating recommendations for how the USAF should design their research efforts today to most effectively anticipate and meet national security requirements in the year 2030 and beyond. Participants were asked to organize their thoughts and feedback around 2 main objectives:

1. Identify best practices and/or next practices that can be adopted at an institutional level to encourage innovation and agility;
2. Think about how examples from other sectors might be applied to the practice of research within the USAF.

Following a roundtable discussion, participants were led in structured brainstorming sessions around the 4 focus themes. Then 4 breakout groups (one for each theme) of ~10 people (and at least 2 participant-facilitators) came up with 2-5 models or approaches that could be used to support the USAF in meeting its research goals. For each model, groups specified advantages and disadvantages, examples from other sectors of how the model has been implemented in the past, and key considerations regarding the models’ scope and applicability.

On day 2, the larger group reconvened to view the output of each breakout session. Breakout group facilitators presented to small groups during a “round-robin” period so that all participants had the opportunity to provide specific feedback on the models being developed within each focus theme. This also set the stage for a larger group discussion of priorities and cross-cutting themes.

Immediately following the round-robin session, participants were invited to “vote” for up to 3 models across all themes that they felt best support institutional agility or best support mission-driven research scenarios. Some models had strengths in one or the other category while others received roughly equal votes for both categories. The results served as a jumping-off point for the final roundtable discussion.

At the closing session, participants offered their thoughts on a single "most important" recommendation they felt should be included in the study report (Figure 1). Ideas, discussion points, data, and conclusions from the entire workshop were recorded and have been incorporated in this final report. Appendix C provides picture of the graphical recordings created based on workshop discussions in real-time.

Figure 1. A graphical representation, generated in real-time, of the final roundtable discussion at the workshop held on June 1-2, 2018.

Page intentionally left blank

2. A CALL FOR CHANGE: IDENTIFYING RESEARCH AREAS

2.1 Introduction

Effectively managing a research portfolio—including initiating new research areas and ramping down efforts in others—is key to an agile and innovative S&T organization. This section describes best practices to determine and prioritize research areas that continually evolve based on progress in science and, technology, as well as societal, and customer needs. It identifies 3 models that research enterprises, including AFRL, are using to inform their decision as to when to ramp up/down investments in particular research areas. The hope is that this discussion will help inform the balance of such approaches in the future and help identify ways to transition successes in basic research into applied research projects with well-defined milestones and timelines.

The first model addresses on-the-ground challenges; the second focuses on emerging research areas and technologies; and the third involves building a culture that fosters and protects innovative thinking. All 3 require a partnership among the military, research institutions, and industry, for each brings a unique set of perspectives and skills to the table: the military branches know their unmet needs, research institutions know scientific and technological advances that have promise in addressing those needs, and industry has the insight into how to best commercialize for rapid deployment in the field. While these models can stand individually, each has a set of strengths that compensates for the weaknesses of the others. Thus, the team recommends an integrated and combined approach that leverages the strengths of each model to manage the research portfolio. These models, tightly coupled to a larger goal, will result in a whole that is substantially more than the sum of its parts.

2.2 Problem-Focused Research

This first model is highly problem-focused and involves applied research dedicated to current, on-the-ground challenges faced by personnel in the field. Scouts identify field challenges, then research areas and teams are chartered to address those specific problems or needs. This is a top-down approach, within which needs and priorities are dictated from leadership while maintaining a customer-present strategic vision. There is clear alignment between this approach and AFRL needs and objectives.

2.2.1 Scope and Applicability

This model is designed to solve immediate problems and is most appropriate for BA2 applied research. Discoveries will tend to be incremental—mostly adapting existing technology—but will more quickly translate to the field. Immersing researchers or technology scouts in the field increases communication and bridges the gap between research advancements and needs.

2.2.2 Advantages and Disadvantages

The value of problem-focused research is easy to appreciate, as it has direct relevance to problems faced by personnel in the field. This focus allows for more rapid technology advancement. In addition, success and failure are clear: either the project solves an on-the-ground problem or it does not. Work here may lead into advanced technology development (BA3) if there is inherent commercial value.

Problem-focused research comes with the disadvantage of potentially missing emerging, so-called "blue skies" research areas, as it does not leave much room for exploratory studies or truly open innovation. In addition, this type of research output is generally iterative, refining or expanding upon existing processes, rather than disruptive. Thus, the potential to trigger paradigm shifts or reveal completely new ways of approaching a problem is limited, though there is always the possibility of serendipitous discovery.

2.2.3 Best Practices and Next Practices

There are several examples from both the government and the private sector of how to best implement problem-focused research. In problem-focused research, cross-disciplinary teams actively engage the customer and are given room to create a solution to a technological challenge (see Section 4.2 for information on best practices for the organization structure of challenge-driven teams). In examples below, “scouts” or groups of people familiar with the challenges are surveyed to gather intimate knowledge of acute research needs and problems. These are communicated to research teams via solicitations or strategic reports. Within the context of AFRL, this could take the form of scouting teams comprising: (1) a representative of AFRL or similar research institution to relate the current state of research and current research projects to AFRL goals and objectives; (2) a senior USAF official or officer familiar with current USAF technology challenges; and (3) an industry representative familiar with the market who can speak to commercialization potential. The goal of these teams would be to identify precise technology challenges, address the challenges in the laboratory, and build out a solution quickly to equip the warfighter as rapidly as possible. Below are some specific examples of best practices from industry and government.

General Electric's Fastworks Program. The Fastworks program is based on the "The Lean Startup" methodology[3]. This program devotes a significant amount of time to customer discovery and understanding the customer’s needs. Problems to solve are drawn from this customer input. A team develops hypotheses relevant to possible solutions, and then conducts targeted tests of these hypotheses.

National Cancer Institute’s (NCI) Provocative Questions Program. In 2011 the National Cancer Institute (NCI) established the Provocative Questions Initiative to support research projects that solve specific problems and paradoxes in cancer research. NCI identifies so-called "Provocative Questions" (PQs) through a series of workshop seminars hosted around the nation and through the website. The call for research in response to PQs is funded via grants awarded to single-investigators or research teams.

BP Grand Challenges. In 2012, BP’s office of the chief technology officer (CTO) undertook the first of what became known as “Grand Challenges:” extremely difficult business problems with the potential to create hundreds of millions—or billions—of dollars in business value if solved.[4] After searching various online solutions and IP markets (NineSigma, OmniCompete, and Iprova), BP hosted an ideation and collaboration workshop with external experts and internal leaders carefully chosen for their complementary skillsets and viewpoints. The group included distinguished professors and scientists from a variety of disciplines and organizations, as well as out-of-the box thinkers, inventors, and pragmatic corporate leaders.[5] The workshop was designed around the concept that important, innovative solutions lie at the intersection of multiple domains and perspectives, and that such solutions can best be found by creating an environment in which basic beliefs, assumptions, and conventional thinking can be constructively challenged. The workshop produced 42 new ideas. After rigorous evaluation, the ideas were prioritized and shortlisted. The most promising and executable ideas were incorporated into the top tier of BP’s five-year technology plan. This ideation event was successful because it clearly defined the problem to be solved,

---

[3] Kellner, Tomas. “The Biggest Startup: Eric Ries and GE Team Up to Transform Manufacturing,” GE Reports, December 9, 2013. (https://www.ge.com/reports/post/82723688100/the-biggest-startup-eric-ries-and-ge-team-up-to/)

[4] This section is excerpted from Robert C. Wolcott and Michael J. Lippitz, “BP’s Office of the Chief Technology Officer (B): Driving Open Innovation Through an Advocate Team” (Kellogg School of Management Business Case and Teaching Note 5-407-752(B), 2015).

[5] Participants were not paid, other than reimbursement for travel expenses. The attraction of the event was the caliber of the attendees and the opportunity to interact with an interesting and diverse group with a passion for advancing and applying knowledge. Egos were put aside as minds opened and people became engrossed in finding creative solutions. As one workshop participant expressed it, “[This workshop was] very different from those I normally attend: highly informative, stimulating, and energetic.”

involved a highly curated team of participants, provided the necessary stimulus for ideation, encouraged free thinking and trust among participants, and ended with clearly defined next actions.

Defense Advanced Research Projects Agency (DARPA). DARPA programs are examples of high-risk, problem-driven research. Rotating DARPA program managers act as scouts on the ground assessing problems and needs. Teams are established with clear milestones and goals in mind, and research progress is assessed regularly. Through the DARPA Young Investigator Program (YIP), extramurally-funded researchers can gain on-the-ground experience through DOD site visits. These visiting programs have added tremendous value, leading other institutions to try to copy this model.

2.3 Discovery-Based Research

The discovery-based research approach is designed to balance pure discovery with mission-driven research. The expectation is that "blue skies" research projects in fields relevant to an organization's mission will lead to advances and novel technologies that can be translated to relevant applications. Brainstorming and creative thinking is highly encouraged. The larger goal is still important and informs the supported research areas, but there is greater latitude in the types of projects supported. Within the context of AFRL, this approach addresses the need to stay ahead of the competition/adversary. A constant infusion of new ideas is critical to achieving that goal.

As in the previous model, technology scouts are important in implementing discovery-based research. However, in this case scouts identify new/emerging areas of research. Rotating the individuals used as scouts can help maintain a fresh perspective and promote cross-pollination among different fields. In addition to scouting, it is especially important to benchmark the competition—an adversary—to anticipate their strengths and what fields may be necessary to counter them. Disruptive rather than iterative ideas are encouraged to best maintain competitiveness. To implement these processes, it is crucial to have leadership that understands these challenges.

2.3.1 Scope and Applicability

This model is amenable to basic research, including research contracted out to universities and research groups that maintain ties to the military. Researchers must still have an understanding of on-the-ground problems and research fields should be chosen with the end user in mind. However, within those fields, basic studies with no defined application should be encouraged to maximize the potential for discovery. Flexibility and time needs to be given to researchers for these more open-ended, discovery-based research projects (see enabler model in section 4.3).

2.3.2 Advantages and Disadvantages

Advantages of discovery-based research include a high likelihood of breakthroughs in unexpected places. Focusing on new fields of research will generate significant new knowledge. In addition, this approach can strengthen an organization's workforce, as it tends to attract particularly creative thinkers by providing an unrestrained environment. Freedom to pursue one's own ideas and interests is attractive from a recruiting standpoint and allows an organization to more effectively compete for the best talent.

Disadvantages of this model include a high and/or ambiguous failure rate. Projects may never generate actionable output or any results relevant to current needs or problems. For this reason, the metrics of success are challenging to outline and hard to track.

2.3.3 Best Practices and Next Practices

Below we describe 3 distinct examples of approaches that fall under the discovery-based research model for identifying research areas. Each approach solicits input from experts, cross-disciplinary teams, or data to identifying emerging research areas.

Horizon Scanning. Horizon scanning is a technique used to explore novel and unexpected issues or emerging trends. Horizon scanning can be done manually or via increasingly automated approaches (Figure 2).[6] In one example, the Australian and New Zealand scientific funding agencies have established the Australasian Joint Agencies Scanning Network (AJASN).[7] AJASN consists of a database of 10,000 articles, peer-reviewed and new stories, hand-selected by each agency (~20 articles per quarter per agency). The articles cover early science developments and issues under debate. The database helps detect weak signals of potential advancements and is used to make forecasts about programs that may need to be amended. In another example, Pepsico has established a 4 component system to scan emerging technologies. The first 2 stages are people focused (interviews with senior executives and using external consultants to scan for weak signals via the Delphi Technique, see section 4.3). The team then takes weak signals and builds a tree of 1st, 2nd, and 3rd stage impacts and runs workshops with futurists and creatives to refine predictions of emerging trends.[8]

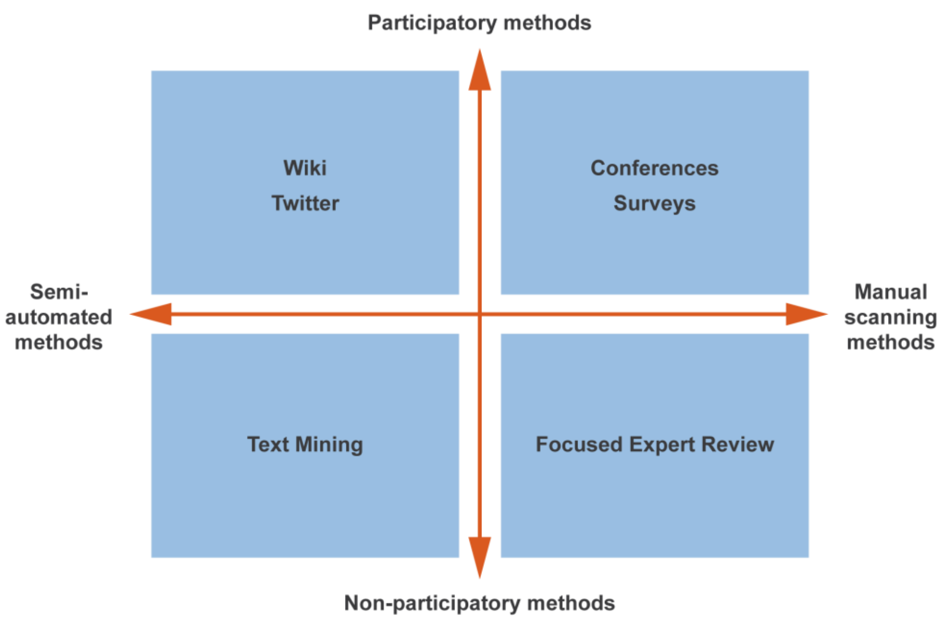


Figure 2. Various methods used in horizon scanning. (Adapted from Amanatidous et al. 2012)

The Sandpit/Ideas Lab. The sandpit approach was conceived by the Engineering and Physical Sciences Research Council (EPSRC) in 2003 to generate more innovative bottom-up research proposals in emerging areas. Sandpits are 5-day events with 20-30 invited participants from different disciplines and organizations. During the week, the group is guided by professional facilitators to work in teams to generate novel

[6] Amanatidou et al. "On concepts and methods in horizon scanning: lessons from initiating policy dialogues and emerging issues." Science and Public Policy 39 (2012) pp. 208–221

[7] http://www.ajasn.com.au/

[8] Farrington, Ted; Henson, Keith; Crews, Christian. "Research Foresights: The Use of Strategic Foresight Methods for Ideation and Portfolio Management," Research-Technology Management, 2012, Vol 55, Issue 2, Pages 26-33. (https://doi.org/10.5437/08956308X5502023)

interdisciplinary proposals. This approach tends to generate innovative, high-risk research proposals that would be unlikely to get funded through traditional study sections. Previous sandpits have addressed topics such as ensuring digital privacy and consent, using big data to obtain knowledge, understanding uncertainty in climate predictions, and detecting terrorist activity. Other UK- and US-based research organizations have adopted the process, including the Technology Strategy Board (now known as Innovate UK), the Natural Environment Research Council (NERC), the National Science Foundation (NSF), and the National Institutes of Health (NIH).[9]

Open Calls for High Risk Proposals. In 2004, the National Institutes of Health (NIH) started a high-risk, high-reward research program to accelerate the pace of discovery by supporting exceptionally creative scientists pursuing highly innovative research. The program seeks to identify scientists with high-impact ideas that may be risky or at a stage too early to fare well in the traditional peer review process. The program is independent of any specific institute or program, thus encouraging out-of-the box ideas relevant to any part of the NIH mission.[10]

2.4 Challenge Current Thinking

The challenge current thinking model focuses on organizational attitudes that can help identify promising, or ill-fated, research areas with an emphasis on a "bottom-up" approach. Assumptions can drive the implementation of technology, and often the direction of research moving forward. Some these assumptions are long-held and deeply embedded in current practice even though they may no longer be relevant. Challenging such assumptions can lead research in new directions, increasing the potential for breakthrough technologies. While a top-down approach is useful in identifying broad research areas, innovative solutions often come from the bottom-up. They arise from individuals or units who are empowered to challenge assumptions. Thus, the likelihood of revealing a novel or paradigm-shifting idea increases when more people have a chance to participate and offer their ideas. Many DARPA programs are based on this approach.

The challenge current thinking model relies on an established culture of perceived psychological safety. Interestingly, when Google studied hundreds of their teams to figure out why some stumbled while others thrived (Project Aristotle)[11], they found that psychological safety, more than anything else, was critical to making a team work. Psychological safety has been an important discussion area in the fields of psychology, management, healthcare, and behavioral management. It should be noted that leadership buy-in is critical to establish and maintain a culture of psychological safety.

2.4.1 Scope and Applicability

This model can be applied to both basic and applied research. The practice of challenging current thinking would benefit both defined, applied research and "blue skies" basic research. Within the context of AFRL, any successful strategy will need to involve regular, systematic reevaluation and realignment of priorities. A method through which current ideas can be challenged is crucial to that process.

2.4.2 Advantages and Disadvantages

Challenging existing thinking enables breakthroughs by exposing research paths that may not have been considered previously. This approach can also help promote recruitment and retention of talent because all

---

[9] https://knowinnovation.com/expertise/facilitating/
[10] https://commonfund.nih.gov/highrisk/
[11] Duhigg, Charles. "What Google Learned From Its Quest to Build the Perfect Team," New York Times, February 25, 2016. (https://www.nytimes.com/2016/02/28/magazine/what-google-learned-from-its-quest-to-build-the-perfect-team.html)

team members feel like they have a voice in the process. In implementing this type of approach, an institution will likely take on more high-risk, high-reward research projects, which are, by definition, both potentially advantageous and disadvantageous. It also requires a more long-term shift in culture towards one in which individuals feel psychologically safe enough to offer ideas, questions, concerns, or make mistakes without fear of punishment or humiliation.[12] Thus, this shift involves significant investments of time and other resources to achieve. Leadership at the highest levels must support this model for it to succeed.

2.4.3 Best Practices and Next Practices

This model is best implemented by focusing, engaging, and listening to talent. Diverse and inclusive teams are a must; everyone in the organization must have an opportunity to participate. New ideas come from fresh perspectives, which is why boundary spanners—individuals who can provide a bridge across different disciplines—are essential, as are rotating non-experts who may ask questions not apparent to those fully involved in the field. Eric Ries's "The Lean Startup" describes how this model can be implemented. He suggests that it is not possible to obtain "unfiltered" truth from the top levels of the organization. Thus, it is necessary to involve everyone from the bottom-up to thoroughly consider all aspects of the research process.[13]

Breaking into new research areas and changing paradigms often requires a critical mass of resources and people. The idea is that a few years later, as more people recognize the value and promise of the new area, this activity will start attracting other money or begin generating useful output. Two national labs have developed systems to protect and support emerging and provocative ideas. The high energy physics research group at FermiLab periodically conducts a community-wide process to identify investments for the next 20-50 years. Simulations and calculations are performed in a sandbox environment to achieve consensus on research directions. In a novel approach, the Pacific Northwest National Laboratory (PNNL) established an internal research and development (IR&D) fund to support a hub of more than a dozen internal principal investigators (most devoting part time to the effort with the exception of a single full-time lead PI) to explore new areas for research. In addition to the PIs, an external advisory committee reviews the exploratory activities, and in the end, recommends a set of activities to fund.

Bringing in fresh perspectives also helps to challenge current thinking within the organization. The two-year Defense Science Study Group (DSSG) program invites mentee-mentor pairs with no previous experience conducting defense-funded research to attend immersive, secret-cleared site visits to various DOD installations. Through these visits researchers gain first-hand knowledge of the challenges faced by frontline troops that will ultimately inform their thinking when coming up with research proposals. With this external perspective, DSSG scientists will ideally be more likely to challenge current paradigms.

[12] Edmondson, Amy. "Psychological safety and learning behavior in work teams," Administrative Science Quarterly, 1999, Vol 44, Issue 2, Pages 350-383.
[13] Ries, Eric. (2011) *The Lean Startup*. New York, NY: Random House, Inc.

3. A CALL FOR CHANGE: RETURN ON INVESTMENT

3.1 Introduction

Carefully made investment decisions at key decision points in the S&T process are the essence of good stewardship and good portfolio planning. Return on investment (ROI) techniques, tailored to measure performance of research programs or organizations, help inform these decision-making processes.

The key to a satisfactory ROI is assessing research alongside its applications or objectives. Towards this end, it is useful to distinguish types of research programs, such as discovery-based (section 2.3) or problem-focused research programs (section 2.4). Discovery-based research is proactive: research and technology development precedes application understanding. Hence, not all the applications will be apparent or relevant to the organization. Indeed, discovery-based research often leads to unforeseen outcomes. In contrast, problem-focused research is more reactive and assures better mission alignment. However, the impact on applications may still be difficult to quantify, particularly when the value to the mission does not relate to more traditional commercial measures of success. Moreover, reactive efforts are likely to lead to technology discoveries that are narrower and perhaps less valuable overall.

In addition to considering the type of research, the method for developing and evaluating ROI will vary depending on the following factors:

- Audience. The definition of value changes depending on the audience (i.e. U.S. Congress, AFRL, the warfighter, the scientific community). For example, congress may focus on technology applications—particularly those that impact businesses in their districts or states—and make funding decisions on that basis, while AFRL needs to consider its innovative capacity as a whole; perhaps valuing such contributions over individual innovations.
- Value of direct vs. indirect outputs. In addition to direct research outputs, such as publications, patents, and technology, laboratories develop general capabilities: people (researchers), tools, knowledge, and communities of practice that are indirect outputs of research efforts. These general "innovation capacities" underlie future technology discoveries and impact the economy but do not have a direct impact on the research objective. The importance of these outputs needs to be defined.
- Scale. Time (short vs. long) and scale within the organization (single project vs. organization as a whole) should be clearly defined and considered when evaluating ROI. These factors influence the choice of approach and/or indicators used to measure ROI.

The team identified 3 different types of models to address these factors. To be successful, any approach must also align with research areas (section 2) and strategy formulation (section 4). A multi-faceted approach ensures that measurements of ROI help facilitate the decision-making process. Thus, integrating these models is recommended.

1. Measuring the effectiveness of the overall S&T strategy. In this approach, the ROI is developed and evaluated in connection with the overall S&T strategy of the organization. This model assesses the organization as a whole, is applicable to multiple audiences, accommodates different types of research programs, and can focus on both short term and long term progress.
2. Using Key Performance Indicators (KPIs). In this approach, ROI is based on key performance indicators highly tailored to specific programs, objectives, or values. KPIs are measurable outputs ideally identified at the start of each new program or objective. Different evaluation processes can be established based on specific KPIs.
3. Contribution Analysis. Contribution analysis is used to attribute outcomes or value to initial discoveries or organizational approaches.

3.2 Measuring Effectiveness of S&T Strategy

This model entails developing and regularly evaluating performance objectives and indicators based on the organization's strategic plan. The ability to measure performance is linked to making good management decisions, thus an engaged leadership is required. Management and stakeholder feedback are incorporated into the review process to refine the organization's strategy. Performance objectives embedded in the organization's strategic plan are used to measure progress. Performance objectives for research will be stated as scientific questions to answer and/or technological challenges to overcome. Reviews can focus on either short term (e.g., quarterly) or long-term (e.g., annual) progress. In all cases, performance evaluations must take into account the inherent uncertainty of S&T research.

3.2.1 Scope and Applicability

Evaluating ROI based on organizational strategy can be applied to discovery-based or problem-focused research programs. The key is that the metrics are based on the nature of the activities as well as their relationship to the larger innovation system.

3.2.2 Advantages and Disadvantages

Performance monitoring and additional in-depth evaluations provide information for planning/investment decisions and program improvement. It holds people and the organization accountable for achieving stated strategies/goals/objectives. In turn, achievement of specified goals can serve as incentives for researcher performance. However, constant thorough evaluations can be resource-intensive; the organization needs to define the logical framework to evaluate the right metrics, analyze the data, and provide feedback to inform, report, and improve its strategy. This investment is critical, as the wrong set of metrics can cause behaviors that work against achieving goals of the organization.

3.2.3 Best Practices and Next Practices

Various laws—Managing for Results; Government Performance and Results Act (GPRA); and more recently, Evidence-Based Decision Making—required the Executive Branch (through the Office of Management and Budget, OMB) to implement strategic assessments for all federal agencies.[14] Thru GPRA, for instance, the Department of Health and Human Services (HHS) evaluates their strategy for scientific discovery through pre-identified programs and metrics over five-year periods. Several research programs are identified each year to be monitored via GPRA. Anticipated outcomes for each year are visualized in a table format and year-by-year results are compared to anticipated outcomes. The collection of programs subject to GPRA evaluation reflect the entire HHS strategy, ranging from support of trainees, to biomarker discovery, to data sharing, demonstrating the adaptability of the approach.[15]

The National Science Foundation (NSF) develops an annual performance plan against which it evaluates ROI. Each year selected programs are evaluated against a common set of indicators. For example, the fiscal year 2018 plan included 6 performance goals: ensure that key program investments (1) and infrastructure investments (2) are on track, (3) use evidence to guide management decisions, (4) make timely award decisions, (5) improve the review quality, and (6) foster an inclusive culture through change management. Each goal is supported by appropriate target measures, milestones, or deliverables.[16]

---

[14] OMB Circular No. A–11: Preparation, Submission, And Execution of the Budget, Part 6. Related approaches used by industry include Plan-Do-Check-Act, Total Quality Management, and Balanced Scorecard.
[15] FY 2017 Annual Performance Plan and Report - Goal 2 Objective A. (https://www.hhs.gov/about/budget/fy2017/performance/performance-plan-goal-2-objective-a/index.html)
[16] NSF FY 2018 Annual Performance Plan (https://www.nsf.gov/about/budget/fy2018/pdf/55_fy2018.pdf)

3.3 Using Key Performance Indicators to Measure the Effectiveness of Research Organizations

KPIs for S&T research include: (1) knowledge and technology generation; (2) research capabilities (i.e., talent development); (3) applications of technology; and (4) commercialization/technology transfer (Figure 3). Each of these indicators should be aligned with organizational goals and measured using both quantitative (i.e., statistical analyses) and qualitative (i.e., expert/peer review) metrics. One of the key strengths of the KPI model is the potential for highly tailored, nested performance indicators within each of these categories that ultimately allows organizations to measure the success of their programs based on data that best reflect the programs' specific mission, goals, and/or objectives. The associated KPIs can be reviewed and modified, as necessary, to ensure effectiveness.[17]

The generation of new/improved knowledge and technology is the primary KPI for determining the value of discovery –based research. The value of the knowledge advances can be linked to specific objectives, changes from the current state of the art, or assessments of importance/centrality to a field of inquiry. The most common quantitative data used to assess the value of knowledge/technology generation are bibliometrics, i.e., publication and citation counts or related indices.[18] In addition, best practice indicates that more qualitative metrics (i.e., expert judgement) are a necessary part of assessing this indicator.

Effectively encouraging and supporting people with highly developed research capabilities is another KPI. Highly qualified, S&T-trained researchers carry tacit knowledge with them that leads to social and economic impact. In addition, collaboration stimulates and speeds innovation. Thus, it is important to track external research funding, the recognition individuals receive on the national stage, quality of staff, number of students trained, the ability to attract high quality people, quality of the facilities and resources that support the investigator, and the number and quality of networks among top researchers. An individual's expertise/experience, influence, and activities should also be considered.[19]

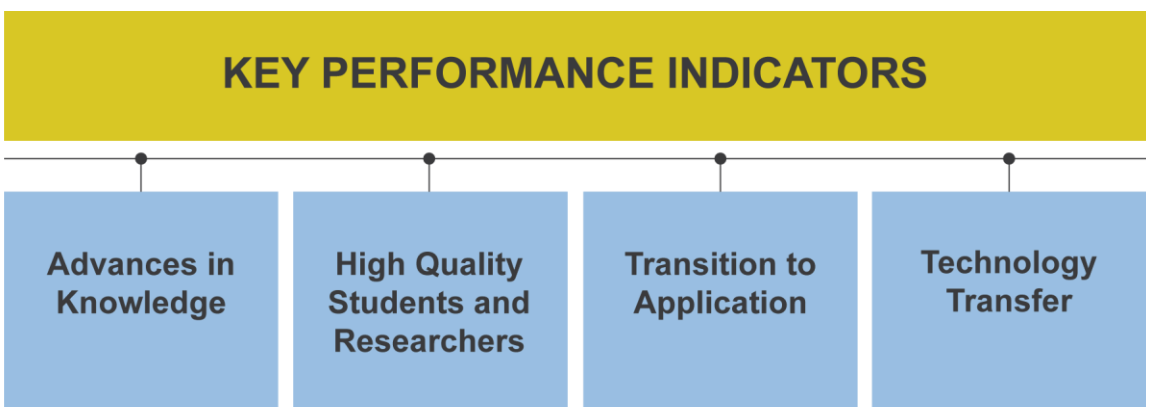


Figure 3. A range of key performance indicators (KPI) were identified and recommended by the study participants to assess the multi-level performance of a research organization.

A third KPI is the number and relevance of the possible applications supported by research and its progress towards achieving those applications. New technology can be evaluated at pre-defined intervals based on criteria tied to developmental stage, including progress towards the proposed business model, strength of

[17] Council of Canadian Academies, "Informing Research Choices: Indicators and Judgment: The Expert Panel on Science Performance and Research Funding," 2012.

[18] The h-index, for instance, rates author, group, department, university, or country on the basis of the most cited papers and the number of citations.

[19] Hicks, Diana; Wouters, Paul; Waltman, Ludo; de Rijcke, Sarah; Rafols, Ismael. "The Leiden Manifesto for research metrics," Nature, 2015, Vol 520, Issue 7548, Pages 429-431.

the business case, alignment with the organization's mission, readiness of the technology for the marketplace or deployment, and the risks associated with continued development. These KPI are often used in stage gate analysis. Each gate represents a go/no go decision based on the projected net income, risks, and progress. Thus, the organization can build a decision tree identifying all possible outcomes at each branch point, including estimated probabilities and expected monetary or mission value.

Finally, a fourth KPI of research effectiveness is the extent to which research projects lead to successful commercialization or technology transfer. Measuring this is relatively straightforward. Project success can be measured quantitatively in terms of the intellectual property produced (i.e., patents, licensing agreements), revenue generated, discussions with venture capital firms, emerging companies, connections or acquisition with a larger company.[20] More qualitative metrics might include counting the number of companies whose business models rely on a given idea or piece of technology and stakeholder surveys. To stimulate entrepreneurship, some federal laboratories developed programs that allow employees to leave the laboratory to establish or expand a company (see section 3.3.3 for examples). Such programs generate additional indicators that can be used to assess research effectiveness and technology transfer.

3.3.1 Scope and Applicability

Overall, these 4 key indicators can be applied to all levels of S&T research. Assessments of knowledge generation are particularly applicable to mission oriented research organizations, including those developing discovery-based and problem-focused research portfolios. Bibliometric methods may be used for single investigators or groups of researchers (i.e., by unit, by organizations, or within a specific field/discipline). This latter approach can increase the validity of the metric.[21] In contrast, stage gate analysis is most appropriate for problem-focused research (i.e., subset of BA2 projects) and beyond. Since the process looks at ROI prospectively (i.e., the likelihood of success and potential payoff), it could also be used to decide what projects should transition from BA1 to BA2, and from BA2 to BA3. Because costs increase during development and scale-up of a new technology, many organizations use the stage gate analysis to make decisions at multiple points along the basic-applied research continuum. Indicators based on people or technology transfer are more widely applicable as research capabilities can be built via work at any stage of research.

3.3.2 Advantages and Disadvantages

One of the major strengths of this model is that it covers all reasonable expectations of discovery-based and problem-focused research, while at the same time offers the potential to tailor metrics according to the goals of the organization or even individual research efforts. For example, if a goal is discovery for unidentified future purposes, assessments of the value of applications and/or commercial potential can be defined accordingly. If the goal is to answer specific scientific questions related to accomplishing some part of the mission, the assessments can be shifted to focus on those goals.

There are specific strengths associated with each indicator as well. A focus on knowledge generation indicators holds scientists accountable to their research objectives, which is an appropriate measure of ROI for discovery-based research. Moreover, bibliometrics used in aggregate can identify the relative impact of the research compared to other units or other organizations (i.e., percentage of total publications from an institution compared to the field). Evaluating people relates directly to the nature of research and its sustainability. Indeed, most organizations already recognize the value of knowledge embedded in the S&T trained workforce. Applying a stage-gate analysis makes the decision-making process exceptionally well-

---

[20] Zuckerman, Brian; Hautala, Judith; Nek, Rashida. Technology Development at the National Institutes of Health (NIH): Summary Report, 2015. (https://www.ida.org/idamedia/Corporate/Files/Publications/STPIPubs/2016/D-5712.pdf)

[21] Council of Canadian Academies, *op. cit*.

defined. Unlike analyses based on technology readiness level (TRL), stage-gate analysis helps build a more comprehensive case for research to continue, including technical, business, and strategic considerations.

The disadvantage in using KPIs is that there is a tendency is to measure what is easy to quantify instead of what is important. Key resource-intensive qualitative indicators must also be included (subject matter expert review, tracking over time). In addition, this model does not include input and process indicators, such as "quality of research environment", despite how important these are for enabling research.

Specific disadvantages of knowledge generation-based indicators include:

- Bibliometrics are unable to measure the qualitative value of knowledge produced (except to the extent that peer review selects for quality/new ideas).[22,23]
- Qualitative evaluations are complicated, resource intensive, may favor lower risk and single discipline research, and have the potential for bias.
- Measuring against research objectives requires a research project plan that takes time, resources, and may stifle creativity.
- It is difficult to determine credit for scientific advances, as many build on past work.
- The value of research is not always obvious in the near-term.

Specific disadvantages of people-based indicators include:

- Tracking the movement of people can be challenging to perform systematically.
- Indicators must be measured over years.
- Metrics can be subjective and difficult to quantify.

3.3.3 Best Practices and Next Practices

The 4 KPIs we present align well with how federal science organizations measure performance, relevance to mission, and impact. For example, NSF measured "ideas, people, and tools" in response to GPRA in the 1990s. It has since added broader, more qualitative societal impacts to its metrics. In addition, many S&T organizations, including public and private organizations, measure advances in knowledge and tools using the methods we describe. The Institute for Research on Innovation and Science (IRIS) extends the analysis by integrating data on people, research outputs (including grants and publications), and expenditures with economic data to more fully assess the public value of research.[24] Specifically, relevant to the research capabilities indicator, all US federal science agencies/offices measure the number of students trained, degrees held by staff, awards, and recognition received. Indeed, all but the latter are among the indicators routinely collected by the National Science Board. Industry and universities also collect and advertise statistics on S&T staff and students (i.e., Silicon Valley, Microsoft, MIT, Stanford). Analyses include movement of staff/students to startups.

Real-time technology assessment (TA) is an example of a KPI approach applied to research projects that present significant uncertainty. Used to evaluate the National Nanotechnology Initiative, the approach integrates viewpoints from scientists, social scientists, and a range of potential stakeholders interacting on the impact of the technology. The real-time TA model has 4 components and uses a number of anecdotal and quantitative performance indicators. The first component uses analogical case studies of past transformational innovations to develop frameworks for anticipating future interactions between society and new technologies. The second component uses bibliometrics to identify research trends, participants, organizations, and relationships. The third component monitors changing knowledge, perceptions, and

---

[22] Hicks, Diana, et al. "The Leiden Manifesto for research metrics." *Nature* 520.7548 (2015): 429.
[23] DORA: San Francisco Declaration on Research Assessment, College & Research Libraries News, 2014, Vol 75. (https://crln.acrl.org/index.php/crlnews/article/view/9104/9996).
[24] http://iris.isr.umich.edu/

attitudes among stakeholders. The fourth component gauges society's preparedness for the anticipated societal impact.[25]

The stage gate analysis method, as referenced above, was developed by industry.[26] Exxon/Mobil later added a stage for discovery-based research. The Department of Energy (DOE) Office of Biomass Program (OBP) has used stage gate analysis since 1998 to guide decision-making on research and development efforts to support portfolio development/management, project alignment with program objectives, and project evaluation. Projects on a commercial track must have a vision for commercialization, whereas projects on the research track should contribute to new knowledge or capabilities that can be applied to commercially-focused projects. Projects move along each track in distinct stages (i.e., work that is required to achieve the objectives) that are marked by gates (i.e., project review and decision points) that differ by track and project. Projects at each gate are evaluated for strategic fit, market/customer, technological feasibility/risks, competitive advantage, legal/regulatory compliance, critical success factors and show stoppers, and plan to proceed. There are 4 possible outcomes for each gate: pass (criteria met; project moves forward), recycle (progress made, keep working at previous stage), hold (suspend the project pending changes in market needs), and stop (permanent halt to the project). If the project passes the gate, a new work plan for the next stage (i.e., objectives, milestones, work breakdown and schedule, resources) must be developed and approved before moving to the next stage. Ultimately, the stage gate process enables OBP to perform high quality work, assess multiple aspects of each project simultaneously, and increase potential commercial impact. The entire process requires engagement from DOE Headquarters, DOE-Project Management Center, project leaders, and investigators.[27]

Sandia National Laboratory's Entrepreneurial Separation to Transfer Technology (ESTT) is a valuable program that allows Sandia to monitor and enhance transfer technology to the private sector by permitting its employees to leave the labs to establish or expand technology companies. Entrepreneurs are guaranteed reinstatement for up to 2-years with the option to request a third year. ESTT proposals may be based on a requestor's intent to license Sandia intellectual property (IP) or use his/her "unique expertise" rather than Sandia IP. ESTT must be consistent with Sandia's business development plans and tech transfer mission. Since its inception in 1994, the program's evaluation metrics show that over 150 Sandian employees have taken advantage of the program. Fifty-four companies have been established, 53 companies have expanded, 44 technologies have been licensed.

One intriguing example of a potential next practice in applying performance indicators for technology breakthroughs is described in 'A Dynamic Network Approach to Breakthrough Innovation'.[28] This is a newly validated approach with novel metrics for measuring the extent to which newly patented innovations disrupt the status quo. The study found that disruptive patents decrease the use (i.e., citation) of their predecessors by an average of 60%. Using network approaches, disruptive technologies can be identified retrospectively and used to measure ROI.

---

[25] Guston, David; Sarewitz, Daniel. "Real-time technology assessment," Technology in Society, 2002, Vol 24, Issue 1-2, Pages 93-109. (https://doi.org/10.1016/S0160-791X(01)00047-1)

[26] Cooper Robert; Edgett, Scott; Kleinschmidt, Elko. "Optimizing the Stage-Gate Process: What Best-Practice Companies Do," Research-Technology Management, 2012, Vol 45, Issue 6, Pages 43-49. (https://doi.org/10.1080/08956308.2002.11671532)

[27] US Department of Energy, "Stage Gate Management in the Biomass Program," 2005. (https://www.energy.gov/sites/prod/files/2015/05/f22/stage_gate_management_guide.pdf)

[28] Funk, Russell; Owen-Smith, Jason. "A Dynamic Network Approach to Breakthrough Innovation" (https://arxiv.org/abs/1212.3559)

3.4 Contribution Analysis

In industry, ROI is traditionally defined as the ratio of sales to investment costs; the organization takes 100% of the credit for the ROI. Contribution analysis attributes broader societal or mission impact to a discovery or organization, including events and influence collected along the way. It considers research contribution as a "causal package". Contribution analysis comprises 6th steps: (1) set out the cause-effect issue to be addressed; (2) develop the postulated theory of change and risks to it, including rival explanations; (3) gather the existing evidence on the theory of change; (4) assemble and assess the contribution claim and challenges to it; (5) seek out additional evidence; and (6) revise and strengthen the contribution story.[29] This approach can be used proactively or retroactively to determine the contribution of basic research investments to applications and/or their impact by examining each point of knowledge transfer along the research continuum.

3.4.1 Scope and Applicability

Contribution analysis can be used for all S&T investments. Its applicability depends on the target audience (i.e., Congress may prefer this model over other approaches). If the models described above are implemented concurrently, the accumulated data from indicator monitoring and more in-depth evaluation of performance indicators will be sufficient for impact assessment.

3.4.2 Advantages and Disadvantages

The primary advantage of this model is the ability to map the contribution of research to its impact; understanding the role of each element at its knowledge transfer point. This method is more credible than undocumented claims of impact. The analysis also provides information on success factors that can inform program design. It is important to note that alterative formal attribution methods, such as random controlled trials, are not feasible for basic research.[30]

A disadvantage of contribution analysis is that it requires a historical tracing study, which can be expensive and complicated. Further, it is hard to assess technologies with wide-ranging impacts; scientists may not be able to predict all potential applications, and key technologies are often missed. Adding to the challenges of this approach is that it is more qualitative than quantitative (i.e., need to build a case for how the investment lead to outcome/technology), and there is thus a greater potential for bias. Finally, it would be burdensome and expensive to have a tracking system like this for research projects beyond AFRL and the USAF, although it may be feasible to track a few projects that appear to be "winners" based on early indicators.

3.4.3 Best Practices and Next Practices

Most organizations already value historical tracing studies, but a broader evaluation methodology is also needed. In addition, marketing is key to promoting the results of the contribution analysis and demonstrating ROI to invested audiences. Within DOE, The Office of Energy Efficiency and Renewable Energy (EERE) posts success stories on their website that highlight the positive impact of research supported via EERE on the effectiveness and use of new energy technologies. The stories include a map to show geographical impact as well.[31] In addition to the success stories, DOE conducts a cost-benefit analysis for the research programs.

---

[29] Mayne, John. "Contribution analysis: Coming of age?," Evaluation, 2012, Vol 18, Issue 3, Pages 270-280. (https://doi.org/10.1177/1356389012451663)

[30] Government Accountability Office. Designing Evaluations: 2012 Revision. Report No.: GAO-12-208G

[31] https://www.energy.gov/eere/eere-success-stories-projects-map/

Contribution analysis has been applied in numerous contexts, including developmental aid, agriculture, employment, and governance. In 1 example, the Evaluation Reference Group, evaluated the impact of aid provided by the European Union to the country of Jordan over a 10-year period. The group developed a logic model that included 3 causal claims relevant to the intended impact (i.e., increase Jordanian exports to the EU). Using available information, including possible other contributing factors, the group came to the conclusion that the intervention was insufficient to explain the expected impact. However, their analysis revealed that an alternative causative issue (i.e., the intervention led to growth in exports around the world) would have yielded a positive contribution.[32] In developing best practices for contribution analysis, this example highlights the importance of appropriately defining the causative issue during the assessment (see also a full issue of the journal *Evaluation* which provides a comprehensive overview of contribution analysis[33]).

[32] Delahais, Thomas; Toulemonde, Jacques. "Applying contribution analysis: Lessons from five years of practice," Evaluation, 2012, Vol 18, Issue 3, Pages 281–293. (https://doi.org/10.1177/1356389012450810)
[33] Special Issue: Contribution analysis, Evaluation, 2012, Vol 18, Issue 3. (http://journals.sagepub.com/toc/evia/18/3)

4. A CALL FOR CHANGE: ORGANIZATION STRUCTURE & CULTURE

4.1 Introduction

In a large organization like the USAF, optimizing the organizational structure is not about finding a one-size-fits-all solution. It is about curating and maintaining a collection of substructures optimized to achieve specific objectives. The team focused on structures to support innovative early-stage research.

Within this focus, there are several sub-objectives: encourage and support efforts to meet a well-defined challenge; enable independent pursuits of completely new ideas with no specific mission in mind; and establish a framework that can easily shift to meet emerging challenges. The USAF needs to consider all of these objectives when building an organizational structure to meet future challenges. Thus, the models offered below are all components of a successful S&T organization, supporting overall goals such as: (1) early access to key knowledge and intelligence; (2) attracting and engaging talented people; and (3) generating synergy to amplify the best innovations (Figure 4).

		Components of Successful S&T Organizations		
		Access to key knowledge	Engaging talent	Generating synergy
Models	Challenge-Driven Teams Model			■
	Enabler Model		■	
	Affinity Network Model	■		

Figure 4. Organization structure models aligned with identified components of a successful S&T organization.

4.2 Challenge-Driven Teams

The complexity of today’s challenges has forced S&T research to be more collaborative and flexible. The Challenge-Driven Teams model refers to an approach that focuses on forming multi-disciplinary teams tasked with a specific, clear objective or strategic direction identified by leadership. They can be long term, mission-oriented teams with specific research milestones; rapid response teams that address specific operation needs; or exploratory teams tasked with boundary scanning and discovery-based research in an emerging scientific area. Teams may pull members from different units across the organization or external to the organization. The team is given autonomy and flexibility; once given the purpose from leadership, it is self-led.

Team assignment should be an elevated position to protect the participant and to encourage engagement. People can be designated as ‘floaters’, those with no home laboratory, but whose expertise is pulled into teams as needed, even sometimes as the lead. The teams need to have funding autonomy to protect creative ideas. There is a “science of team science” that can help guide the formation of challenge-driven teams. Characteristics identified for effective teams include: (1) highly diverse team membership, (2) deep knowledge across disparate disciplines, (3) appropriately large size, (4) alignment of goals across all members, (5) wide geographic dispersion, (6) permeable team boundaries, and (7) high task interdependence.[34]

4.2.1 Scope and Applicability

Challenge-driven teams can be most effective when their objective is clearly defined. This includes specific operational problems or exploratory challenges where the final solution is not clear, but the project is still mission oriented and highly cross-disciplinary. The success of such teams relies on knowledgeable participants. Further, the organization must be flexible enough to allow people to move between teams as needed.

4.2.2 Advantages and Disadvantages

Challenge-driven teams that overlay the formal organization can integrate disparate units within the organization and generate synergy. Teams often look different from the overall organization, providing an opportunity for cross-pollination and exposure to different perspectives. The disadvantage of this approach is that it relies heavily on defining the "right" problem, or the one that best aligns with the organization's priorities and objectives. Time and money may be lost if the wrong problem is selected, as moving people and resources can be rigid and disruptive. Moreover, people may tire of being constantly moved among teams, worry about falling short on their regular duties, or their attention may become fragmented from working across too many units. Thus, this approach must include a system to protect people who are being pulled off of regular duties and a reward structure that recognizes people working on multiple projects. This ultimately requires the full engagement of senior leadership to select and direct the teams.

4.2.3 Best Practices and Next Practices

There are best practices of the challenge-driven team model in industry, government, and academia. Below are examples from the RAND Corporation, NSF, Government Services Administration (GSA), and Northwestern University. In these examples, the challenge-driven teams are pulled from across the organization structure and supported by funding or changes to the physical workplace to facilitate the teams.

The RAND Corporation. The researchers at RAND, mostly PhDs, are free agents: principal investigators pull together small teams to tackle a specific problem. The teams then dissolve when the work is done. The result is a relatively flat organizational structure consisting of a constantly changing network of challenge-based teams. The RAND Corporation recently transformed 10,000 sq. ft. of office space from 100% closed, assigned offices and cubicles to nearly 100% open, unassigned seating. An independent study found that the new design increases unplanned interactions among researchers and improves teamwork, while at the same time sustaining or improving the environment for deep concentration. It also increased space utilization by 30-35%.[35]

GSA: 18F Digital Services. 18F is an office within the GSA tasked with fixing technical problems, building products, and improving how government serves the public through technology.[36] Staff members include 200 designers, software engineers, strategists, and product managers, all of whom are federal employees. They effectively form challenge-based teams with each agency, working to identify the problem and then

[34] National Research Council, "Enhancing Effectiveness of Team Science," 2015. (https://www.nap.edu/catalog/19007/enhancing-the-effectiveness-of-team-science)

[35] Wesel, Lisa. "RAND Develops IT Solutions to Enable the Transition to Unassigned Office Space" May 30, 2018. (https://www.tradelineinc.com/reports/2018-5/rand-develops-it-solutions-enable-transition-unassigned-office-space)

[36] https://18f.gsa.gov/

finding and executing the solution. They have offices in Washington, DC, San Francisco, Chicago, and New York, as well as team members working remotely from all over the country.

Northwestern University Research Institutes and Centers (URIC). Northwestern University uses a focus-driven team approach to support interdisciplinary research areas that cross multiple schools. These efforts are collectively called the University Research Institutes and Centers (URIC). The University has 53 UIRCs, with research focus areas ranging from regenerative medicine to energy. The URICs unite faculty teams and offer administrative support, research infrastructure, and resources to support collaborative research. The research topics are selected based on research priorities for the institution and emerging topics that cross many different disciplines. Research conducted in the URICs is primarily discovery-based. However, there is an emphasis on collaborative research and multi-disciplinary proposal development. The director of each URIC is appointed by the Vice President for Research. The primary affiliation of faculty members does not change, and they remain part of their original school/department. Faculty may be members of more than one team.

Sandia National Laboratories. The Sandia National Laboratories in Albuquerque, New Mexico purposely developed a process to help new departments emerge based on needs of the organization. In this approach, new or emerging departments were staffed with half the necessary people; the other half was made up of staff from other departments who were to devote 30% of their time to this new department. In this way Sandia effectively created integrated teams within the organization. The result was greater diversity and lower costs, as fewer full-time, department-exclusive staff were needed.[37]

NSF I-Corps, STC, and ERC Programs. The NSF I-Corps program leverages the curriculum of Stanford University's Lean LaunchPad course[38] and Stephen Blank's Lean Startup model[39] to "flip" entrepreneurship—start with the needs of the end-user or customer rather than an existing idea or technology. In this way, the I-Corps program encourages the development of needs-based, challenge-driven teams. Projects run through a Lean LaunchPad-like program can link to existing entrepreneurial infrastructure, such as accelerators and incubators, both locally and nationally to further the technology transfer process. Challenge-driven teams are also exemplified by NSF's signature large, interdisciplinary programs such as the Engineering Research Centers (ERC) and Science and Technology Centers (STC). These centers require large teams, including collaboration amongst multiple institutions, to address scientific challenges of high national priority. These programs pull individuals together across organizations through virtual networks to address the challenge.

4.3 The Enabler Model

The Enabler Model focuses on the bottom-up generation of ideas. It is designed to help large organizations support and encourage new ideas, and then reliably bring those ideas to the attention of top management. Enabler-style programs help surface people within the organization who have entrepreneurial dispositions and provide them with resources and top executive engagement (Figure 5). Dedicating resources and management attention *enables* teams to pursue ideas largely on their own. In the most evolved versions of this model, organizations provide clear criteria for how they plan to select the ideas they will support, guidelines for applying for funding, decision-making transparency, and, most importantly, clear commitments of engagement from senior management. The selection criteria for project funding can serve as an important expression of strategic intent. In some cases, there may be significant benefits to mine from

[37] Hage, Jerald; Jordan, Gretchen; Mote, Jonathon; Whitestone; Yuko. "Designing and facilitating collaboration in R&D: A case study," Journal of Engineering and Technology Management, 2008, Vol 25, Issue 4, Pages 256-268. (https://doi.org/10.1016/j.jengtecman.2008.10.005)
[38] http://epicenter.stanford.edu/event/lean-launchpad-educators-program/
[39] http://theleanstartup.com/principles

cross-divisional collaboration. In other cases, an organization may want to encourage innovation in the spaces between units or apply its capabilities in new areas.

One of the unique aspects of enabler programs is that people can be part of a broader, long-term plan to change the culture of an organization; that is, an effort to transform an organization that lacks a strong tradition of innovation into one in which entrepreneurship is encouraged and facilitated. This can be hugely beneficial for organizations with particular strategic visions. However, the process of broad cultural change also requires a substantial and consistent commitment of top leadership, along with concomitant changes in many corporate management processes, from development processes to recruiting and human resources management.

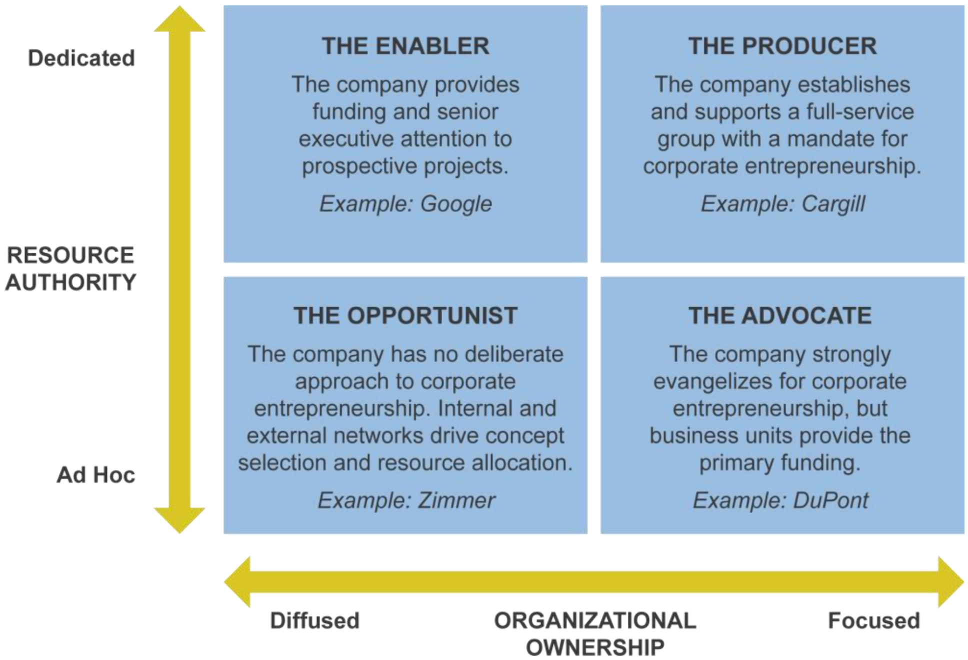


Figure 5. The enabler method is 1 of 4 models of corporate entrepreneurship identified by Lippitz and Wolcott. These models emerge from the 2 dimensions under the direct control of management and differentiate how companies approach corporate entrepreneurship. Adapted from https://sloanreview.mit.edu/article/the-four-models-of-corporate-entrepreneurship/

4.3.1 Scope and Applicability

The enabler model helps recruit and engage top talent within the organization. AFRL has already begun taking important steps toward implementing enabler-style processes. The Innovation Fund and Commander's R&D Fund support cross-cutting S&T research teams. The Entrepreneurial Opportunities Program provides selected researchers a 12-month sabbatical to lay the foundations of a business based on AFRL technology, with the possibility of taking an additional 5 years to launch the business (and returning to AFRL afterwards). These entrepreneurs can also take advantage of a new "444" maker space and USAF-sponsored commercial accelerators.

These current programs are relatively small-scale; the budget is a few tens of millions of dollars (out of a >$4 billion-dollar AFRL budget) and fewer than a dozen sabbaticals have been awarded to date. However, such programs do not necessarily need to be large. The critical effort is not to expand the programs, but rather to make sure that leadership remains engaged so that successful projects continue to move forward. In the case of AFRL, this might mean continuing to support projects during the 2-3 years it takes to have a new PE established, or establishing new offices to support small businesses that want to link to the defense contracting base.

4.3.2 Advantages and Disadvantages

Enabler-style programs can provide important time and space for innovative employees to self-select and explore possibly valuable new directions. If senior leadership is engaged and organizational roadblocks are removed, successful concepts can advance quickly. Over time, examples of people successfully developing ideas and receiving top-level support can change the culture of an organization; people begin to believe that true innovation is possible. However, without this kind of engagement, enabler programs can degenerate into employees "bowling for dollars", or seeking an alternative source of funds for ordinary projects that did not receive funding through standard channels. Failure to follow through with successful projects can also send a message that leadership is not serious about implementation. Finally, such programs tend to be small-scale and do not usually contribute substantive improvements to complex major systems, which represent the bulk of USAF development spending.

4.3.3 Best Practices and Next Practices

Best practices of the enabler model focus on people and not projects. In industry, examples of the enabler model critically include protected time for staff and dedicated funds to support the process. Psychological safety (as mentioned in section 2.4) is key.

Google is a poster child for the enabler model. Despite tremendous growth, Google maintains the open and freewheeling culture of a much smaller company. Employees are allowed to spend 20% of their time promoting their ideas to colleagues, assembling teams, exploring concepts, and building prototypes. If a project team believes that it has a promising idea, it appeals to the Google Product Council for formal project funding. The Product Council, which includes the company founders, top executives, and engineering team leaders, provides broad strategic direction and initial resources. If a team successfully demonstrates proof of concept and consumer interest, the Product Strategy Forum may begin to play a more active role in oversight and support, including applying more significant resources, directing formal and regular engineering reviews, acquiring outside capabilities, or making some other part of Google work with the project team. If a project succeeds, team members can receive substantial bonuses (called Founder's Awards), sometimes amounting to millions of dollars. These bonuses do not match what entrepreneurs might make if they were successful on their own, but most employees see the benefits of remaining within Google where they can receive significant and reliable support of their ideas to increase the probability of success.

Google's entrepreneurial culture, dynamic market, and extraordinary access to capital make the company's success difficult to replicate. Nonetheless, other companies have had success using the enabler model. Boeing, for example, has found that dedicated funds for innovation combined with clear, disciplined processes for allocating those funds can go a long way toward unlocking latent entrepreneurial potential.[40]

Whirlpool began its entrepreneurship journey from a baseline that was considered practically non-innovative. Beginning in 1999, Whirlpool transformed itself over the course of a decade from a conservative company in a slow-moving, commodity-based business into a creative engine spawning significant new revenue from differentiated products and new businesses. Among other efforts—new processes for product development, personnel evaluation, knowledge management, financial accounting, resource allocation and project reviews—the CEO mandated that Whirlpool's business units and regional offices set aside a fixed percentage of the capital expenditure budget for innovation projects. He also maintained corporate seed money to fund worthy ideas that had been rejected by business units or regional offices. Mid-stage funding

[40] Wolcott, Robert; Lippitz, Michael. (2010) *Grow From Within: Mastering Corporate Entrepreneurship and Innovation.* McGraw-Hill. (Page 104)

for innovation or corporate entrepreneurship projects are controlled primarily by new oversight and review bodies known as I-boards, consisting of business leaders, senior executives, or brand teams. People with innovative project concepts are free to shop their ideas around to different I-boards for funding.

Non-profits and foundations have also used the enabler model to organize research programs with intramural and extramural scientists. The Monterey Bay Aquarium Research Institute (MBARI), founded by David Packard, offers significant flexibility to its scientists. Through lessons learned, MBARI found it has to implement institutional mechanisms for setting direction (in a general sense) and encouraging alignment and teaming as part of the model.

The Howard Hughes Medical Institutes' (HHMI) Investigator Program is a "person focused" model that employs and supports nearly 300 investigators, who are based at over 60 universities, colleges, and other research institutions across the US. Total direct costs are approximately $650,000 per investigator, per year with the option of applying for additional equipment funds as needed. The investigators' time is also protected, as they are required to spend at least 75% of their time conducting biomedical research. Consistent with the belief that transformative research is accomplished over long periods of time, the program is designed to provide long-term support. Investigators are evaluated every 5 years and stay with HHMI for an average of 15 years.[41] As evidence of the success of this approach, 28 current or former HHMI investigators have been awarded the Nobel Prize to date.

The MacArthur Fellowship is a $625,000, no-strings-attached prize awarded to extraordinarily talented and creative individuals as an investment in their potential. The program is intended to give investigators the option to pursue their own ideas. Nominees are brought to the Program's attention through a constantly changing pool of invited external nominators chosen from a broad a range of fields and areas of interest. [42] Thus, the MacArthur Fellowship is another example of an award that supports people rather than projects.

4.4 Affinity Networks

The third organizational model offered by the team is the idea of affinity networks. An affinity network is a virtual organization or network of people united by a shared immersive or inspiring experience that establishes a connection. The specific advantage of such networks is that it is infinitely flexible and can broaden the knowledge base of the organization far beyond that offered by its employees. The focus of the team's discussion was on bounded networks, i.e., those that are intentionally established based on organizer invitation or specific criteria. However, affinity networks can also be unbounded (think crowd-sourcing or open hack-a-thons). Most networks have hubs or cores that organize the work being done. A single hub promotes more centralized decision-making, while multiple hubs can lead the self-organization of information sharing or strategy. The affinity network model is ultimately based on the importance of loose ties, and includes consideration of network edges or peripheries made up of people who are involved in the work of the group to a lesser extent.[43] The key to this idea is that such networks generally create value for individual members as well as for the network as a whole and the organization it serves. Thus, incentives are suitably aligned. Affinity networks are known to be extraordinarily inclusive and rich in their diversity. They can be temporary or permanent, planned or spontaneous.

---

[41] Institute for Defense Analyses, Science and Technology Policy Institute, "Outcome Evaluation of the National Institutes of Health (NIH) Director's Pioneer Award (NDPA), FY 2004–2006," August 2012, Paper P-4899. (https://www.ida.org/idamedia/Corporate/Files/Publications/STPIPubs/ida-p-4899.pdf)

[42] MacArthur Fellows Program: Summary of 2012-2013 Review, MacArthur Foundation, August 2013. (https://www.macfound.org/media/files/MacArthur_Fellows_Program_Review_final_1.pdf)

[43] "A Network Way of Working: A Compilation of Considerations about Effectiveness in Networks," Nonprofit Quarterly, December 30, 2013. (https://nonprofitquarterly.org/2013/12/30/a-network-way-of-working-a-compilation-of-considerations-about-effectiveness-in-networks/)

4.4.1 Scope and Applicability

The purpose of initiating an affinity network is to gather data and intelligence from multiple sources. This would be followed by a more detailed analysis of the data to mine for promising research opportunities. Success of the network model relies on a shared experience or interest that can be initiation by the host, such as an annual workshop. There can be an incentive to join the network, which can be internal or external to the sponsoring organization, such as resources, data, or accessibility. Technology platforms and email listservs are often used to communicate across the network. Cross-institution research teams, student sharing, internships, or visiting scholars could be initiated through network activities to support downstream work.

4.4.2 Advantages and Disadvantages

The affinity network model offers a potentially cost-effective way to build a community of trust that brings a diverse group together as needed to meet specific objectives. It is an infinitely agile approach that effectively increases the breadth of available expertise. Networks that include people external to the organization diversify capabilities without the need to support a standing research team.

The affinity network model does require significant effort to initiate, manage, and sustain over time. Though new technologies can help facilitate connections between members, organizers need to carefully consider mutual incentives and benefits at the outset to ensure success. In addition, the affinity network can become an echo-chamber, homogenous, and assumption-based if the membership is not actively managed. There are also challenges around managing intellectual property and confidentiality. Some choose to apply the so-called "Chatham house rule": anything that is said can be used, but its source may not be attributed to any one person.

4.4.3 Best Practices and Next Practices

Best practices of the affinity network model are present in government, professional societies, and industry. The Dephi Technique is a specific example of how an affinity network model can be used to gain information.[44] The technique uses a structure of group communication processes (i.e. surveys and forms) to enable a group of individuals to collectively address a complex problem. Other affinity network approaches unite disparate groups of people via websites, high profile events, and funding mechanisms. The AFOSR supported Centers of Excellence are an example of how AFRL has established collaborative networks of investigators with institutions to work on specific projects. Below are some additional examples:

Canadian Institute for Advanced Research (CIFAR). CIFAR unites leading experts worldwide to work together across disciplines to improve human health and quality of life, create successful societies, and sustain life on earth. The CIFAR Network consists of more than 400 fellows and advisors from more than 130 institutions in 17 countries. Participants are charged with addressing specific programmatic areas.[45]

NCI Collaborative Research Networks. Starting in 2009, NCI initiated the Physical Sciences-Oncology Centers (PS-OC) Network, a collaborative research network consisting of 10-12 independently funded Centers. The resulting network includes 300+ investigators, advocates, and trainees affiliated with the centers who gather for annual meetings, have access to set-aside trans-network seed funds, and shared data, and participate in specific projects managed by NCI program officials.

---

[44] Hasson, Felicity; Keeney, Sinead; McKenna, Hugh. "Research guidelines for the Delphi survey technique," 2000, Journal of Advanced Nursing, Vol. 32, Issue 4, Pages 1008-1015. (https://doi.org/10.1046/j.1365-2648.2000.t01-1-01567.x)

[45] https://www.cifar.ca/about/

Allen and Company Investment Firm. Within the private sector, Allen and Company has forged long-lasting and lucrative relationships with corporate leaders, media moguls, politicians, and celebrities by hosting an annual extravaganza in Sun Valley, Idaho. The event sponsors riveting events that make for an unforgettable experience and long lasting bonds between participants. Interestingly, Allen and Company focuses on the network and the relationships fostered through the annual event, rather than housing an in-house research department like many other investment firms.

GitHub. GitHub is an effective way to collaborate on software development projects. Using GitHub, anyone with an internet connection can share code with the world for free—an unbounded affinity network of computer coders working on similar problems. All stored code is open access; anyone can download and/or modify for free. Any and all resulting code remains linked to the original code (and its creator). GitHub has been adopted as the primary home for source code collaboration and storage by many large open-source projects.

Professional societies, such as the American Physical Society, seek input from its membership and the broader community in a number of ways: from various levels of elected representatives, from their Boards, from a network of leaders/officers of division/section/units within various sub-fields (perhaps via an annual convocation and/or annual meetings), and from surveys of its membership and other committees involving members of the scientific research community. Engaging the entire membership can bring diverse expertise and ideas from other organizations (their own home institutions as well as from other professional societies that they belong to).

5. A CALL FOR CHANGE: FORMULATING STRATEGY

5.1 Introduction

As a research organization, AFRL must remain multi-functional and maintain focus on a range of objectives (from urgent on-the-ground problems to projected needs far into the future). It also operates in a dynamic global and operational space with many uncertainties (including both unknowns and unknowables). Further adding to these challenges, AFRL is made up of effectively siloed directorates, making it difficult to create or implement a cohesive organization-wide strategy.

To address these challenges, the team recommends a three-element interconnected approach to strategy formulation that charts a course to desirable futures, builds in agility to update strategies on a periodic basis, and includes a mechanism to prevent group-think. To be successfully implemented, AFRL needs to adopt the following 3 elements as part of a cohesive, long-term strategy that is robust, proactive, and agile:

1. Trend Mapping. The process of gathering and analyzing data to creatively visualize the future in terms of a number of key dimensions or "swim lanes".
2. Backcasting (also called Normative Scenario Planning). The process of envisioning desirable outcomes or future end-states (as defined through trend mapping) and defining the pathways and capabilities needed to make that future happen (a reverse roadmap).
3. Red Teaming. Encouraging and institutionalizing organized dissent to reduce the risk inherent in strategies formulated from within highly-uncertain and dynamic environments.

Figure 6 illustrates the proposed framework. Trend mapping is designed to provide an inspirational 5-year, 10-year or 20-year vision for the organization. Through backcasting the organization maintains the agility necessary to modify that vision based on emerging events, needs, or trends. Ideally, backcasting is conducted every 2-3 years at the directorate level and every year at the division level, though the precise timing should be based on progress in the trend map. A formal red team review can occur with similar

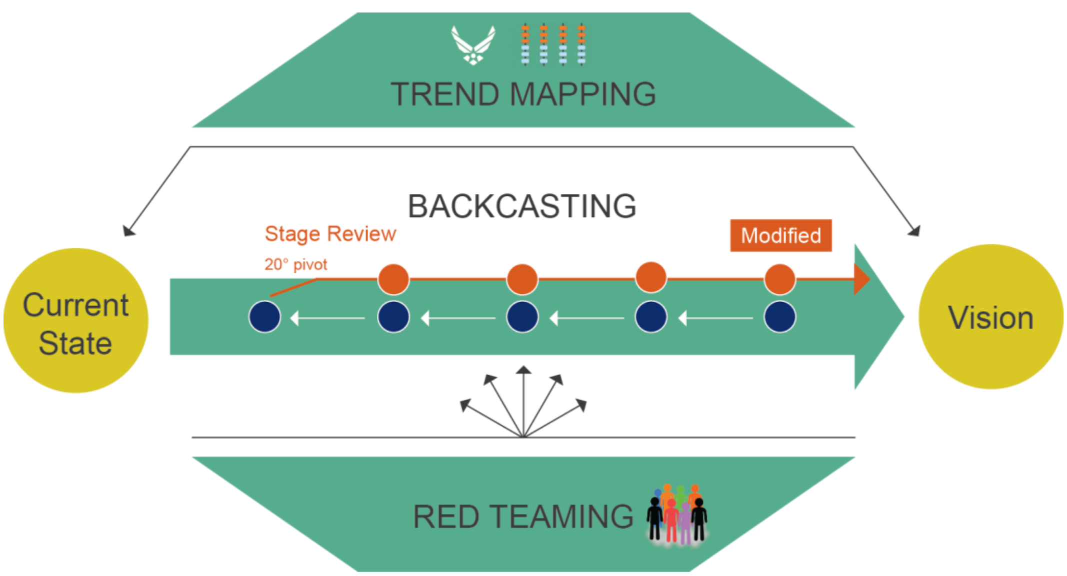


Figure 6. A schematic displaying the interaction between the 3 recommended elements that comprise a robust and agile approach to formulating a long-term research strategy.

frequency, although more informal red teaming, which is an inherently bottom up process, should be built into unit culture and tapped as needed.

5.2 Trend Mapping

Trend mapping helps visualize the "state of the playing field"; the goals and challenges the organization believes it will face as it works towards achieve its 10-15-year vision. Ideally, 4-6 trends are identified as most likely to shape the environment of the future. These trends, or "swim lanes", should be different, yet interconnected; for example, trends in technology, threats, geopolitical climate, demography, or the economy.

Trend mapping provides high-level, strategic input across functional areas and domains. It is constructed by gathering, organizing, analyzing, and visualizing data to define the evolution of a particular environment or technology over time. Thus, to extend the analogy, the vision is made up of "swim lanes within the same pool", highlighting themes and patterns that are likely to characterize the future environment. The resulting map is used as input as the organization charts its course to achieve desired outcomes and capabilities in the future.

As an example, consider a trend mapping enactment for the future environment of autonomous electric vehicles (AEVs). The trends, i.e., swim lanes, can be defined and analyzed as follows:

1. <u>Enabling Technologies</u>. Includes the component or process technologies that underlie the evolution of key enabling technologies. For AEVs, these might be: software and artificial intelligence, battery and energy storage, microelectronics/processors, metals and composites, sensors; and manufacturing automation.
2. <u>Threats</u>. Known and potential competition, including actors and influences on the perceived future possibilities. For AEVs, these might be: incumbent OEMs (internal combustion engines), Chinese AEV players, ride-sharing companies, and semi-private autonomous transportation systems.
3. <u>Geopolitics</u>. Political developments that are likely to impact the AEV landscape: policies impacting oil production in the Middle East, fossil fuel regulations, subsidies for AEVs, or trade tariffs/agreements that affect the import of components like batteries and motor components.
4. <u>Demographics</u>. Changes in the strengths and actions of customers and/or employee talent: AEV demand among millennials and subsequent generations, supply of talented workers to support AEV design, engineering, and manufacture.

As the "swim lanes" listed above illustrate, the trend map can span a number of interconnected dimensions. The map can and should be updated every few years using data and intelligence relevant to each dimension that is gathered on an ongoing basis.

5.2.1 Scope and Applicability

Trend mapping can be applied to many strategy domains at different levels of abstraction. Most relevant to AFRL would be implementation at the directorate level or at the level of the USAF as a whole. It would not be appropriate to apply this approach at the level of an individual technology (for instance, composite materials) as the trend map is designed to be cross-disciplinary and cross-functional. The time horizon that is appropriate for trend maps is 10 years or longer. Trend maps are most useful in domains where there is a high level of uncertainty and dynamism in the future.

5.2.2 Advantages and Disadvantages

Trend mapping allows strategists to look far out into the future while maintaining agility through continual scanning of the environment (using data from a variety of sources, primary as well as secondary, public as well as private). This technique is inherently cross-disciplinary, as it must include consideration of very different facets of the future. It is also highly adaptable, lanes and sub-lanes can reflect the specific context of the organization's goals and allow for infinitely granular analysis of trends. Trend mapping can also be applied to almost any domain of research, with a broad range of applicability that integrates factors beyond technology itself. The approach provides a critical "rolling forecast" that allows for continuous analysis and ongoing, evidence-based adjustment. These adjustments support "strategic incrementalism", including gentle course corrections based on trend forecasts and more drastic pivots based on discontinuous events (e.g., the North Korean nuclear threat).

There is always potential for bias when attempting to define a future environment with incomplete and/or inaccurate data; analyses are only as good as the data available and the teams that analyze them. While it is always difficult to validate some input information, and impossible to identify one's own blind spots, it is possible to minimize the impact of these factors. Preventing blind spots and avoiding the tendency of group-think requires a diverse team that continually updates its assumptions based on evidence related to trend milestones.

5.2.3 Best Practices and Next Practices

To effectively implement a trend map, here are several best practices:

- Think of dimensions holistically and emphasize data collection that does not adhere to directorate/unit buckets.
- Minimize potential bias in defining swim lanes by ensuring diverse contributions to each component. The people who construct the swim lane analyses need to come from different perspectives, internal and external, etc., and be capable of avoiding group-think.
- For security, and to protect confidentiality while sourcing external inputs, it important to identify a trusted network of external partners or extended team members. For example, IBM developed its Global Innovation Outlook 2.0 in 2006 by inviting a "trusted network" of 248 thought leaders from 36 countries for 15 "deep dive" sessions to discuss emerging trends, challenges and opportunities in selected domains. The process was collaborative, but was not open to all (similar to the affinity network organization structure described in section 4.4).[46]
- Be flexible enough to add/remove swim lanes and add new expertise as needed. Experts (internal as well as external) can augment the strategy team when specific domain expertise are needed.

5.3 Backcasting (Normative Scenario Planning)

Trend mapping describes what the future might look like, but says nothing about what an organization *wants* the future to look like. Technology pioneers like AFRL are chartered with *creating* and *shaping* the future, not just reacting to it. Backcasting (also known as Normative Scenario Planning) reverses the approach to strategic planning by starting with a story or vision of a *desirable future* that we want to create through our strategy and actions, you then work backwards to derive the pathways through which to make this future a reality (Figure 7). By anchoring strategy in the future, the backcasting approach prevents the "present-forward" or extrapolative mindset. It is most appropriate for achieving quantum leaps or disruptive technology developments further out into the future.

[46] IBM Global Innovation Outlook 2.0 Report, 2006. (https://www.ibm.com/Fibm/Ffiles/FC685131J48569G91/FGIO_2005_for-printing.pdf)

To successfully backcast, it is important to start with a clear, compelling, proactive vision or mission (without being so broad that it loses any meaning). This vision will serve as an inspirational and shared goal for all stakeholders. A clear and compelling vision energizes and inspires research teams to execute on "moonshot" projects. Indeed, consistent with this namesake, John F. Kennedy's speech in May 1961 painted a clear and compelling vision of America's leadership in space flight that was tied to a specific goal.

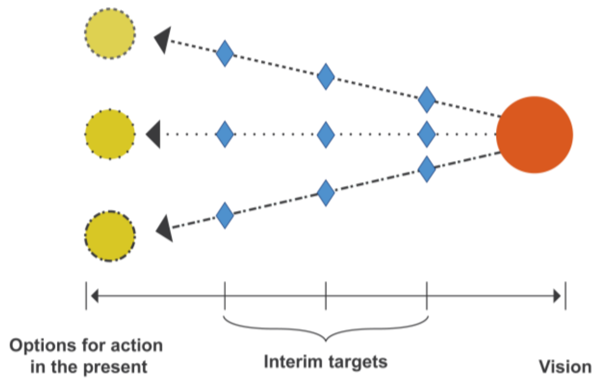


Figure 7. A graphical representation of backcasting. (Adapted from Kasow et al. 2008)

Backcasting involves 4 steps:[47]

1. Visualization. Envisioning, defining, and organizationally aligning behind an ideal future environment or desired capability. The organization must first identify the areas of highest-impact in the likely future environment, i.e., the output from trend mapping. In this vision the organization defines its role as a successful player who has achieved dominance. This process should occur at the Mission (capital M) level as it defines the organization's desired future capabilities, rather than capabilities in general. It is a vision of what the *organization* will become, not what the *environment* will become.
2. Retrospection. Working backwards from future goals to the present and delineating alternative paths to get there. These paths can be analyzed and weighted against each other to choose the best bets, taking into account current limitations.
3. Roadmapping. Outline interim targets along the path. These forward-looking intermediate targets (2020, 2025, 2030, etc.) should be broken down into tracks for identifying the "must-haves" to reach the next target. For example, analyzing tracks for technical research areas, resources, personnel, and external partnerships or ecosystems provides an operational guide for forward progress and will alert the organization to specific gaps that must be addressed in the near term. This is a key step for selecting short-term research areas to focus current resources.
4. Adaptation. Having conceptualized the future, and forecasted a short-term roadmap, it is important to revisit this analysis in order to stay agile. Over long-time frames, on the order of 20 years, it may be vital to revise the desired end-state. The vision thus becomes a slowly moving and adapting target. In the same way, the adaptation of the interim targets and roadmaps will also slowly evolve.

5.3.1 Scope and Applicability

Backcasting is best applied to big and ambitious problems that require technology breakthroughs: proposed solutions that have never been implemented. For instance, Google X (their "moonshot organization") is working on projects like Project Loon (a balloon-based Internet service project), driverless cars, augmented reality glasses, neural networks, and Project Calico (life extension). Backcasting is also best used by large

[47] Kosow, Hannah; Gaßner, Robert. "Methods of Future and Scenario Analysis: Overview, Assessment, and Selection Criteria", German Development Institute, 2008. (https://www.die-gdi.de/en/studies/article/methods-of-future-and-scenario-analysis-overview-assessment-and-selection-criteria/)

organizations that have the capital, technical capability, talent and patience to engage in breakthrough research. It is not suitable for short-term business and revenue goals.

5.3.2 Advantages and Disadvantages

Backcasting is powerful because it is proactive rather than reactive. It views strategy as shaping and creating the future we want. It is flexible, allowing for many paths that are not constrained by current capabilities or assets. Backcasting is also inspiring because it involves telling stories about the future. Such stories provide teams with a sense of a larger purpose and aligns people toward a unified goal. However, to the extent there may be competing and conflicting visions of the desirable future, the strategy team may have trouble converging on a common vision. Or a team may converge too quickly on one vision, without fully considering all possibilities. There may also be conflicting and competing pathways and roadmaps for arriving at the end state. The team has to bet on the best pathway based on the information available at the time. A safeguard against betting on the wrong future vision or the wrong pathway is to adapt the future vision on a periodic basis, similar to the approach in adapting trend maps as data about how the future become available.

5.3.3 Best Practices and Next Practices

Best practices in backcasting are similar those of trend mapping. The team that creates the vision of the ideal future should consist of diverse domain experts from inside and outside the organization. Diversity in expertise and experiences will reduce the probability of groupthink or blind spots. As in trend mapping, backcasting should be revisited on a periodic basis (every 2 to 3 years) to validate the desired future and evaluate feasibility. Finally, backcasting should be informed by trend maps as an input at the outset as well as while updating the roadmaps on a periodic basis.

5.4 Red Teaming

Trend mapping and backcasting address likely futures and desirable futures, respectively. However, as the saying goes, "making predictions is difficult, especially when it comes to predicting the future!" How does an organization prevent biases and current mental models from limiting its ability to formulate a robust strategy? A powerful approach to mitigate risk and to encourage debate is red teaming. This approach is an independent application of a range of critical techniques designed to mitigate risk and create a more robust strategy by challenging an organization and its assumptions. Red teaming allows an organization to encourage dissent through a structured process, thereby strengthening the overall strategy by identifying weak spots.

Red teaming is consistently applied in defense operations strategy.[48] However, this team believes that the technique is also applicable to AFRL. It is an important concept for the USAF because military organizations are hierarchical, with a deeply rooted "command and control" culture that discourages dissent and can predispose an organization towards accepting the viewpoints of higher authorities. Within the context of strategy, conforming to a system where the higher officer/dominant idea is always correct is dangerous and limiting. While obeying the orders of commanders is essential for warfighters in the battlefield, the same mindset is not appropriate for an S&T research organization like AFRL. In S&T research is inherently uncertain; there is rarely a single, clear right answer. Thus, leadership must remain open to alternative viewpoints. Moreover, the environment that defines the USAF's world tends to send weak signals about disruption. These weak signals are usually ignored because they come from the periphery, where the signal to noise ratio is relatively high. Red teaming helps amplify weak signals by

[48] Defense Science Board, "Challenges to Military Operations in Support of U.S. Interests", Vol II, Main Report, December 2008. (https://www.acq.osd.mil/dsb/reports/2000s/ADA491393.pdf)

bringing people in who sit at the peripheries (similar to the challenge current thinking model described in section 2.4).

The red team plays the role of a “thinking enemy” (or challenger). By design, red teams are an independent group that is small, underfunded, and placed at a disadvantage relative to the main team. This gives them strength; they need to be more creative, do more lateral thinking, maximize surprise, and attack dogma to succeed. Red teaming is an approach that recognizes, celebrates, and institutionalizes dissenting points of view to reduce the probability that the dominant logic of an organization is built on flawed or outdated assumptions.

5.4.1 Scope and Applicability

Red teaming is best employed when an organization is at a strategic crossroads and faced with important choices (see 3G example in section 5.4.3). Red teaming is also appropriate when there is “false consensus”, often the result of a culture of passive aggression within an organization. Dissenters are driven underground or are even expelled from the organization, thus eliminating their potentially valuable perspectives. This tends to happen in organizations that have been very successful in the past, have long-tenured employees, and/or have a strong dominant culture. Recognizing these characteristics in an organization and implementing the red teaming strategy could save the organization from dangerous group-think.

5.4.2 Advantages and Disadvantages

Red teaming can help create a culture of respecting thinking that may be heretical or disruptive to the dominant world view. Indeed, such a culture is essential to successful red teaming, as only then can individuals play the devil’s advocate role effectively without worrying about sanctions or being seen as disrespecting hierarchy. Red teams can help avoid blind spots, improve the peripheral vision of an organization and identify opportunities that may not be in clear view because they are not yet mainstream or widely accepted. However, if it is not executed well, the red team will not be heard. There must be a transparent process for listening and acting on red team recommendations. Leaders must support the formation of red teams and create a culture of respect for the minority opinion. There is also a danger that red teams be over-used and over-resourced; too many minority opinions and too much emphasis on second-guessing the mainstream strategy can ultimately lead an organization down the wrong path.[49]

5.4.3 Best Practices and Next Practices

Red teams must be staffed with those not considered established subject-area experts or those on the main strategy team. It is important to bring in points of view that differ from the mainstream organization. Also, red teams need to be supported by senior leaders. They need to be officially blessed and resourced, and there needs to be a process for feedback that ensures leadership receives the input. Leadership needs to honor dissent and respect the minority opinion. Red teams are psychological “safe places” for dissent and they should be treated as such so that people can offer dissenting points of views without fear of retribution or ridicule. Other best practices include:

- Establish “rules for dissent”: Members must be trained to dissent in constructive ways.
- Establish red teams at the outset: Plan red teams proactively as an integral component of the strategy formulation process.
- Match teams to the tasks: The skills and experience of team members should be task-specific and must include those whose opinions and points of view are respected in the broader organization.

---

[49] Zenko, Micah. (2015) *Red Team: How to Succeed by Thinking Like the Enemy.* New York, NY: Basic Books

In the late 1990s, wireless service providers in the United States needed to decide which standard they would bet on among 3G (third-generation) wireless communications technologies.[50] This decision point represents the perfect opportunity for red teams; a bet on the wrong standard would have massive consequences for the business. In another example, in the late 1990s, as Boeing was reaching the end of the lifecycle of the 767 and 747 passenger aircraft, it had to decide between the "hub-and-spoke theory" and the "point-to-point theory" of future air transportation. The hub and spoke theory posited that airlines would fly large planes to a few giant global hubs, from which they would fly smaller planes on shorter routes. The point-to-point theory, in contrast, argued that passengers would prefer to fly directly between destinations in smaller planes, preferring point-to-point connections and reducing congestion in large hub airports. This was a "bet the company" decision. Boeing ended up making the right call, focusing on smaller aircraft, while Airbus focused on larger aircraft designed to fly between global hubs, and suffered billions of dollars in losses.[51]

Red teams can even include individuals who "rebel" against the mainstream of the organization. A great example is J. Allard, a low-level program manager at Microsoft, who was frustrated with the company's lack of recognition of the disruptive potential of the internet. In January 1994, Allard wrote a "call-to-arms" memo that recommended Microsoft "embrace" internet standards and "extend" Windows to the internet. He advocated building an internet browser and viewing the browser as a complement to the desktop operating system. Allard's memo caught the attention of Bill Gates, resulting in his "Internet Tidal Wave" memo in May 1995 that caused Microsoft to pivot its development efforts to "embrace and extend" the internet.[52]

---

[50] "Migration to 3G Technology Standards: A Comparison of Selected Countries", Richard Nunno, International Bureau, FCC, September 2003.

[51] "The Giant on the Runway", Economist, October 11, 2007. (https://www.economist.com/briefing/2007/10/11/the-giant-on-the-runway)

[52] McHugh, Josh. "The Xbox Reloaded," Wired, June 1, 2005. (https://www.wired.com/2005/06/xbox-3/)

Page intentionally left blank

6. TRANSFORMATIONAL NECESSITIES AND CONCLUSIONS

In summary, this report has proposed the following models/approaches for USAF to implement (adapted to its particular circumstances):

- Problem-focused approaches that support applied research directly aligned with well-specified challenges, implemented with (among other methods) challenge-driven teams and, where appropriate, backcasting to develop a roadmap that proactively moves towards a desired future.
- Discovery-based approaches that support exploratory projects in new fields relevant to the USAF mission, using trend mapping as needed to define the future landscape of needs and influences and, as appropriate, creating and leveraging affinity networks.
- Challenge current thinking approaches based on fostering an organizational culture that questions assumptions, including, as warranted, red teams aimed at identifying risks and guarding against group-think. The enabler model can support the entrepreneurial efforts of employees by creating an outlet for ideas that do not fit existing programs. These approaches can also play an important role in changing the organizational culture.
- Broad approaches to measuring ROI, using metrics from leading research institutions, can support decision-making in all of the above approaches. ROI models need to cover not only outcomes but also general innovation capabilities: people (research talent), tools, patents, and knowledge communities/networks.

Collectively, these various models and approaches support 3 overriding ideas that form the basis for the NU team's specific recommendations:

- Remove obstacles that stifle innovation.
- Be a learning organization.
- Attract the best people.

Removing obstacles to innovation and proactively implementing structures and processes that facilitate continuous learning will help USAF attract the best people, who will then drive innovation and sustain an agile culture from which breakthrough solutions are most likely to emerge.

6.1 Remove Obstacles that Stifle Innovation

The models described in this report for selecting research areas, measuring results, organizing teams, and setting strategy will go a long way toward facilitating the kind of agility and autonomy sought by USAF leadership and researchers. Lightening the touch of oversight can encourage high performance and greater employee engagement. Most of the suggested models, such as challenge current thinking, enabler model, and red teams, may be implemented on a small scale at first and then expanded as USAF gains experience with the various approaches.

Beyond these models, it is important to eliminate various potential impediments to innovation such as inefficient contracting processes or incommodious IT systems (most notably, videoconferencing). The NU team endorses the idea, raised during our site visit, to embed acquisition staff in directorates and enable communication with potential vendors earlier in the contracting process. Leading organizations, particularly in the IT space, are now using "smart buyer" organizations (sometimes referred to as "strategic sourcing groups") with exactly these features in order to streamline and improve contracting and external partnerships.[53] The USAF's Air Combat Command, Acquisition Management and Integration Center (AMIC) is an excellent example of such an organization. It describes itself as:

> *"an integrated team of 270 acquisition professionals…(with) an integrated culture model that links those responsible for setting the requirements and overseeing the execution with those who are experts in the contracting mechanisms. Projects are managed as multi-functional teams with functional expertise on location (i.e., Logistics, Quality Assurance, Civil Engineer, and Communications)…. Program managers and contracting officers work side-by-side, speak the same language, understand each other's constraints.*[54]

Finally, during our site visit the NU team learned about various programs and resources—the Entrepreneurial Opportunities Program, Partnership Intermediary Agreements, the 444 maker space, the i2i (intellect to intellect) exchange program with industry—that are providing new pathways for entrepreneurial people at AFRL to develop innovative ideas. The USAF has recently been leading the DOD in the use of commercial venturing mechanisms, such as accelerators and incubators. Greater linkages with these sister organizations, such as AFWERX,[55] should be encouraged. The team advocates for the continuation and expansion of the Entrepreneurial Opportunities Program to attract highly skilled and motivated individuals, and to build an external community familiar with and invested in helping to fulfill USAF needs.

The NSF I-Corps model, described in section 4.2, is a particularly suitable model for AFRL. Linking basic and applied research programs to downstream applications can inspire design-thinking approaches and imbue research programs with agility as needs and technologies evolve. Many academic institutions have found that their entrepreneurial faculty benefit tremendously from programs such as the I-Corps. Projects run through a Lean LaunchPad-like program can link to existing entrepreneurial infrastructure both locally and nationally such as accelerators and incubators to further the technology transfer process. Additionally, as these types of programs advance the principal investigators in the initial stages of technology transfer, follow-on programs are often necessary to insure researchers can fully advance the technologies. Principal investigators who have enrolled in the I-Corps program have found the curriculum beneficial not only for their immediate entrepreneurial endeavors, but also for their research programs, grant applications, and relationships with corporate partners.

6.2 Be a Learning Organization

The "learning organization" concept was popularized by Peter Senge in his book, *The Fifth Discipline*. According to his view, learning organizations share 5 key characteristics:[56]

- Systems thinking. A focus on measuring the performance of the whole organization as well as its various components.
- Personal mastery. Individuals committed to continuous self-improvement.
- Mental model. Commitment to challenging practices dictated by institutional memory in an open and constructive way.

---

[53] Graham, David; Johnson, Hansford; Kelly, Julie; Lippitz, Michael; Richmann, James; Van Atta, Richard. "Improving Department of Defense (DoD) Contracting for Services," Institute for Defense Analyses Paper P-5010, July 2013.
[54] *Ibid*., Pages 30-31.
[55] From the website http://afwerxdc.org/: Established in 2017…AFWERX is a catalyst for agile Air Force engagement across industry, academia, and non-traditional contributors to create transformative opportunities and foster an Air Force culture of innovation.
[56] Excerpted from Wikipedia, "Learning Organization," June 20, 2018. (https://en.wikipedia.org/wiki/Learning_organization)

- Shared vision. Promoting a common identity that provides focus and energy for learning.
- Team learning. Structures that facilitate team learning with features, such as boundary crossing and openness (dialogue and discussion).

The systems thinking aspect may be implemented as described in the ROI section above by defining KPIs that span multiple levels of the organization. The organization can then use these to evaluate its overall performance as well as that of its individual programs. The various models described above for facilitating small team collaborative research and enabling individuals can go a long way to enhancing personal mastery, team learning, and organizational "unlearning" of inhibitory standard operating procedures. In particular, incentive programs and recognition offered to people that question the standard paradigm or go against the grain can generate an environment of psychological safety.

Unlearning can also be facilitated by creating "sunset" mechanisms for programs, or standardized ways to review and shift research foci over time. Making the end of programs more routine and expected removes the stigma and fear associated with change. For instance, 3M Corporation employs a process called Product Migration Planning (Figure 8.) that identifies a strategic series of incremental innovations that build capabilities toward breakthrough outcomes. The process highlights multiple pathways, allowing researchers to shift directions if a particular line of research begins to not look promising. "Managers are more comfortable terminating a failing project early because they can look at the Migration Map and readily identify the next promising alternative."[57]

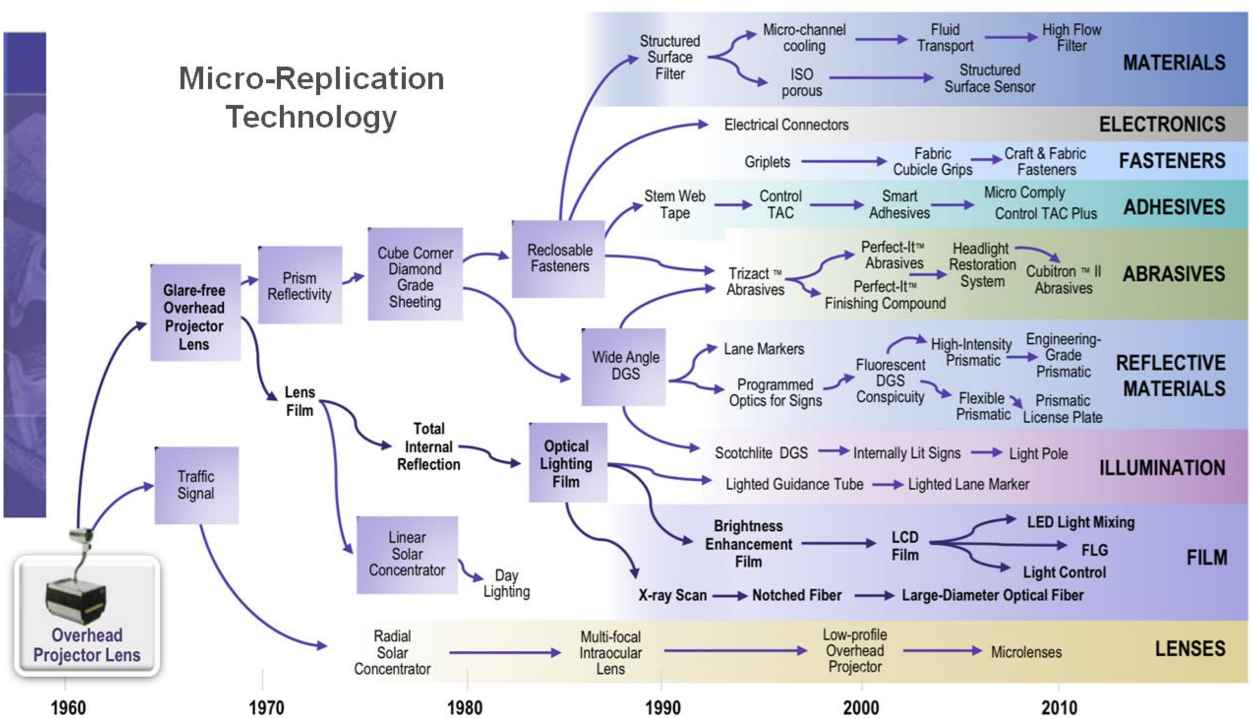


Figure 8. A graphical representation of Product Migration Map.[58]

---

[57] Corporate Executive Board, "3M's Product Migration Planning" (2012).
[58] Buckley, George. "An Emerging Strategy for Growth," 3M Investor meeting, 2006. (https://www.slideshare.net/finance10/george-w-buckley-chairman-president-and-chief-executive-officer)

Beyond these 5 characteristics, the NU team recommends that AFRL develop narratives that trace breakthroughs and technologies back to basic research. Stories are a very effective method for communicating the impact of research. Thus, it is important to continually trace technologies and breakthroughs back to original scientific discoveries. Several narratives should be constructed for each directorate. These narratives could even be part of the sunset provisions of programs, thereby honoring the people and efforts involved.

6.3 Attract the Best People

To realize the desired future for 2030 and beyond, one must also anticipate the future of research organizations and business processes. The next-generation of research organizations will need to have fewer boundaries and be more agile, global, and transparent.[59] The workplace environment is expected to go through major changes that will reshape how organizations operate, including new technologies, high workforce turnover, and a focus on teams. Widespread internet access and cloud-based applications will change how and where work is performed.[60] The strict corporate organization structures will disappear, and projects will be identified to meet specific objectives with teams forming and disbanding dynamically.[61] Organizations will embrace and optimize the use of smart technology for enhancing communication and research. Keeping these likely scenarios in mind will help AFRL compete for talent in 2030 and burnish its already good reputation for quality research. Beyond this, the NU team recommends the following:

- Increase diversity. (1) Enhance AFRL's public-facing website to bring more awareness to scientific challenges, research programs, and interests most relevant to the USAF mission; and (2) engage a diverse scientific community through networking events or scientific professional societies.
- Fund "people" not "projects". Develop a program like the HHMI Investigator Program (see section 4.3) to facilitate long-term relationships with high performing researchers. These people would be employed by the USAF but reside at universities.
- Initiate an ROTC-type program. Offer graduate education fellowships in exchange for a commitment to serve within the USAF research organizations for a period after graduation.
- Develop "urban outposts". Many top people may be reluctant to relocate to an AFRL site versus better-known, more vibrant innovation hubs, such as Silicon Valley, California. AFRL should experiment with setting up offices in various innovation hubs and attractive urban centers where locals can learn about the AFRL research agenda, interact with personnel on temporary duty assignment, and make other contributions.

[59] Boudreaux, J. 'Work in the Future Will Fall into These 4 Categories' Harvard Business Review. 2016
[60] 'Cisco Connected Workplace. The Workplace of Tomorrow', Cisco Systems Inc. White Paper. 2013
[61] Hansen, T. 'The Future of Knowledge Work', Intel Corporation White Paper. 2014

APPENDIX A

Agenda for Site Visit to Wright-Patterson Air Force Base

On April 9, 2018, seven members of the NU study team interviewed twenty-eight AFRL personnel at Wright-Patterson Air Force Base to identify strengths and challenges in each of the four thematic areas. The participating NU study team members were Jay Walsh, Prem Kumar, Mark Werwath, Lisa Dhar, Michael Lippitz, Mohanbir Sawhney, and Jian Cao.

AIR FORCE RESEARCH LABORATORY
Northwestern University
09 April 2018

<u>DRESS</u>
Military: UOD
Civilian: Business Attire

4 Apr 2018 @ 1745

Visitors: 8 personnel, including Dr. Joseph "Jay" Walsh, Northwestern University's VP for Research

Purpose	To understand history, challenges, and priorities of AF S&T, as well as what change initiatives have worked or not worked.	
Note: Times are EASTERN	**Group 1** Bldg 15, Rm 250 - Fish Bowl Dial-in: 937-656-8621 Conference ID: 97475055# Passcode: 994994#	**Group 2** Bldg 15 Rm 253 - Cave Dial-in: 937-656-8621 Conference ID: 97475028# Passcode: 324324#
0830-0900 (30 min)	**Dr. Morley Stone** Chief Technologist, AFRL	**Mr. Tom Lockhart** Director, Plans & Programs and Strategic Development Planning & Experimentation
0900-0930 (30 min)	**Dr. Siva Banda** Chief Scientist, Aerospace Systems	**Dr. Mary Kinsella** University Relations Manager, Personnel **Mr. Kurt Masser** Corporate Recruiting & Employee Development, Personnel
	Note: 0900-0930 Maj Gen Bill Cooley, AFRL Commander Office Call with Dr. Jay Walsh, NU VP for Research	
0930-1000 (30 min)	**Ms. Lisa LeDuc** Director, Contracting	**Col Elena Oberg** Vice Commander, AFRL
1000-1030 (30 min)	**Dr. Kelly Hammett** Director, Directed Energy VTC - Albuquerque NM (0800 Mtn Time)	**Col David Winebrener** Acting Director, AF Office of Scientific Research VTC - Arlington VA
1030-1100 (30 min)	**Mr. Rich Bagnell** Program Manager, Directed Energy VTC - Albuquerque NM (0830 Mtn Time)	**Ms. Jennifer Morgan** Director, Financial Management & Comptroller
1100-1130 (30 min)	**Dr. Alok Das** **Mr. Kirt Moser** Director, Center for Rapid Innovation	**Mr. Brent Gibson** Plans & Programs, AF Life Cycle Management Center
1130-1200 (30 min)	**Mr. Jacob Hinchman** **Ms. Mary Kate Yost** Program Managers, Aerospace Systems	**Col Chuck Ormsby** Acting Director, Materials and Manufacturing **Dr. Tim Bunning** Chief Scientist, Materials and Manufacturing
1200-1300 (60 min)	**Lunch**	
1300-1400 (60 min)	**Tour – Hypersonics, Bldg 18**	
1400-1430 (30 min)	**Mr. Chris Ristich** Strategic Development Planning & Experimentation	**Mr. Jeff Stanley -** in person Deputy Assistant Secretary of the Air Force for Science, Technology, and Engineering
1430-1500 (30 min)	**Mr. Wayne Ayer** Director, Engineering & Technical Management	**Mr. Bill Harrison** Director, Small Business
1500-1530 (30 min)	**Ms. Ruth Moser** Director, Sensors	**Col Garry Haase -** in person Director, Munitions
1530-1600 (30 min)	**Dr. Jessica Salyers** Deputy Exectuive Director, AFRL	**Ms. Rachel Jakubiak** Program Manager, Materials and Manufacturing
1600	**End of Visit**	

APPENDIX B

Agenda for the Northwestern University Business Organization and Processes Study Workshop

On June 1 and June 2, 2018, the NU study team convened 45 participants with diverse backgrounds and expertise from academic, commercial, and government sectors to identify key challenges and approaches to manage an early-stage research enterprise. The agenda was organized around the four study themes and included both full-group brainstorming sessions, small-group breakout sessions, and inter-theme sessions.

WORKSHOP AGENDA

DAY 1 // FRIDAY, JUNE 1, 2018

7:30 AM - 8:30 AM	**Registration and Breakfast** *Heritage Ballroom, 2nd Floor*
8:30 AM - 9:15 AM	**Welcome, Orientation, and Opening Roundtable** Jay Walsh, *Vice President for Research, Northwestern* Robert Mittman, *Workshop Facilitator*
9:15 AM - 9:45 AM	**The Context: Why Are We Here?** Frank Donnelly, *Strategic Advisor, Financial Management, AFRL* Nicole Moore, *Director, Office of Research Development, Northwestern*
9:45 AM - 10:00 AM	**Break**
	Brainstorming Models, Examples, and Best Practices
10:00 AM - 10:05 AM	Overview
10:05 AM - 10:50 AM	Session 1 | Identifying Research Areas
10:50 AM - 11:35 AM	Session 2 | Return on Investment
11:35 AM - 12:20 PM	Session 3 | Organization Structure
12:20 PM - 1:15 PM	**Lunch**
1:15 PM - 2:00 PM	Session 4 | Strategy
2:00 PM - 2:15 PM	**Charge to Breakout Groups**
2:15 PM - 2:30 PM	**Break** *Hinman Foyer, 9th Floor*
2:30 PM - 4:25 PM	**Breakout Sessions** Identifying Research Areas — *Rogers Room, 9th Floor* Return on Investment — *Bonbright Room, 9th Floor* Organization Structure — *Haven Room, 9th Floor* Strategy — *Cummings Room, 9th Floor*
4:25 PM - 4:30 PM	**Refreshments**
4:30 PM - 5:00 PM	**Closing Session** *Hinman Auditorium, 9th Floor*
5:00 PM	**Adjourn** *Dinner at Chef's Station*

WORKSHOP AGENDA

DAY 2 // SATURDAY, JUNE 2, 2018

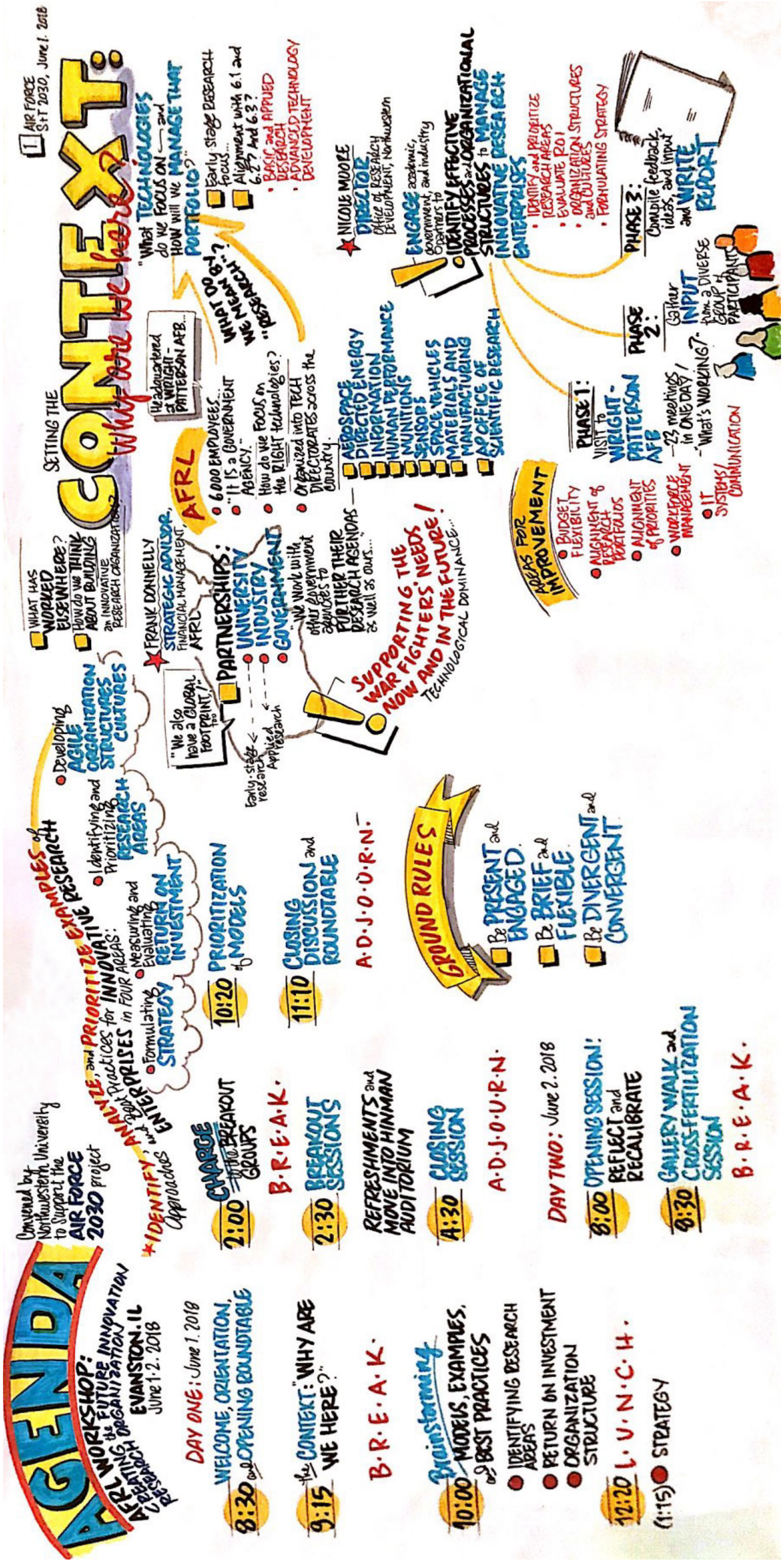
7:30 AM - 8:00 AM	Breakfast *Heritage Ballroom, 2nd Floor*
8:00 AM - 8:30 AM	Opening Session: Reflect and Recalibrate
8:30 AM - 10:00 AM	Gallery Walk and Cross-Fertilization Session
10:00 AM - 10:20 AM	Break
10:20 AM - 11:10 AM	Prioritization of Models
11:10 AM - 12:00 PM	Closing Discussion and Roundtable
12:00 PM	Adjourn *Boxed Lunches Available*

Page intentionally left blank

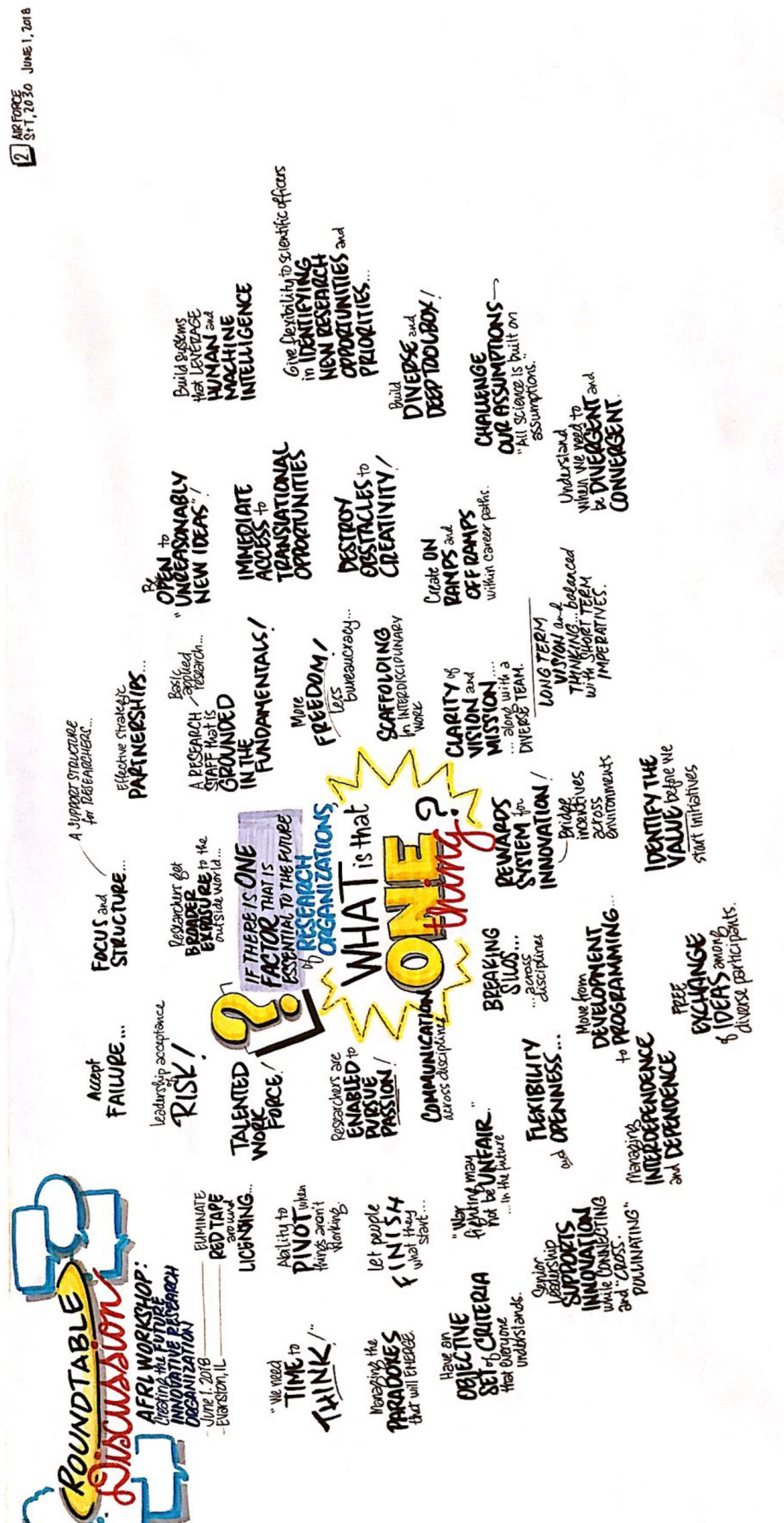
APPENDIX C

Graphical Records of the Northwestern University Business Organization and Processes Study Workshop Sessions

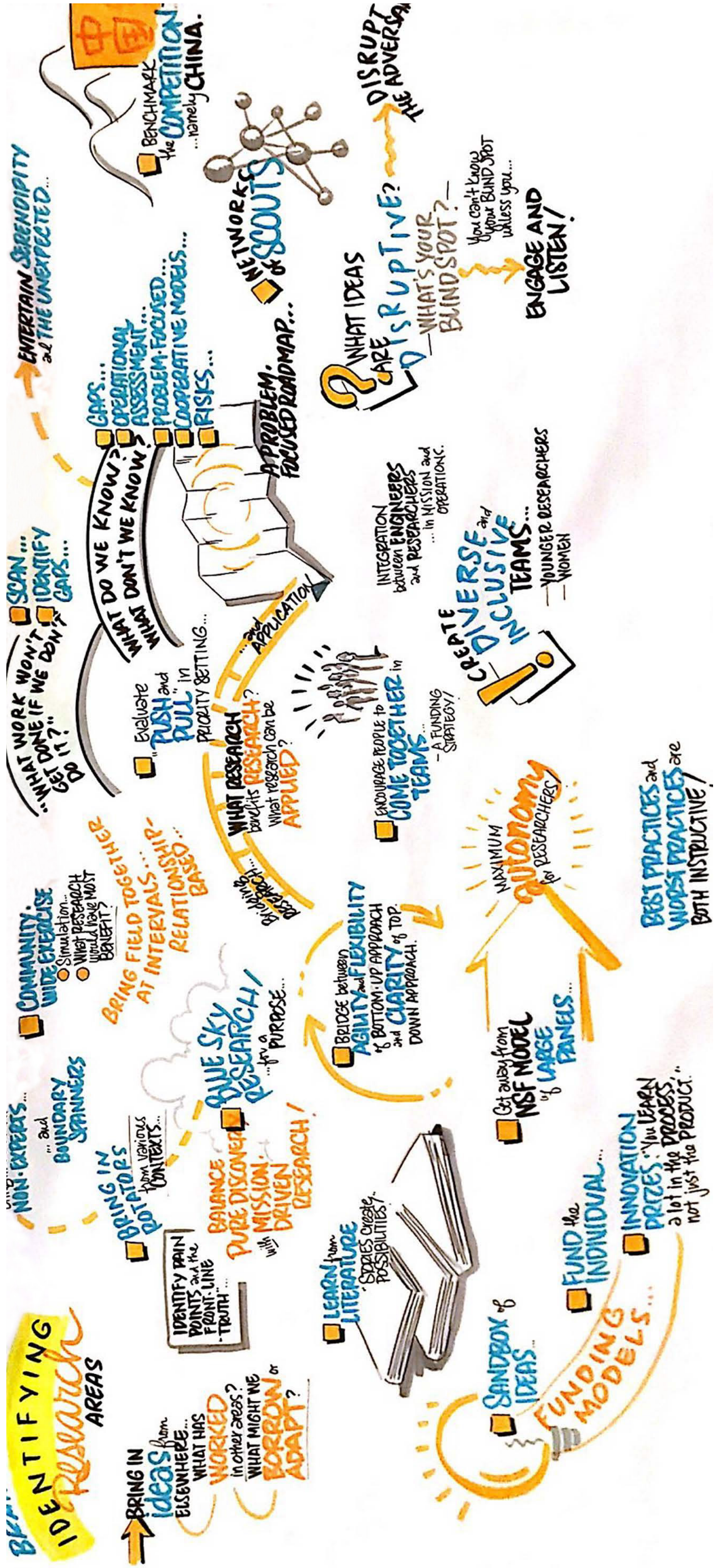
During the workshop held on June 1-2, 2018, the primary discussion points were captured in real time by a graphical artist who created pictographic records of each of the full-group sessions on large (8’x4’) poster boards displayed in the front of the room. These images are photographs of the resulting graphical records.

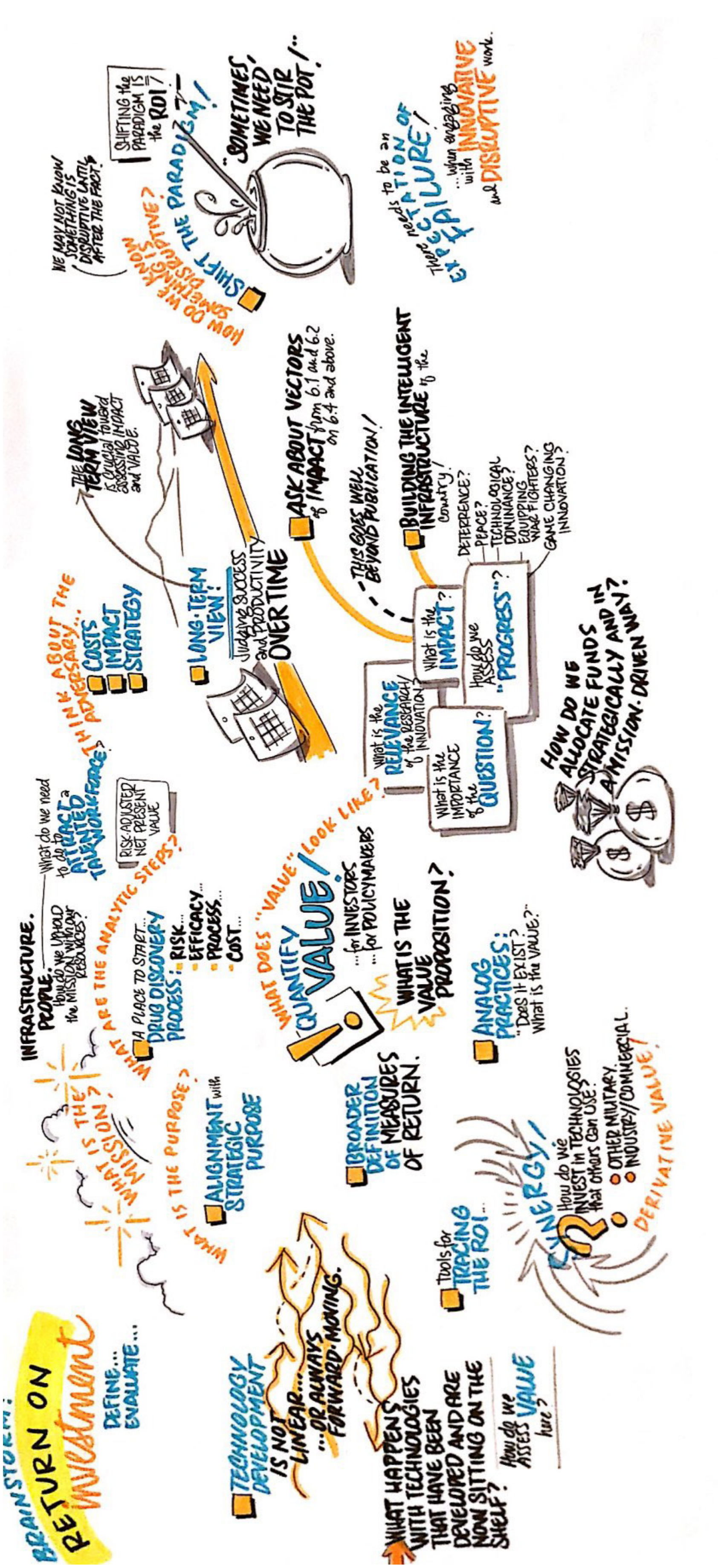


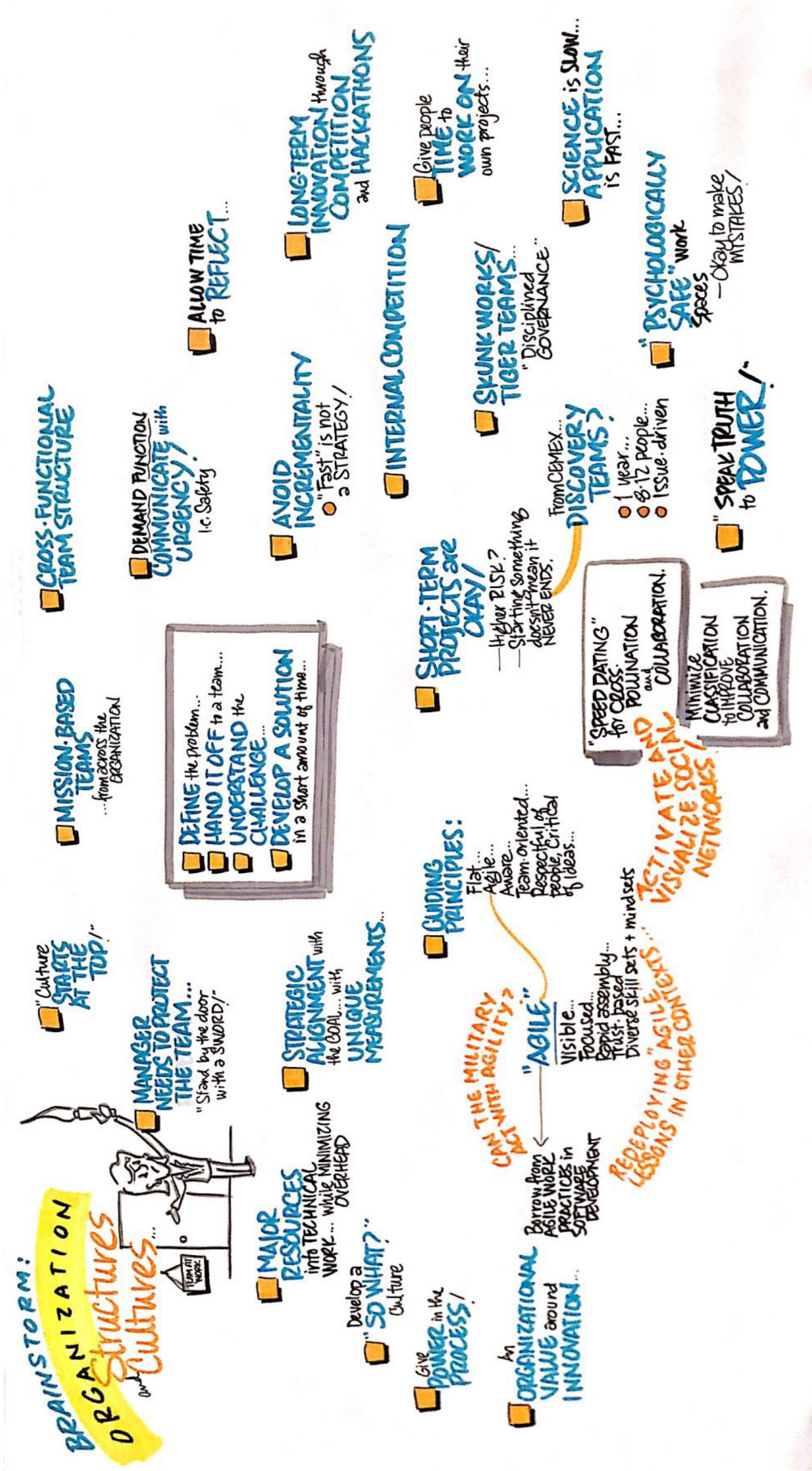
AGENDA
AFRL WORKSHOP: CREATING the FUTURE INNOVATION RESEARCH ORGANIZATION
EVANSTON, IL
June 1-2, 2018
Convened by Northwestern University to support the AIR FORCE 2030 project
DAY ONE: June 1, 2018
8:30 WELCOME, ORIENTATION, and OPENING ROUNDTABLE
9:15 the CONTEXT: "WHY ARE WE HERE?"
B·R·E·A·K·
Brainstorming
10:00 MODELS, EXAMPLES, and BEST PRACTICES
IDENTIFYING RESEARCH AREAS
RETURN ON INVESTMENT
ORGANIZATION STRUCTURE
12:20 L·U·N·C·H·
(1:15) STRATEGY
2:00 CHARGE to the BREAKOUT GROUPS
B·R·E·A·K·
2:30 BREAKOUT SESSIONS
REFRESHMENTS and MOVE INTO HINMAN AUDITORIUM
4:30 CLOSING SESSION
A·D·J·O·U·R·N·
DAY TWO: June 2, 2018
8:00 OPENING SESSION: REFLECT and RECALIBRATE
8:30 GALLERY WALK and CROSS-FERTILIZATION SESSION
B·R·E·A·K·
*IDENTIFY, ANALYZE, and PRIORITIZE EXAMPLES of Approaches and Best Practices for INNOVATIVE RESEARCH ENTERPRISES in FOUR AREAS:
Formulating STRATEGY
Measuring and Evaluating RETURN ON INVESTMENT
Identifying and Prioritizing RESEARCH AREAS
Developing AGILE ORGANIZATION STRUCTURES and CULTURES
10:20 PRIORITIZATION of MODELS
11:10 CLOSING DISCUSSION and ROUNDTABLE
A·D·J·O·U·R·N·
GROUND RULES
Be PRESENT and ENGAGED.
Be BRIEF and FLEXIBLE
Be DIVERGENT and CONVERGENT
1 AIR FORCE S&T 2030, June 1, 2018
SETTING THE CONTEXT: Why are we here?
WHAT HAS WORKED ELSEWHERE?
How do we THINK ABOUT BUILDING an INNOVATIVE RESEARCH ORGANIZATION?
FRANK DONNELLY STRATEGIC ADVISOR, FINANCIAL MANAGEMENT, AFRL
"We also have a GLOBAL FOOTPRINT!"
PARTNERSHIPS:
UNIVERSITY
INDUSTRY
GOVERNMENT
Early-stage research
Applied research
We work with other government agencies to FURTHER THEIR RESEARCH AGENDAS as well as ours...
SUPPORTING THE WAR FIGHTERS' NEEDS! NOW AND IN THE FUTURE!
TECHNOLOGICAL DOMINANCE...
AFRL
6,000 EMPLOYEES.
"It is a GOVERNMENT AGENCY."
How do we focus on the RIGHT technologies?
Organized into TECH DIRECTORATES across the country.
Headquartered at WRIGHT-PATTERSON AFB...
AEROSPACE
DIRECTED ENERGY
INFORMATION
HUMAN PERFORMANCE
MUNITIONS
SENSORS
SPACE VEHICLES
MATERIALS AND MANUFACTURING
AF OFFICE of SCIENTIFIC RESEARCH
WHAT DO WE MEAN by "RESEARCH"?
"What TECHNOLOGIES do we FOCUS ON — and HOW will we MANAGE THAT PORTFOLIO?"
Early stage RESEARCH focus...
Alignment with 6.1 and 6.2? And 6.3?
BASIC and APPLIED RESEARCH
ADVANCED TECHNOLOGY DEVELOPMENT
NICOLE MOORE DIRECTOR, Office of Research Development, Northwestern
ENGAGE academic, government, and industry partners to IDENTIFY EFFECTIVE PROCESSES and ORGANIZATIONAL STRUCTURES to MANAGE INNOVATIVE RESEARCH ENTERPRISES
IDENTIFY and PRIORITIZE RESEARCH AREAS
EVALUATE ROI
ORGANIZATION STRUCTURES and CULTURES
FORMULATING STRATEGY
AREAS FOR IMPROVEMENT
BUDGET FLEXIBILITY
ALIGNMENT of RESEARCH PORTFOLIOS
ALIGNMENT of PRIORITIES
WORKFORCE MANAGEMENT
IT SYSTEMS/COMMUNICATION
PHASE 1: VISIT to WRIGHT-PATTERSON AFB
~23 meetings in ONE DAY!
"What's WORKING?"
PHASE 2: Gather INPUT from a DIVERSE GROUP of PARTICIPANTS
PHASE 3: Compile feedback, ideas, and input and WRITE REPORT



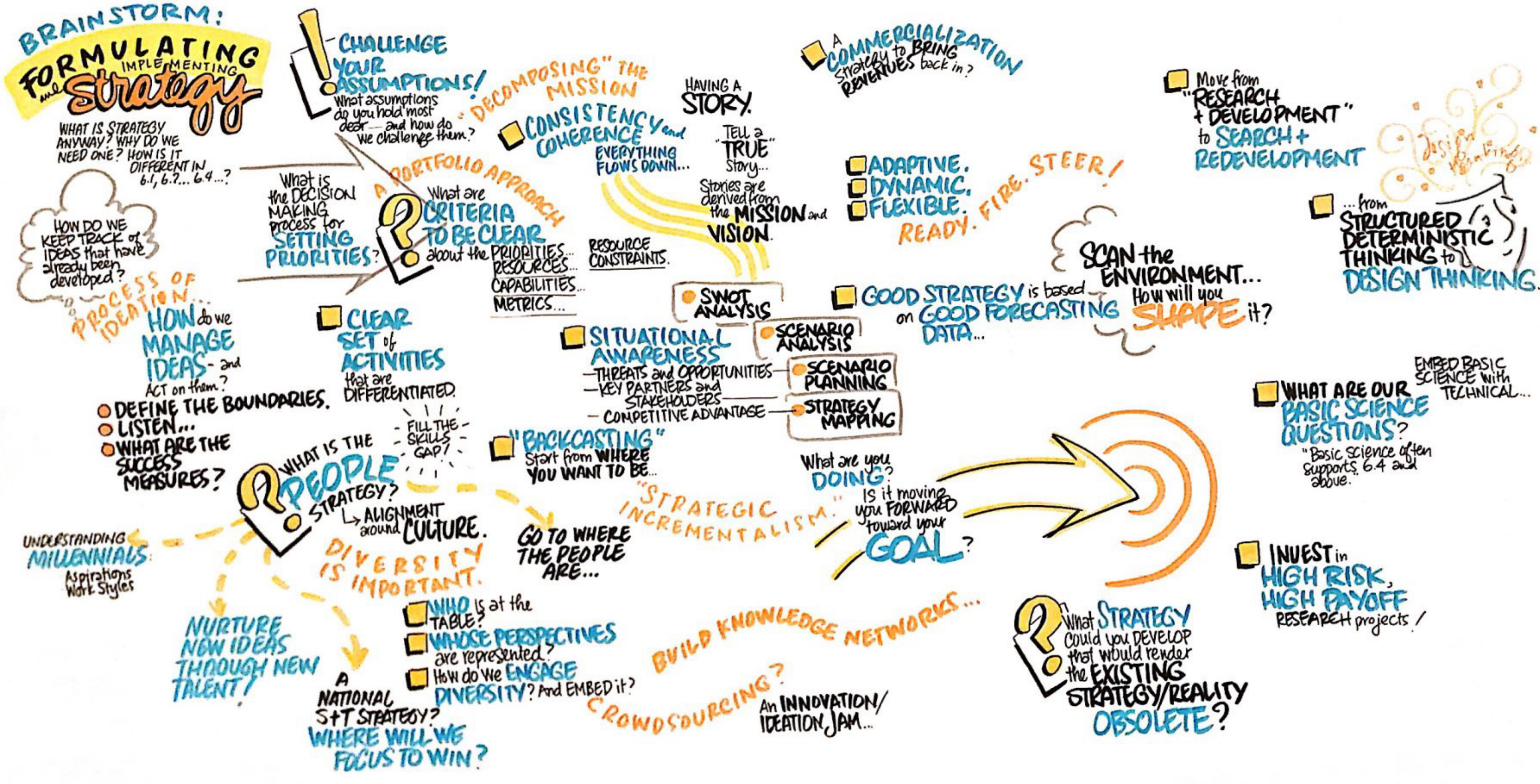
ROUNDTABLE Discussion
AFRL WORKSHOP: Creating the FUTURE INNOVATIVE RESEARCH ORGANIZATION
June 1, 2018
Evanston, IL
AIR FORCE S&T 2030 JUNE 1, 2018
ELIMINATE RED TAPE around LICENSING...
"We need TIME to THINK!"
Ability to PIVOT when things aren't working.
Managing the PARADOXES that will EMERGE.
Let people FINISH what they start...
Have an OBJECTIVE SET of CRITERIA that everyone understands.
"War fighting may not be UNFAIR." ...in the future
Senior leadership SUPPORTS INNOVATION while CONNECTING and "CROSS-POLLINATING"
FLEXIBILITY and OPENNESS...
Managing INTERDEPENDENCE and DEPENDENCE
Accept FAILURE...
Leadership acceptance of RISK!
TALENTED WORK FORCE!
Researchers are ENABLED to PURSUE PASSION!
COMMUNICATION across disciplines
FOCUS and STRUCTURE...
A SUPPORT STRUCTURE for RESEARCHERS...
Researchers get BROADER EXPOSURE to the outside world...
IF THERE IS ONE FACTOR THAT IS ESSENTIAL TO THE FUTURE of RESEARCH ORGANIZATIONS, WHAT is that ONE thing?
BREAKING SILOS... ...across disciplines
Move from DEVELOPMENT to PROGRAMMING...
FREE EXCHANGE of IDEAS among diverse participants.
Effective strategic PARTNERSHIPS...
A RESEARCH STAFF that is GROUNDED IN THE FUNDAMENTALS!
Basic applied research...
More FREEDOM! less bureaucracy...
SCAFFOLDING for INTERDISCIPLINARY WORK
CLARITY of VISION and MISSION... ...along with a DIVERSE TEAM.
REWARDS SYSTEM for INNOVATION!
Bridge incentives across environments
IDENTIFY THE VALUE before we start initiatives
LONG TERM VISION and THINKING... balanced with SHORT TERM IMPERATIVES.
Be OPEN to "UNREASONABLY NEW IDEAS"!
IMMEDIATE ACCESS to TRANSLATIONAL OPPORTUNITIES
DESTROY OBSTACLES to CREATIVITY!
Create ON RAMPS and OFF RAMPS within career paths.
Build systems that LEVERAGE HUMAN and MACHINE INTELLIGENCE
Give flexibility to scientific officers in IDENTIFYING NEW RESEARCH OPPORTUNITIES and PRIORITIES...
Build DIVERSE and DEEP TOOLBOX!
CHALLENGE OUR ASSUMPTIONS "All science is built on assumptions."
Understand when we need to be DIVERGENT and CONVERGENT.


IDENTIFYING Research AREAS
BRING IN ideas from ELSEWHERE... WHAT HAS WORKED in other areas? WHAT MIGHT WE BORROW or ADAPT?
IDENTIFY PAIN POINTS and the FRONT-LINE "TRUTH"...
NON-EXPERTS... and BOUNDARY SPANNERS
BRING IN ROTATORS from various CONTEXTS...
BALANCE PURE DISCOVERY with MISSION-DRIVEN RESEARCH!
BLUE SKY RESEARCH! ...for a PURPOSE...
COMMUNITY-WIDE EXERCISE
Simulation...
What RESEARCH would have MOST BENEFIT?
BRING FIELD TOGETHER AT INTERVALS... RELATIONSHIP-BASED...
"WHAT WORK WON'T GET DONE IF WE DON'T DO IT?"
SCAN...
IDENTIFY GAPS...
Evaluate "PUSH and PULL" in PRIORITY SETTING...
WHAT DO WE KNOW? WHAT DON'T WE KNOW?
GAPS...
OPERATIONAL ASSESSMENT...
PROBLEM-FOCUSED...
COOPERATIVE MODELS...
RISKS...
ENTERTAIN SERENDIPITY and THE UNEXPECTED...
BENCHMARK the COMPETITION ...namely CHINA.
中国
Bridging RESEARCH...
WHAT RESEARCH benefits RESEARCH? What research can be APPLIED?
...and APPLICATION
A PROBLEM-FOCUSED ROADMAP...
NETWORKS of SCOUTS
LEARN from LITERATURE "STORIES create POSSIBILITIES!"
BRIDGE between AGILITY and FLEXIBILITY of BOTTOM-UP APPROACH and CLARITY of TOP-DOWN APPROACH.
ENCOURAGE PEOPLE to COME TOGETHER in TEAMS... - A FUNDING STRATEGY!
INTEGRATION between ENGINEERS and RESEARCHERS ... in MISSION and OPERATIONS.
WHAT IDEAS ARE DISRUPTIVE?
DISRUPT THE ADVERSARY
-WHAT'S YOUR BLIND SPOT?-
You can't know your BLIND SPOT unless you...
ENGAGE AND LISTEN!
SANDBOX of IDEAS...
FUNDING MODELS...
Get away from NSF MODEL of LARGE PANELS...
MAXIMUM autonomy for RESEARCHERS!
CREATE DIVERSE and INCLUSIVE TEAMS...
—YOUNGER RESEARCHERS
—WOMEN
FUND the INDIVIDUAL...
INNOVATION PRIZES: "You LEARN a lot in the PROCESS, not just the PRODUCT."
BEST PRACTICES and WORST PRACTICES are BOTH INSTRUCTIVE!


BRAINSTORM:
RETURN ON Investment
DEFINE... EVALUATE...
WHAT IS THE MISSION?
INFRASTRUCTURE.
PEOPLE. How do we UPHOLD the MISSION with our RESOURCES?
What do we need to do to ATTRACT a TALENTED WORKFORCE?
THINK ABOUT THE ADVERSARY...
COSTS
IMPACT
STRATEGY
WHAT ARE THE ANALYTIC STEPS?
A PLACE TO START... DRUG DISCOVERY PROCESS: RISK... EFFICACY... PROCESS... COST...
RISK-ADJUSTED NET PRESENT VALUE
WHAT IS THE PURPOSE?
ALIGNMENT with STRATEGIC PURPOSE
TECHNOLOGY DEVELOPMENT IS NOT LINEAR... ...OR ALWAYS FORWARD-MOVING.
WHAT HAPPENS WITH TECHNOLOGIES THAT HAVE BEEN DEVELOPED AND ARE NOW SITTING ON THE SHELF?
How do we ASSESS VALUE here?
BROADER DEFINITION OF MEASURES OF RETURN.
WHAT DOES "VALUE" LOOK LIKE?
QUANTIFY VALUE!
...for INVESTORS ...for POLICYMAKERS
WHAT IS THE VALUE PROPOSITION?
Tools for TRACING THE ROI...
ANALOG PRACTICES: "Does it EXIST? What is the VALUE?"
SYNERGY!
How do we INVEST in TECHNOLOGIES that others can USE?
OTHER MILITARY. INDUSTRY/COMMERCIAL.
DERIVATIVE VALUE!
THE LONG TERM VIEW is crucial toward assessing IMPACT and VALUE.
LONG-TERM VIEW! Judging SUCCESS and PRODUCTIVITY OVER TIME
ASK ABOUT VECTORS of IMPACT from 6.1 and 6.2 on 6.4 and above.
-THIS GOES WELL BEYOND PUBLICATION!
BUILDING THE INTELLIGENT INFRASTRUCTURE of the country!
What is the RELEVANCE of the RESEARCH/INNOVATION?
What is the IMPORTANCE of the QUESTION?
What is the IMPACT?
How do we ASSESS "PROGRESS"?
DETERRENCE? PEACE? TECHNOLOGICAL DOMINANCE? EQUIPPING WAR FIGHTERS? GAME CHANGING INNOVATION?
HOW DO WE ALLOCATE FUNDS STRATEGICALLY AND IN A MISSION-DRIVEN WAY?
WE MAY NOT KNOW SOMETHING IS DISRUPTIVE UNTIL AFTER THE FACT.
HOW DO WE KNOW SOMETHING IS DISRUPTIVE?
SHIFTING the PARADIGM IS the ROI!
SHIFT THE PARADIGM!
"SOMETIMES, WE NEED TO STIR THE POT!"
There needs to be an EXPECTATION OF FAILURE! ...when engaging with INNOVATIVE and DISRUPTIVE work.

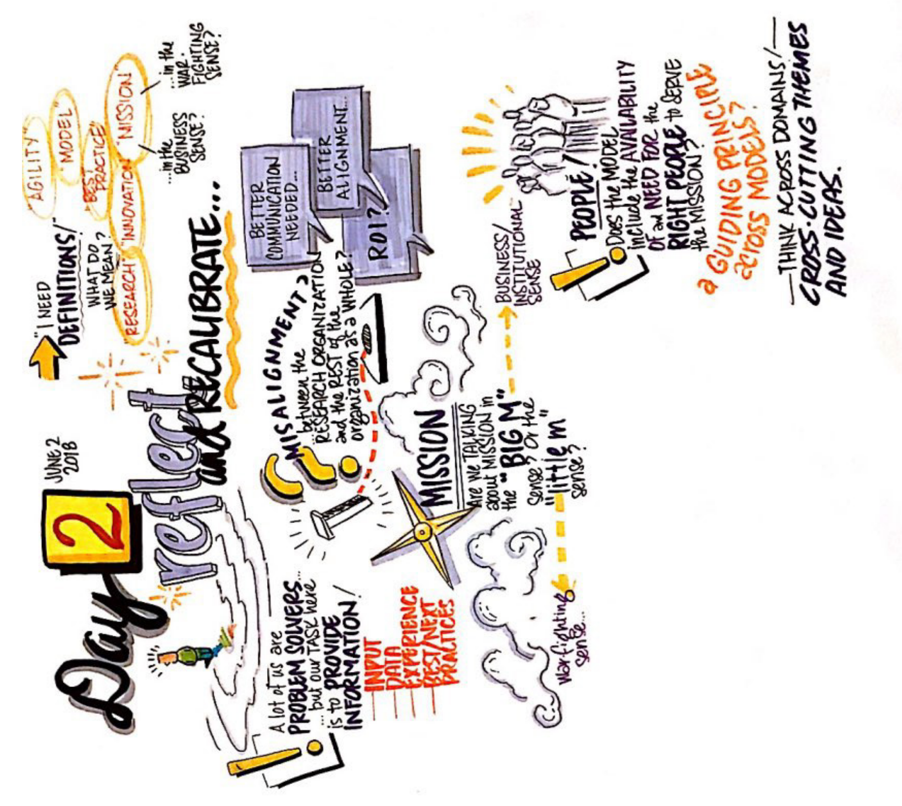


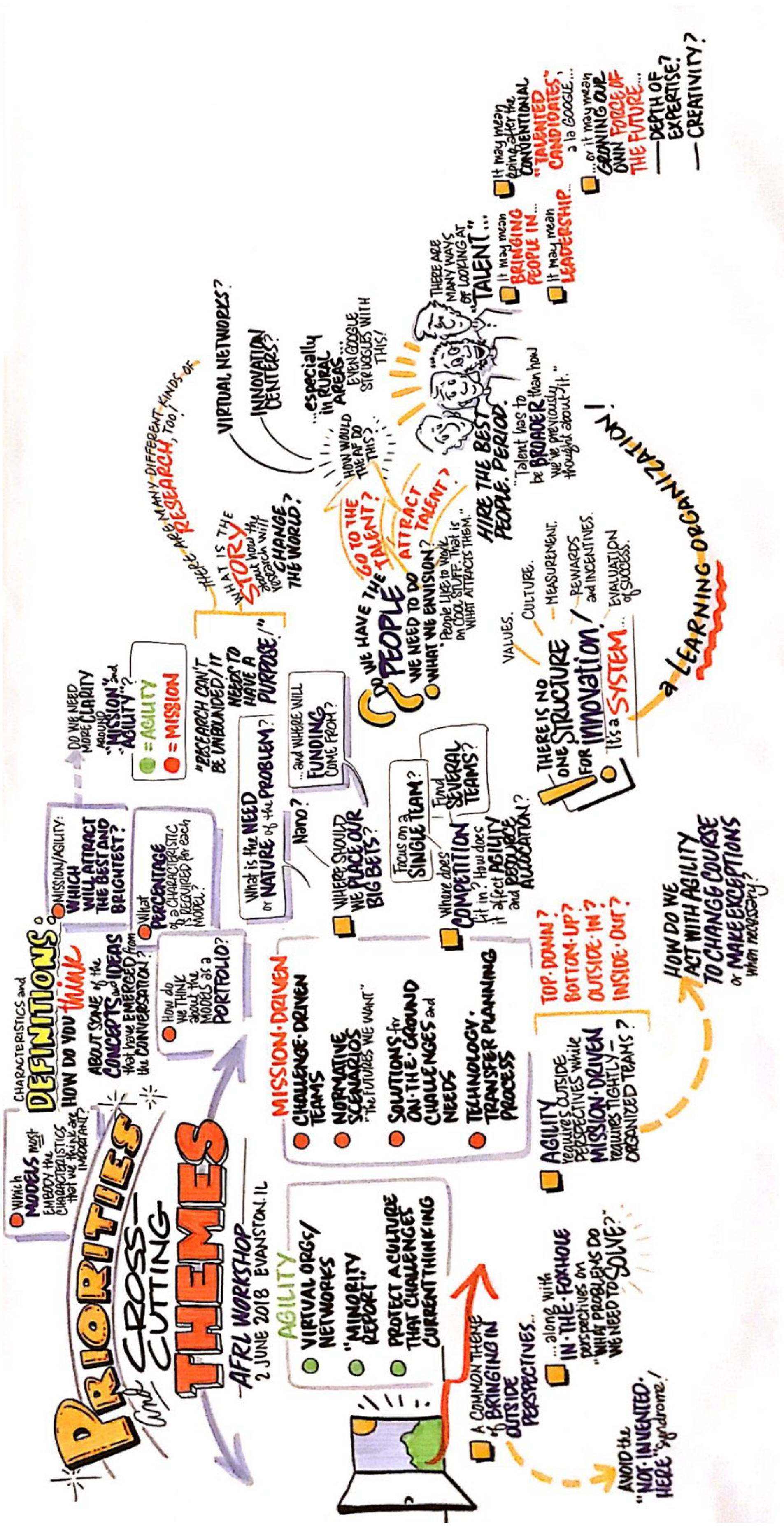
BRAINSTORM: ORGANIZATION Structures and Cultures...
TEAM AT WORK
"Culture STARTS AT THE TOP!"
MANAGER NEEDS TO PROTECT THE TEAM... "Stand by the door with a SWORD!"
MAJOR RESOURCES into TECHNICAL WORK... while MINIMIZING OVERHEAD
STRATEGIC ALIGNMENT with the GOAL... with UNIQUE MEASUREMENTS...
Develop a "SO WHAT?" Culture
Give POWER in the PROCESS!
An ORGANIZATIONAL VALUE around INNOVATION...
MISSION-BASED TEAMS ...from across the ORGANIZATION
DEFINE the problem...
HAND IT OFF to a team...
UNDERSTAND the CHALLENGE...
DEVELOP A SOLUTION in a short amount of time...
CROSS-FUNCTIONAL TEAM STRUCTURE
DEMAND FUNCTION COMMUNICATE with URGENCY! i.e. Safety
ALLOW TIME to REFLECT...
AVOID INCREMENTALITY
"Fast" is not a STRATEGY!
LONG-TERM INNOVATION through COMPETITION and HACKATHONS
INTERNAL COMPETITION
Give people TIME to WORK ON their own projects...
GUIDING PRINCIPLES:
Flat...
Agile...
Aware...
Team-oriented...
Respectful of people, Critical of ideas...
CAN THE MILITARY ACT WITH AGILITY?
Borrow from AGILE WORK PRACTICES in SOFTWARE DEVELOPMENT
"AGILE"
Visible...
Focused...
Rapid assembly...
Trust-based
Diverse skill sets + mindsets
REDEPLOYING "AGILE" LESSONS IN OTHER CONTEXTS...
ACTIVATE AND VISUALIZE SOCIAL NETWORKS!
SHORT-TERM PROJECTS are OKAY!
—Higher RISK?
—Starting something doesn't mean it NEVER ENDS.
From CEMEX... DISCOVERY TEAMS?
1 year...
8-12 people...
Issue-driven
SKUNK WORKS/ TIGER TEAMS... "Disciplined GOVERNANCE"
SCIENCE is SLOW... APPLICATION is FAST...
"SPEED DATING" for CROSS-POLLINATION and COLLABORATION.
Minimize CLASSIFICATION to IMPROVE COLLABORATION and COMMUNICATION.
"SPEAK TRUTH to POWER!"
"PSYCHOLOGICALLY SAFE" work spaces —Okay to make MISTAKES!

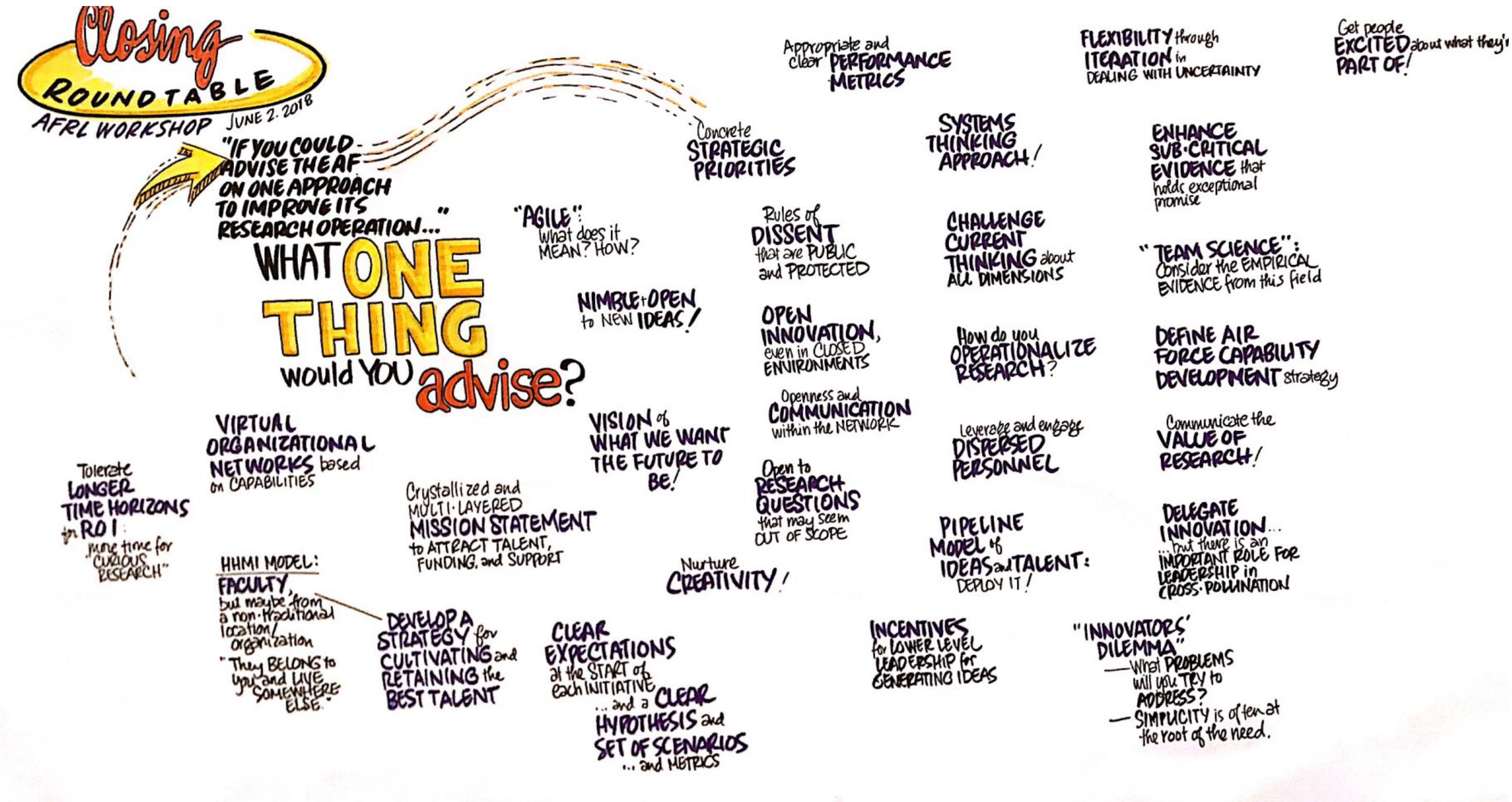


BRAINSTORM: FORMULATING and IMPLEMENTING STRATEGY
WHAT IS STRATEGY ANYWAY? WHY DO WE NEED ONE? HOW IS IT DIFFERENT IN 6.1, 6.2... 6.4...?
HOW DO WE KEEP TRACK OF IDEAS that have already been developed?
PROCESS OF IDEATION...
HOW do we MANAGE IDEAS - and ACT on them?
DEFINE THE BOUNDARIES.
LISTEN...
WHAT ARE THE SUCCESS MEASURES?
CHALLENGE YOUR ASSUMPTIONS!
What assumptions do you hold most dear — and how do we challenge them?
What is the DECISION MAKING process for SETTING PRIORITIES?
A PORTFOLIO APPROACH
What are CRITERIA TO BE CLEAR about the PRIORITIES... RESOURCES... CAPABILITIES... METRICS...
RESOURCE CONSTRAINTS.
CLEAR SET of ACTIVITIES that are DIFFERENTIATED.
WHAT IS THE PEOPLE STRATEGY?
FILL THE SKILLS GAP!
ALIGNMENT around CULTURE.
UNDERSTANDING MILLENNIALS: Aspirations Work Styles
NURTURE NEW IDEAS THROUGH NEW TALENT!
A NATIONAL S+T STRATEGY?
WHERE WILL WE FOCUS TO WIN?
DIVERSITY IS IMPORTANT.
WHO is at the TABLE?
WHOSE PERSPECTIVES are represented?
How do we ENGAGE DIVERSITY? And EMBED it?
"DECOMPOSING" THE MISSION
CONSISTENCY and COHERENCE
EVERYTHING FLOWS DOWN...
HAVING A STORY.
TELL a "TRUE" Story...
Stories are derived from the MISSION and VISION.
SWOT ANALYSIS
SITUATIONAL AWARENESS
— THREATS and OPPORTUNITIES
— KEY PARTNERS and STAKEHOLDERS
— COMPETITIVE ADVANTAGE
SCENARIO ANALYSIS
SCENARIO PLANNING
STRATEGY MAPPING
"BACKCASTING"
Start from WHERE YOU WANT TO BE...
GO TO WHERE THE PEOPLE ARE...
"STRATEGIC INCREMENTALISM."
BUILD KNOWLEDGE NETWORKS...
CROWDSOURCING?
An INNOVATION/IDEATION JAM...
A COMMERCIALIZATION Strategy to BRING REVENUES back in?
ADAPTIVE.
DYNAMIC.
FLEXIBLE.
READY. FIRE. STEER!
GOOD STRATEGY is based on GOOD FORECASTING DATA...
SCAN the ENVIRONMENT... How will you SHAPE it?
What are you DOING? Is it moving you FORWARD toward your GOAL?
What STRATEGY could you DEVELOP that would render the EXISTING STRATEGY/REALITY OBSOLETE?
Move from "RESEARCH + DEVELOPMENT" to SEARCH + REDEVELOPMENT
... from STRUCTURED DETERMINISTIC THINKING to DESIGN THINKING...
WHAT ARE OUR BASIC SCIENCE QUESTIONS?
"Basic science often supports 6.4 and above."
EMBED BASIC SCIENCE with TECHNICAL...
INVEST in HIGH RISK, HIGH PAYOFF RESEARCH projects!


Day 1 CLOSING
AFRL WORKSHOP
JUNE 1, 2018
HOW DO WE BUILD THE AIR FORCE OF THE FUTURE? ...and BUILD THE FOUNDATION IN THE PRESENT?
Our charge is to provide DATA... not RECOMMENDATIONS or PROBLEM SOLVING...
OBSERVATIONS and TAKEAWAYS...
"I'm struck by what OTHER PARTS of DoD are DOING... that we COULD LEARN FROM!"
WHERE ARE THE POCKETS OF EXCELLENCE?
A SCALE ISSUE?
A SEED, not a TREE.
It's not an INNOVATION ISSUE... it's an issue of SCALE!
NEW heroes? Who is the HERO of TODAY'S TECHNOLOGIES? ...and of the FUTURE?
More SELF-MANAGEMENT?
"We're doing a LITTLE BIT OF THIS... and a LITTLE BIT OF THAT."
AUTONOMY, ROBOTICS, MACHINE LEARNING, AI.
Use technology to Build TECHNOLOGY!
Do we have the RIGHT BALANCE of "RESEARCH" and "DEVELOPMENT"?
Yeah, yeah... we're doing that...
ARE YOU?
We tried that already... Didn't work...
What's the RESEARCH ORGANIZATION of the FUTURE?
IS THERE INCENTIVE AND WILL TO DO ANYTHING DIFFERENT?
WE ARE LOOKING at a FUTURE OF:
NEW TECHNOLOGIES
NEW ORGANIZATIONAL STRUCTURES... and CULTURES.
NEW ADVERSARIES
NEW CAPABILITIES
Is there ANYTHING transformative GOING ON?
ARE WE PUSHING THE ENVELOPE?
NEXT PRACTICES, not "BEST PRACTICES."
ARE WE USING OUTDATED TECHNOLOGIES, R&D METHODS, and STRATEGIES FOR DEPLOYMENT OF RESOURCES?


Day 2 reflect and RECALIBRATE...
JUNE 2 2018
"I NEED DEFINITIONS!"
WHAT DO WE MEAN?
"AGILITY"
"MODEL"
"BEST PRACTICE"
"RESEARCH"
"INNOVATION"
"MISSION"
...in the BUSINESS SENSE?
...in the WAR-FIGHTING SENSE?
A lot of us are PROBLEM SOLVERS... but our TASK here is to PROVIDE INFORMATION!
INPUT
DATA
EXPERIENCE
BEST/NEXT PRACTICES
MISALIGNMENT? between the RESEARCH ORGANIZATION and the REST of the organization as a WHOLE?
BETTER COMMUNICATION NEEDED...
BETTER ALIGNMENT.
ROI?
MISSION
Are we TALKING about MISSION in the "BIG M" sense? Or the "little m" sense?
BUSINESS/INSTITUTIONAL SENSE
War-fighting sense...
PEOPLE!
Does the MODEL include the AVAILABILITY OF and NEED FOR the RIGHT PEOPLE to SERVE the MISSION?
a GUIDING PRINCIPLE across MODELS?
—THINK ACROSS DOMAINS/— CROSS-CUTTING THEMES AND IDEAS.


PRIORITIES and CROSS-CUTTING THEMES
AFRL WORKSHOP
2 JUNE 2018 EVANSTON. IL
Which MODELS most EMBODY the CHARACTERISTICS that we think are IMPORTANT?
CHARACTERISTICS and DEFINITIONS: HOW DO YOU think ABOUT SOME of the CONCEPTS and IDEAS that have EMERGED from the CONVERSATION?
MISSION/AGILITY: WHICH WILL ATTRACT THE BEST AND BRIGHTEST?
What PERCENTAGE of a CHARACTERISTIC is REQUIRED for each MODEL?
How do we THINK about the MODELS as a PORTFOLIO?
DO WE NEED MORE CLARITY AROUND "MISSION" and "AGILITY"?
= AGILITY
= MISSION
"RESEARCH CAN'T BE UNBOUNDED/IT NEEDS TO HAVE A PURPOSE!"
THERE ARE MANY DIFFERENT KINDS OF RESEARCH, TOO!
WHAT IS THE STORY about how the research will CHANGE THE WORLD?
AGILITY
VIRTUAL ORGs/NETWORKS
"MINORITY REPORT"
PROTECT A CULTURE THAT CHALLENGES CURRENT THINKING
MISSION-DRIVEN
CHALLENGE-DRIVEN TEAMS
NORMATIVE SCENARIOS "The FUTURES WE WANT"
SOLUTIONS for ON-THE-GROUND CHALLENGES and NEEDS
TECHNOLOGY-TRANSFER PLANNING PROCESS
What is the NEED or NATURE of the PROBLEM?
Nano?
...and WHERE WILL FUNDING COME FROM?
WHERE SHOULD WE PLACE OUR BIG BETS?
Focus on a SINGLE TEAM?
Fund SEVERAL TEAMS?
Where does COMPETITION fit in? How does it affect AGILITY and RESOURCE ALLOCATION?
A COMMON THEME of BRINGING IN OUTSIDE PERSPECTIVES...
...along with IN-THE-FOXHOLE perspectives on "WHAT PROBLEMS DO WE NEED TO SOLVE?"
AVOID the "NOT-INVENTED-HERE" syndrome!
AGILITY requires OUTSIDE PERSPECTIVES while MISSION-DRIVEN requires TIGHTLY-ORGANIZED TEAMS?
TOP-DOWN? BOTTOM-UP? OUTSIDE-IN? INSIDE-OUT?
HOW DO WE ACT WITH AGILITY TO CHANGE COURSE or MAKE EXCEPTIONS when necessary?
DO WE HAVE THE PEOPLE WE NEED TO DO WHAT WE ENVISION?
GO TO THE TALENT?
ATTRACT TALENT?
"People LIKE to Work on COOL STUFF. That is WHAT ATTRACTS THEM."
HOW WOULD THE AF DO THIS?
VIRTUAL NETWORKS?
INNOVATION CENTERS?
...especially in RURAL AREAS... EVEN GOOGLE STRUGGLES WITH THIS!
HIRE THE BEST PEOPLE. PERIOD.
"Talent has to be BROADER than how we've previously thought about it."
THERE ARE MANY WAYS OF LOOKING AT "TALENT"...
It may mean BRINGING PEOPLE IN...
It may mean LEADERSHIP...
It may mean going after the CONVENTIONAL "TALENTED CANDIDATES" a la GOOGLE...
...or it may mean GROWING OUR OWN FORCE OF THE FUTURE...
—DEPTH OF EXPERTISE?
—CREATIVITY?
THERE IS NO ONE STRUCTURE FOR innovation/ It's a SYSTEM...
VALUES.
CULTURE.
MEASUREMENT.
REWARDS and INCENTIVES.
EVALUATION of SUCCESS.
a LEARNING ORGANIZATION!


Closing
ROUNDTABLE
AFRL WORKSHOP JUNE 2. 2018
"IF YOU COULD ADVISE THE AF ON ONE APPROACH TO IMPROVE ITS RESEARCH OPERATION..."
WHAT ONE THING would YOU advise?
Concrete STRATEGIC PRIORITIES
Appropriate and Clear PERFORMANCE METRICS
FLEXIBILITY through ITERATION in DEALING WITH UNCERTAINTY
Get people EXCITED about what they're PART OF!
"AGILE": what does it MEAN? HOW?
Rules of DISSENT that are PUBLIC and PROTECTED
SYSTEMS THINKING APPROACH!
ENHANCE SUB-CRITICAL EVIDENCE that holds exceptional promise
CHALLENGE CURRENT THINKING about ALL DIMENSIONS
"TEAM SCIENCE": Consider the EMPIRICAL EVIDENCE from this field
NIMBLE+OPEN to NEW IDEAS!
OPEN INNOVATION, even in CLOSED ENVIRONMENTS
How do you OPERATIONALIZE RESEARCH?
DEFINE AIR FORCE CAPABILITY DEVELOPMENT strategy
VIRTUAL ORGANIZATIONAL NETWORKS based on CAPABILITIES
VISION of WHAT WE WANT THE FUTURE TO BE!
Openness and COMMUNICATION within the NETWORK
Leverage and engage DISPERSED PERSONNEL
Communicate the VALUE OF RESEARCH!
Tolerate LONGER TIME HORIZONS for ROI: more time for "CURIOUS RESEARCH"
Crystallized and MULTI-LAYERED MISSION STATEMENT to ATTRACT TALENT, FUNDING, and SUPPORT
Open to RESEARCH QUESTIONS that may seem OUT OF SCOPE
PIPELINE MODEL of IDEAS and TALENT: DEPLOY IT!
DELEGATE INNOVATION... ...but there is an IMPORTANT ROLE FOR LEADERSHIP in CROSS-POLLINATION
HHMI MODEL: FACULTY, but maybe from a non-traditional location/organization
"They BELONG to you and LIVE SOMEWHERE ELSE."
Nurture CREATIVITY!
DEVELOP A STRATEGY for CULTIVATING and RETAINING the BEST TALENT
CLEAR EXPECTATIONS at the START of each INITIATIVE ... and a CLEAR HYPOTHESIS and SET OF SCENARIOS ... and METRICS
INCENTIVES for LOWER LEVEL LEADERSHIP for GENERATING IDEAS
"INNOVATORS' DILEMMA"
— What PROBLEMS will you TRY to ADDRESS?
— SIMPLICITY is often at the root of the need.

Northwestern