ENHANCING THE IMPACT OF RESEARCH AT FEDERAL RESEARCH ORGANIZATIONS

by

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Abstract

This study explored the contributors and limiters to impact achievement in the mission-oriented research that takes place in the federal research environment. Research organizations in this environment include federal government laboratories, University Affiliated Research Centers (UARCs), and Federally Funded Research and Development Centers (FFRDCs). These organizations are funded and overseen by the United States federal government. The federal research program used for data collection was The MITRE Corporation's Innovation Program spanning seven FFRDCs. A convergent mixed methods approach was used with a multiple case study design. An expert panel performed validation of the research questions, data collection and analysis plan, findings, and recommendations. The study identified, tested, and validated an evaluative framework and methodology adapted from Martin Buxton and Stephen Hanney's Payback Framework (1994) for performing multiple case studies of completed federal research projects. Forty-one findings resulted from the data analysis across eight themes: Research Topic Selection, Research Team, Collaborative Behavior, Research Achievement, Research Culture, Research Program Management, and Research Automation Services. From these themes, factors that contribute to and limit researchers' ability to achieve research outcomes and impacts in the federal research environment were identified. Seven recommendations were made for consideration by federal research organizations to enhance their researchers' ability to achieve outcomes and make an impact.

Keywords: research impact, federal research, FFRDC, ROI, FR-CI^{2}TES, Payback Framework

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Endeavors such as this require sacrifices. The greatest sacrifice has been the missed opportunities to enjoy life with my family and friends. I look forward to spending more time with these fine people, especially my wife and two daughters, Christine and Jessica.

I dedicate this publication to my mother, Joyce, and my wife, Laura, the two people most influential in my life. They have helped me, more than they will ever know, stay focused and grounded, and strive to continually better myself. Thank you from the bottom of my heart!

Table of Contents

Contents

List of Figures

List of Tables

Enhancing the Impact of Research at Federal Research Organizations

Chapter 1: Introduction

Ideas for federal research are spawned from many sources. Some originate from federal researchers who are credentialed by and immersed in the research culture. Other ideas come from non-researchers who work in the government and military environment and recognize mission-related challenges and gaps that could benefit from study. This dissertation built upon the foundation of knowledge and experience on research impact established to date and applied it towards the understanding of the factors that contribute to and limit the achievement of research impact. The following story describes the origins of this study's research questions.

Operations Inspired Research: An Example

I was pacing nervously around the floor of the operations center of the Joint Analysis Center (JAC) in England. It had been six hours since the Global Hawk unmanned aircraft had taken off on its first trans-Atlantic mission; by this time, we should have started receiving reconnaissance imagery from the onboard sensor package. But there was nothing: silence. As the head of the JAC technical team, I was sweating bullets: had the experimental airplane with the wingspan of a commercial 737 airliner flying at 60,000 feet plunged into the ocean?

It was the dawn of the Drone Age. The Global Hawk would evolve into an important intelligence-gathering capability, not only for the U.S., but also for our allies. For this historic mission, the Global Hawk took off from Patuxent River Naval Air Station, in Maryland. The aircraft was programmed to cross the Atlantic Ocean and collect imagery over Portugal in support of a North Atlantic Treaty Organization (NATO) military exercise called Linked Seas 2000 (the year of the exercise). My team's mission was to receive the imagery from the Global Hawk ground station and route it to intelligence analysts who produced products for use by the

NATO exercise participants. The flight plan and imagery collection plan had been determined before the flight began and was programmed into the Global Hawk computers. The aircraft was supposed to overfly and collect data at specific locations and times, but the imagery files were not showing up as expected, and we had no idea why. Many hours later we learned that the aircraft had lost its satellite communications link with the ground station somewhere over the Atlantic Ocean. The aircraft was programmed to fly in a circular holding pattern until the problem was fixed. Once the ground station personnel fixed the communication problem, the Global Hawk continued its now abbreviated programmed flight path to the skies above Portugal and collected only a few of the expected dozens of images before returning to the U.S.

This mission experience with Global Hawk during Linked Seas 2000 marked my entry into the world of federally funded research. In the early 1990s, I had been involved in the introduction of web browser technology to the U.S. military, well before it became implemented commercially. Soon after the Linked Seas exercise concluded, it occurred to me that web browser technology could be applied to unmanned aircraft to provide stakeholders with near real-time situational information on the aircraft's status (i.e., location, speed, altitude, direction of flight), and access to the data being collected (i.e., imagery, video, radar data). I proposed an applied research project in 2001 and was granted $1 million dollars over two years to build and demonstrate a prototype. The research lessons learned and prototype attracted the interest of multiple U.S. military organizations (Kane & Games, 2002). As a result, the U.S. Department of Defense (DoD) funded an Advanced Concept Technology Demonstration (ACTD) project to build an operational prototype. I led the ACTD technical development of the prototype and demonstrated its military utility across the DoD. This led to U.S. Air Force, Army, and Marine

Corp requests for the capability to be deployed to Iraq and Afghanistan in support of U.S. and NATO operations.

This research project had positive impact. Soldiers in the war zone reported that use of the capability had saved lives. A researcher could not ask for a more important impact. However, 19 years after I conceived the idea, it would take considerable work to trace and understand the impacts of the research. The transition of my research to an operational system was not documented in any peer reviewed article. No metrics of research impact were collected. No study has explored the influence that the research had on commercial industry's development of similar capabilities. No assessment has been performed to determine how the knowledge gained by those involved in the early application of the prototype capability has been used to advance related research and development. Most significantly though are the following two concerns: 1) there is no accountability for the return on investment of public funding for the research; and 2) there is no transparency and discoverability of the research activity, lessons learned, and achievements for current and future researchers to leverage.

This is one example of what I believe are many research projects in the federal research environment that have achieved significant impacts over time, but for which their valuable research information has been allowed to atrophy. The reasons for the atrophy of federal research results, outcomes, and impacts are debatable and are explored in the literature review to follow. But from my 25-year experience in the Federally Funded Research and Development Center (FFRDC) domain, the answer seems multifaceted to include: decades of federal research and development (R&D) funding oscillation; the extensive and decentralized structure of the federal research environment; the challenges of identifying the impacts of research; and a research process that lacks support for sharing and accountability. These factors have been acknowledged by the governments of many countries over the years. These governments attempt to address the accountability shortfall through legislation requiring assessment of research return on investment (ROI) and implementation of technology transfer programs.

Research Impact Policy

The Trump Administration provided a recent example of government attempts to address the federal research accountability shortfall. In an August 17, 2017 memorandum, the U.S. Executive Office of the President set the Trump Administration's R&D budget priorities for fiscal year 2019. The memo issued guidance stating, "To the extent possible, quantitative metrics to evaluate R&D outcomes should be developed and utilized for all Federal R&D programs" (2017, August, para. 8). The memo provides no details on how federal agencies are to evaluate the impact of their R&D investments, but it does imply the expectation that they will. On September 18, 2017, the U.S. Air Force Secretary Heather Wilson, perhaps in response to the White House R&D priorities memo, told reporters that the Air Force Research Laboratory was assigned to lead a study to determine the degree to which its multibillion-dollar annual science and technology (S&T) research budget is producing scientific advances that are relevant to the Air Force mission over the next 20 years (Serbu, 2017).

In 2018, the Trump Administration published the *President's Management Agenda* (PMA) containing 14 Cross Agency Priority (CAP) Goals (OMB, 2018). Goal #14 seeks to "Improve Transfer of Federally-Funded Technologies from Lab-To-Market" (OMB, 2018, p. 47). The CAP goal states that "The Federal Government invests approximately $150 billion annually in research and development (R&D) conducted at Federal laboratories, universities, and other research organizations. For America to maintain its position as the leader in global innovation, bring products to market more quickly, grow the economy, and maintain a strong national security innovation base, it is essential to optimize technology transfer and support program optimization is essential to increase the return on investment (ROI) from federally funded R&D" (OMB, 2018, p. 47). The PMA prioritizes the use of modern information technology (IT) to achieve the CAP goals and states that "data, accountability, and transparency initiatives must provide the tools to deliver visibly better results to the public" (OMB, 2018, p. 7).

These government thrusts indicate an increasing emphasis on rapid transition of research output to operational use within the government and military and/or the commercial sector. While exemplary, this emphasis will put pressure on research funding decision makers to bias their decisions toward applied research and away from basic research with its longer-term and less tangible impacts. If such a short-term bias is allowed to diffuse into the federal research community, it may negatively impact the ability of the United States to maintain its position as the leader in global innovation. The development of a new, more robust approach to capturing, tracking, and enhancing the impacts of research could address the accountability needs of the government and equitably demonstrate the value of a mixed basic and applied research portfolio.

The remainder of this introductory chapter dives deeper into research impact, the specific research impact related problem that was studied, the purpose and significance of the study, and the research questions that the study sought to answer.

History and Background of Research Impact

How and whether to assess research impact has been debated for decades. This debate is closely tied to a larger question: how to balance basic and applied research investments. Both questions trace back to the mid-1940s and the conclusion of World War II. The U.S. government had just won the war with significant help from a highly classified portfolio of R&D programs that produced capabilities that were pivotal to the outcome of the war, such as radar and the nuclear bomb. President Roosevelt wanted the government research apparatus to evolve in ways that would directly benefit the public. At the president's tasking, Vannevar Bush published the seminal report titled *Science: The Endless Frontier* (1945), which proposed the government's foundational role as a sponsor of basic and applied research, and the government's research relationship with both academia and industry. The report also proposed the creation of the National Research Foundation, which was established in 1950 as the National Science Foundation (NSF). The Bush report created the relationship that is still in place today between the federal government, academia, and commercial industry regarding federally funded scientific research. It also started the great debate and politicization of the federal funding balance between basic and applied research, and the assessment of the impact of those investments that carries on decades later (Adams, 1971; Kreilkamp, 1971; Kostoff, 1994; Pinch & Bijker, 2012).

The topic of how to allocate federal funding between basic and applied research has seemingly received more attention over time than the topic of research impact assessment. However, research impact successes have been used to support both sides of the basic-applied funding debate. Billions of dollars of federal research funding are the primary driver of the debate. In the mid-1960s, the U.S. DoD's research investments were being criticized for being too "basic" -- not related closely enough to the DoD's military mission (Mirowski, 2011). In response, the DoD sponsored a study called Project Hindsight to determine the role that research played in the development of major weapon systems of that time (e.g., Minuteman missile, Polaris missile, Mark 46 torpedo, C-141 aircraft) (Sherwin & Isenson, 1966; Sherwin & Isenson, 1967). The study concluded that DoD funding for applied research provided the majority contribution over a 20-year period to the development of the weapon systems. The Project Hindsight conclusion favoring applied research was not received well by the NSF. In 1966, the

NSF sponsored a study structured similarly to Project Hindsight called TRACES – Technology in Retrospect And Critical Events in Science. TRACES studied five non-DoD innovations (i.e., magnetic ferrites, video tape recorder, oral contraceptive pill, electron microscope, matrix isolation) and traced their research roots as far back in time as necessary (i.e., no time limit). The study concluded that basic research provided the majority contribution to the development of the innovations (Illinois Institute of Technology, 1968). Project Hindsight and TRACES seemingly contradicted each other. Both studies have been critiqued as having flawed methodologies based on organizational biases: a mission oriented (i.e., applied research) bias in the DoD, and a basic research bias in the NSF (Adams, 1971; Kreilkamp, 1971; Kostoff, 1994; Pinch & Bijker, 2012). However, looked at together, they reinforce the notion that the impacts of both basic and applied research are critically linked and contribute over time to innovations of value to federal government missions and to the public. These studies also highlight the lack of transparency in the federal research community at that time, since two studies were required in order to understand the impact of past research, whether basic or applied. Little progress has been made in this regard in the past 50 years.

Project Hindsight and TRACES are examples of the divide between basic and applied categories, a divide that continues to present day. Each U.S. presidential administration creates a new political focus for the federally funded R&D community. President George Bush created the American Competitiveness Initiative in 2006, which proposed an increase in federally funded basic research (Domestic Policy Council, 2006). President Obama's 2013 budget proposed moving funding to applied research in fields such as renewable energy and climate change, causing concern among some politicians that the U.S. would lose its future technology leadership by reducing basic research funding (Showstack, 2013). Most recently, President Trump is seeking improvements to the federal research process to increase the return on investment and accelerate technology transfer to foster American global competitiveness.

Notable work has been conducted to explore and propose alternatives to the basic/applied research paradigm. In 1997, Donald Stokes, a professor of politics and public affairs at Princeton University, published *Pasteur's Quadrant: Basic Science and Technological Innovation*, in which he challenged Vannevar Bush's linear model of basic and applied research. Stokes used Louis Pasteur's seminal research as an example of Use-Inspired Basic Research. Stokes proposed a research quadrant characterized by 1) the quest for fundamental understanding, and 2) considerations of use. In his model, pure basic research addresses only the question of fundamental understanding. Pure applied research addresses only the considerations of use. Stokes adds a new category of research that addresses both characteristics as exemplified by Pasteur's research (Stokes, 1997). The use-inspired basic research category is highly applicable to the federal research environment, which is oriented toward mission-focused research. The author's Global Hawk introductory story is a good example of mission-focused research. Whether use-inspired basic or applied, federally funded research is an investment to improve government missions.

Stokes's work, however, maintains the notion and terminology of basic and applied research, which failed to go far enough for some academics. Dr. Venkatesh Narayanamurti from the Harvard Kennedy School and Dr. Toluwalogo Odumosu from the University of Virginia published a book in 2016 titled *Cycles of Invention and Discovery: Rethinking the Endless Frontier* that explored the politics played with federal research funding. They made the case that the standard categories of basic and applied research have become a hindrance to the organization of the U.S. science and technology enterprise. They proposed doing away with the linear and division-causing basic/applied research framework to be replaced by "a framework for research that is aligned with the need to address complex twenty-first century problems" (Narayanamurti & Odumosu, 2016, p. 149). Their proposal was for a discovery-invention cycle that acknowledges and promotes the integration of knowledge as it travels and fuels a cycle between research discovery and invention.

Even with the compelling work of Stokes, Narayanamurti, and Odumosu, the current basic/applied research framework will likely persist for the foreseeable future. As such, developing an approach for enhancing research impact that is agnostic toward, yet supportive of, the notions of basic, applied, and use-inspired basic research, as well as the discovery-invention cycle, would be of value to federal research organizations. This supposition is supported by efforts both within the federal government and within academia to develop such approaches. In 1997, Dr. Ronald Kostoff, from the U.S. Office of Naval Research, published *The Handbook of Research Impact Assessment* (1997b). This was a culmination of over 40 studies that Kostoff published on federal research impact assessment (RIA) evaluation techniques, performance measures, and metrics (Kostoff, 1993; Kostoff, 1996; Kostoff, 1997a). The handbook provided a comprehensive description and critique of the different approaches and measures that can be used for federal research assessment including retrospective methods such as those used in Project Hindsight and TRACES, qualitative methods such as peer review, and quantitative methods such as cost-benefit analysis and bibliometrics. Addressing the importance of basic research in the impact assessment approach, Kostoff stated that "the RIA should be structured to identify impacts which occur many decades after the research is performed…also, the indirect impacts of the research must receive a proper accounting" (1997, p. 10). Kostoff concluded that the methods have shortfalls and that a combination of methods and techniques provide the best impact assessment. He also acknowledged the scarce evidence of RIA being employed throughout the federal government, specifically within the DoD, due to the added cost and time of performing the assessments and the lack of benefit and/or reward for performing the activity. Kostoff's acknowledgement is true to this day. In hopes of overcoming these barriers to assessment, this study explored approaches to research impact assessment that minimize cost and time while maximizing the benefits.

During the time of Kostoff's research impact assessment studies, the U.S. Congress passed the Government Performance and Results Act (GPRA) of 1993 (updated in 2010). The purpose of GPRA was to provide accountability for federally funded R&D to the American people by requiring periodic reporting of research outcomes (defined in the *Definitions of Terms*). The Act designated pilot projects across the government to develop best practices for complying with the planning and measuring requirements of the Act in preparation for full implementation in 1998. The Army Research Laboratory (ARL) volunteered to represent the government R&D community in the pilot phase. ARL developed a process and set of metrics to capture research outcomes. The focus on outcomes in the Act was intended to drive research organizations towards reporting on longer term impacts rather than discussing research results in terms of project inputs and outputs (Brown, 1996; GPRA Act of 1993, 1993; GPRA Modernization Act of 2010, 2011). ARL learned valuable lessons during their GPRA pilot that were institutionalized and are still in place today. However, the evidence is not clear whether GPRA reporting requirements have led to an increase in research return on investment or have helped researchers achieve their outcomes.

Like the U.S. federal government, academia has struggled with how best to assess research impact. The quest for federal research funding has driven higher education institutions, and the government commissions that oversee and grant that funding, toward development of methodological approaches to assess the impact of funded research. Academia makes research funding decisions across a high diversity of science. This complicates the challenge of developing a research impact assessment approach that works across science disciplines (Grant & Wooding, 2010). In 2009, a study was commissioned by the Higher Education Funding Council for England (HEFCE) to review the approaches to research impact assessment that were in practice at the time (Grant, Brutscher, Kirk, Butler, & Wooding, 2009). The HEFCE's objective was to identify a new approach to research impact assessment for the United Kingdom (UK), called the Research Excellence Framework (REF), which was intended to address the shortcomings of the approaches in use at the time. The HEFCE study identified 14 research impact frameworks used by the UK, the U.S., Australia, the Netherlands, Sweden, Canada, and Japan (Grant et al., 2009). Studies of those approaches had found them ineffective in measuring research impact due to their use of single measurement methods such as bibliometrics (Smith, E. Crookes & P. Crookes, 2013). Bibliometrics is a method used to analyze the number of scientific publications by an author and the number of citations received by those publications (Gingras, 2016). Literature bibliometrics, patent bibliometrics, and linkage bibliometrics are popular because of the lack of other quantitative metrics of research impact (Panaretos & Malesios, 2009). The use of single metric approaches for assessing research impact resulted in governments and academic institutions focusing on raising their standing in research rankings by increasing the number of publications and associated citations (Panaretos & Malesios, 2009; Gingras, 2016; Smith et al., 2013). Studies of research impact assessment approaches also found heavy use of singular qualitative methods such as peer review that are criticized as being highly sensitive to methodological assumptions (Panaretos & Malesios, 2009). These shortcomings were addressed by the HEFCE in their development of the REF. The REF approach uses peer review panels that assess case studies of completed research projects. The case studies measure and evaluate impact across social, cultural, economic, environmental, public policy, and quality of life categories using a mix of qualitative and quantitative methods (Smith et al., 2013; HEFCE, 2014; Jones, Manville, & Chataway, 2017).

The efforts to date to define and implement a research impact assessment framework by academia and governments is explored in more detail in Chapter 2. The studies and activities highlighted in this brief introduction show that the pursuit of an approach to enhance research impact is significant and warranted. In 2013, the University of Exeter DESCRIBE Project, which studied definitions, measures, and approaches to assess research impact in the UK, found that "there is no one-size-fits-all approach to assessing and evidencing impact which meets with universal approval, particularly at an international level and across disciplines" (Stevens, Dean, & Wykes, 2013, p. 4). While a great deal of work has gone into the understanding of research impact, much more is needed. There is no evidence yet of cultural diffusion of research impact assessment and enhancement within the research community. The DESCRIBE Project declared the research community as being at the "end of the beginning in terms of its understanding of the blueprint for impact" (Stevens et al., 2013, p. 4).

This dissertation built upon the foundation of knowledge and experience on research impact established to date and applied it towards the understanding of the factors that contribute to and limit the achievement of research impact.

Statement of the Problem

This study addressed the immense challenge of increasing the return on investment of federally funded research through an understanding of the contributors and limiters to achieving impact in the federal research environment. In too many cases, impacts are not being realized or are short lived because of the uninformed and ad-hoc approaches taken to achieving research outcomes. This is complicating federal researchers' ability to substantiate positive impact on their government sponsors' missions and the public's health and welfare. Additionally, the lack of criteria and methods for analyzing and characterizing federal research impact has led to the use of indefensibly subjective impact assessments in reporting to government sponsors and the public. Furthermore, research projects with no tangible short-term outputs, or with disproven hypotheses, are being perceived as failures due to the lack of comprehensive impact assessment methods that can identify, capture, and track the long-term impacts of these projects.

With the renewed emphasis on research return on investment from the federal government, federal research organizations need to address these problems or risk the integrity and relevance of their R&D programs. R&D funding streams to these organizations could conceivably be tied in the future to the ability to enhance, communicate, and promote the impacts of their research programs to benefit federal funding sponsors and the taxpaying public. Having an impact on government missions and operations is, after all, the primary reason for performing federally funded research (Federal Acquisition Regulation, 2007).

Purpose of the Study

The purpose of this study was to understand the contributors and limiters within the research process to achieving outcomes and impact in federal research. With that understanding, the study proposed enhancements to research processes, management, tools, and behaviors that better enable researchers to achieve their outcomes and make an impact. A mixed-methods case study design with a convergent approach was used, which involved the collection of quantitative data via a survey of 875 federal research principal investigators, followed by the collection of qualitative data via a multiple-case study of purposefully selected completed federal research projects that helped in the understanding of the challenges faced by federal researchers in achieving their research outcomes and making an impact.

Research Questions

The following research questions (RQs) were designed to achieve the objective of this study. They are ordered in the sequence of discovery.

- RQ1: What are the factors that contribute to or limit the achievement of research outcomes and impacts?
- RQ2: What can be done to enhance researchers' ability to achieve outcomes and impacts?

The factors attributed to research impact [RQ1] and associated metrics were identified in the literature review and incorporated into a survey of federal research principal investigators who completed research projects prior to 2018. The survey identified the breadth, depth, and relevancy of the metrics and factors within the federal research environment. An analysis of the research process and of the prominent and relevant research impact assessment methodologies found in the literature was conducted to identify and adapt a data collection methodology for use in this study. The methodology selected was used in a multiple case study of completed federal research projects which included both basic and applied research. Finally, the convergent findings from the survey and case studies were used to recommend best practices, enhancements to the research process, and research program management approaches to better enable federal researchers to achieve their research outcomes and impact government sponsor missions [RQ2].

Significance of the Study

Pam Denicolo, in her book titled *Achieving Impact in Research*, characterized the effect research impact assessment is having on higher education, researchers, and research benefactors as a paradigm shift (2014). The topic of assessing research impact has been a source of friction within academia for decades, and this friction seems to be intensifying as impact frameworks proliferate. This is well articulated by John Brewer, Professor of Sociology at the University of Aberdeen, who wrote: “Impact is at one and the same time an object of derision and acclaim, anxiety and confidence. It is troubled terrain, discussed from quite different directions, and there seems little prospect of developing a common conversation between those who traverse it” (2011, p. 255). Brewer provides suggestions for developing a common conversation about research impact between researchers, research sponsors, and the beneficiaries of the research outputs from which a taxonomy could be derived. This could establish a conversational foundation and framework for the research community to build upon.

The significance of enhancing research impact across federal research organizations is considerable when the breadth and depth of the programs are recognized. As noted above from the 2018 President’s Management Agenda, the federal government invests approximately $150 billion annually in federal research conducted at federal laboratories, universities, and other research organization such as Federally Funded Research and Development Centers (FFRDCs). In 2017, 42 U.S. FFRDCs were reported in operation by the NSF (2017). The U.S. Congress assigned responsibility to the NSF to survey and report annually on FFRDC R&D portfolio statistics (Shahidi & Xue, 1994). FFRDCs fall into three administrative categories: (1) university-administered, (2) nonprofit-administered, and (3) industry-administered. Examples of university-administered FFRDCs include the Jet Propulsion Laboratory, Lincoln Laboratory, and the Software Engineering Institute. Examples of industry-administered FFRDCs include Los Alamos National Laboratory, Sandia National Laboratory, and Frederick National Laboratory for Cancer Research. Examples of nonprofit-administered FFRDCs include Aerospace, the Center for Naval Analysis, and the National Security Engineering Center. These highly reputable organizations had a combined R&D budget of $18.5 billion in fiscal year 2015. Over 98% of the $18.5 billion FFRDC R&D budget in 2015 was funded by the federal government (NSF, 2017). Basic research received 22% of those funds, and applied research 39% (NSF, 2017). The remaining 39% was spent on development projects (NSF, 2017). The categories of R&D are differentiated and defined in the *Definitions of Terms* section.

The level of federal funding for research is a significant investment of public tax dollars. The outcomes of these research programs are applied to improving the efficiency and capability of the federal government, including the military. The research is also a direct contributor to the health and welfare of the public in the form of contributions to modernization, safety, security, and capability in the energy, health, transportation, and financial sectors. Increasing the impact of federal research and being able to evidence the value and return on investment of the research is critical for defending these funding levels in a fiscally constrained and politically uncertain environment (King-Jones, 2017). Research impact performance measures provide evidence that federal research organizations are making beneficial use of allocated public funding (Merrill & Olson, 2011).

The understanding this study provides of the challenges associated with achieving research objectives within the federal research environment creates the foundation upon which to develop specific improvements. The recommendations from this study regarding these specific improvements are intended to enable federal research organizations to improve collaboration with research stakeholders early in the research process. The integration of transparency into the research process via knowledge management IT augmentation is expected to raise the level of research impact within federal research organizations by providing discoverability of research efforts, outputs, outcomes, and impacts. This may allow research stakeholders, including current, past, and future researchers, and potential users of that research, to search for and discover opportunities for collaboration, cooperation, and the transfer of knowledge and technology.

Boundaries/Delimitations of the Study

The federal research environment is vast and inclusive of federal government laboratories (e.g., Army Research Laboratory, Transportation Security Laboratory, and Office of Naval Research), University Affiliated Research Centers (UARCs) (e.g., Massachusetts Institute of Technology Institute for Soldier Nanotechnologies, Johns Hopkins University Applied Physics Lab, and Utah State University Space Dynamics Lab) and Federally Funded Research and Development Centers (FFRDCs). This study collected data from seven of the 42 FFRDCs. These seven FFRDCs support government agencies that include the DoD, the Federal Aviation Administration, the Department of Homeland Security, the Department of Health and Human Services, the National Institute of Standards and Technology, the Department of the Treasury, and the Justice Department. All seven FFRDCs are managed by The MITRE Corporation, a not-for-profit corporation with a centrally-managed research program covering the seven FFRDCs. As such, the results of the study reflect an FFRDC research program that may not be representative of the federal laboratories, UARCs, and other FFRDCs. However, the results of this study are expected to be relevant and adaptable across the federal research environment.

This study did not consider the development portion of R&D. References to "research" in the study are limited to basic and applied categories. The R&D categories are defined and differentiated in the *Definition of Terms* section below.

Definition of Terms

Research Impact

Defining impact within the context of research is complicated by the multiple stakeholder communities that use the term. Politicians approach research impact from the policy perspective. Researchers approach impact from the perspective of the production of knowledge. Academic organizations have developed an "audit culture" (Brewer, 2011, p. 255) around research impact derived from the establishment of proposal funding criteria associated with achieved impact within an organization's research portfolio (Brewer, 2011; Penfield, Baker, Scoble, & Wykes, 2014; Chikoore, 2016). Establishing a clear definition of research impact has been advised by authors in this space as a requirement to avoid miscommunication (Donovan, 2008; Grant et al., 2009; Denicolo, 2014; Penfield et al., 2014). A clear definition of impact was important to set the stage for this study and those building upon it.

Examining the evolution of the definition of research impact provided important insight. The Australian government in 2004 developed the Research Quality Framework (RQF), which proposed to measure the impact of publicly funded research. They defined impact as "The social, economic, environmental and/or cultural benefit of research to end users in the wider community regionally, nationally and/or internationally" (Grant et al., 2009, p.7). While the Australian government decided not to implement RQF due to a change in political administration from conservative to liberal, the United Kingdom developed from it the Research Excellence Framework (REF), which was implemented in 2014. The REF defined research impact as "an effect on, change or benefit to the economy, society, culture, public policy or services, health, the environment or quality of life, beyond academia" (Chowdhury, Koya, & Philipson, 2016, p. 4). The RQF and REF definitions of research impact were based on the political motivation of academic organizations to gain government research funding and thus excluded impacts on future academic research. Greenhalgh, Raftery, Hanney, and Glover offered a more inclusive description of research impact from a narrative review of the topic in 2016. They state that, "impact occurs when research generates benefits (business, health, economic, cultural) in addition to building the academic knowledge base" (p. 1).

This study used the following definition derived from the above sources: An effect on, change, or benefit to government, industry, and/or society, inclusive of building the academic knowledge base. Impacts from research are often intangible, unplanned, and unanticipated.

Research Outcome

The terms "outcome" and "impact" are used throughout the literature in discussions on research results and benefits. Outcomes are the tangible results achieved from the outputs of the research. Examples of outcomes are cost reduction, product improvement, and capability improvement. Outcomes are often pre-planned objectives of the research with measurable effects on the government mission the research was focused on.

Basic Research

The definition of basic research used for this study is the "systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind" (NSF, 2011, p. 4). Basic research is often the source or base upon which applied research builds. The

U.S. DoD budgets, funds, and reports on basic research under the Research, Development, Test, and Evaluation (RDT&E) budget activity 6.1 (NSF, 2011).

Applied Research

The definition of applied research used for this study is the "systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met" (NSF, 2011, p. 4). Applied research often translates promising basic research into solutions for broadly defined needs but does not extend into capability development. The U.S. DoD budgets, funds, and reports on applied research under the RDT&E budget activity 6.2 (NSF, 2011).

Development

Development involves "prototype and engineering design directed toward the demonstration of a specific process or product" (Illinois Institute of Technology, 1968). The U.S. DoD breaks development into multiple categories that are used for budgeting, funding, and reporting. These categories are: 1) *advanced technology development* under budget activity 6.3; 2) *demonstration and validation* under budget activity 6.4; 3) *engineering and manufacturing development* under budget activity 6.5; 4) *RDT&E management support* under budget activity 6.6; and, 5) *operational systems development* under budget activity 6.7 (NSF, 2011).

Use-Inspired Basic Research

Introduced earlier in this chapter, Stokes (1997) proposed the use-inspired basic research category characterized by the quest for fundamental understanding but with considerations of use. This category bridges between pure basic and applied research.

Overview of the Document

Building on the introduction to this study in Chapter 1, the literature review in Chapter 2 provides a deep dive into significant work that has been conducted on the topic of research impact. This begins with the identification of the key research impact metrics that have been used across research domains and that could be utilized to analyze federal research impact. These metrics were used in this study's survey of FFRDC principal investigators to gather data on the most prominent metrics of impact within past research projects. Chapter 2 continues with a deep dive into the research process and key research impact assessment methodologies that have been developed and implemented within the research community. Other topics discussed in Chapter 2 include tools and techniques that researchers use to analyze impact, and the challenges associated with pursuing the evaluation of research impact. Chapter 3 details the research analysis framework selected and adapted for use in this study. Also provided is an overview of the study strategy including the data collection approach and plan used for data analysis. Chapter 4 provides a detailed review and analysis of the collected data. Chapter 5 provides findings and conclusions regarding the enhancement of the federal research process towards significant increases in research impact. The chapter also provides recommendations for implementing the research process improvements across the federal government and suggestions for further study.

Chapter 2: Literature Review

This chapter deep dives into the key research impact metrics and evaluative methods that have been developed and implemented within the government and academic communities. The topic of research impact was found to be studied from multiple cultural and scientific perspectives. However, as Brewer (2011) noted, the topic is the focus of discord amongst some academics. This is explored further in this study. Much of the literature on research impact is focused on its assessment. Some researchers consider assessment to mean the evaluation and/or grading of the value of their research results, which fosters a portion of the discord referred to by Brewer. The academic work that has been conducted on research impact assessment was of value but not the focus of this study. To be specific, this study used research impact assessment methods and techniques from the literature in the development and validation of a methodology for capturing data on the inputs, outputs, outcomes, and impacts of federal research during the case study phase of the study.

Other topics discussed in this chapter include the tools, measures, and automation support that researchers use to capture impact information, and the challenges associated with pursuing the evaluation of research impact. Figure 1 depicts the map of research impact topics explored in the course of the literature review. The first-level nodes in the diagram correspond to sections in Chapters 1 and 2.

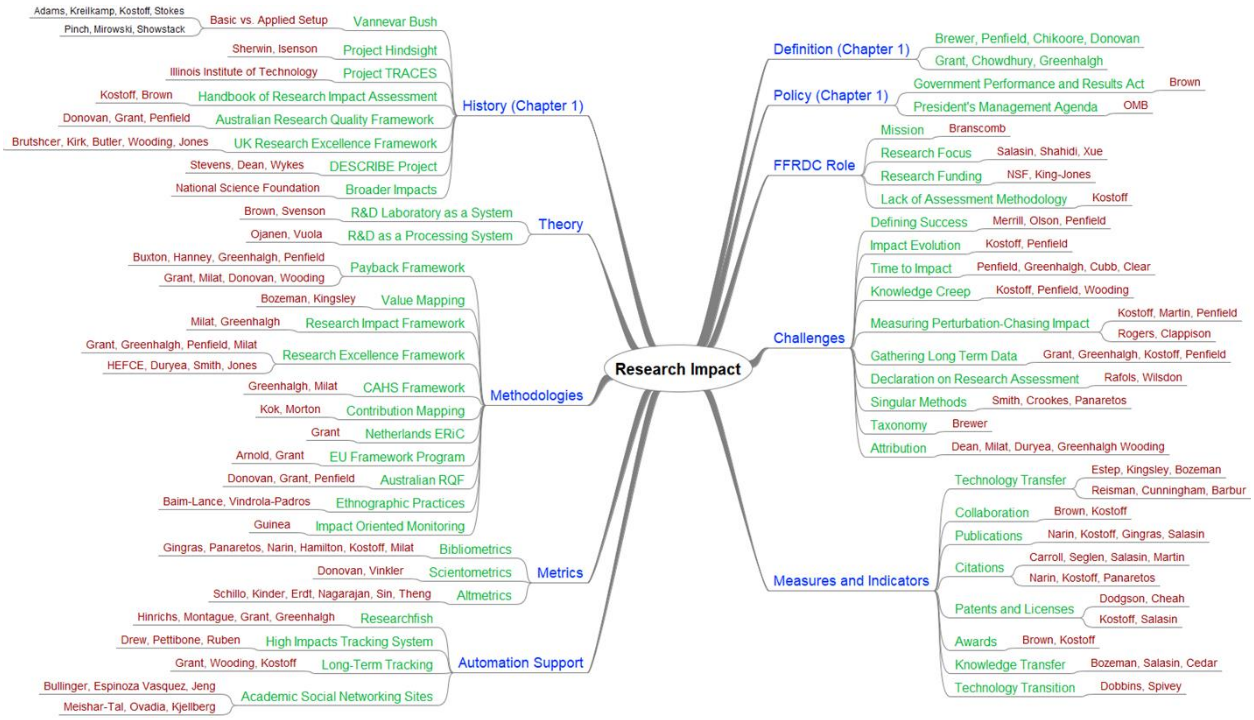

Figure 1. Context map of research impact literature review.

Theory: Research as a System

Different terms are found in the literature for a set of common components that make up the research process. Brown and Svenson (1988) defined the research process as a system that exists within all research organizations. They developed their system diagram, depicted in Figure 2, to help explain the overall research process and how measurement and feedback contribute to that process in commercial sector research laboratories. Inputs include funding, researchers, questions, hypotheses, current knowledge, equipment, and facilities. The research laboratory is referred to as the processing system in the diagram and includes activities such as proposal writing, conducting the research, and producing results. The outputs are the result of the processing system and include products, processes, publications, and patents. The receiving system consists of the consumers of the research outputs and can include a commercial company's product development organization, or another research organization to further develop the output. Outcomes, also referred to as impacts in the literature, are defined by Brown and Svenson as "the accomplishments that have value for the organization" (1988, p. 106) and include increased sales, higher profits, lower costs, and increases in market share. Brown and Svenson also include measurements and feedback loops in their research system model that enable continuous improvements during the research process by way of evaluative situational awareness (1988).

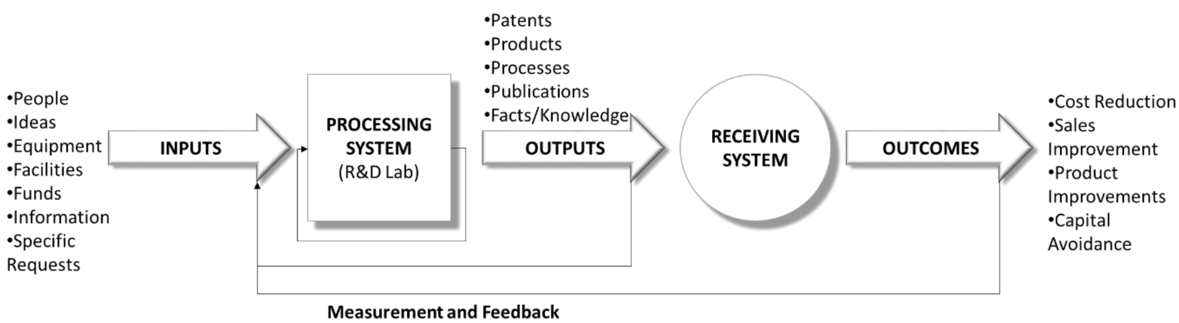

Figure 2. The R&D laboratory as a system. Adapted from "Measuring R&D Productivity," by M. Brown and R. Svenson, 1988. *Research-Technology Management, 31*(4), p. 106.

Ojanen and Vuola reviewed the state-of-the-art of R&D performance analysis in 2003 and built upon Brown and Svenson's R&D system model. Ojanen and Vuola's model, shown in Figure 3, adds the following: inputs such as strategies and competencies that are elements of the front end of the innovation process; more inclusive measurements and feedback; and the concept of monitoring all phases of research to identify further opportunities and support decisions on investment (2003).

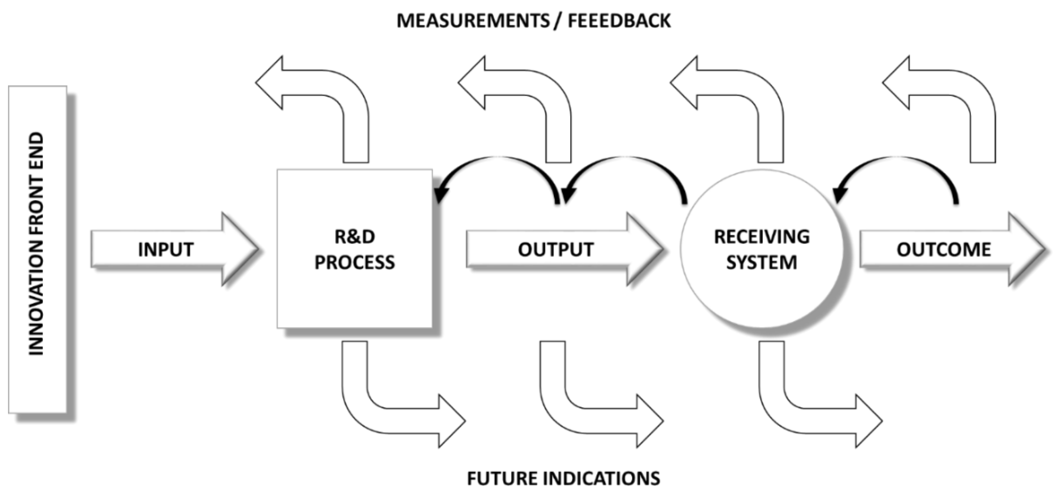

Figure 3. R&D as a processing system. Adapted from "Categorizing the Measures and Evaluation Methods of R&D Performance," by V. Ojanen and O. Vuola, 2003, *Lappeenranta University of Technology*, p. 11.

Depicting the research process as a system model can help frame the discussion of research performance evaluation and measurement (Ojanen & Vuola, 2003).

Research Impact Assessment Methodologies

Both R&D models described above depict aspects of the research process, such as feedback, measurements, and outcomes that can be used to assess the impact of research. Research impact assessment is widely covered in the literature across differing disciplines and perspectives. The majority of the literature on the topic originates from academia, but federal government researchers contribute also. The main driver of study on research impact assessment methodology appears to be government requirements for fiscal transparency of federally funded research performed by both academia and the government laboratories. However, the motivations to meet government requirements are different for academia than for the government laboratories. Government laboratories are legislatively required to demonstrate that public funds are being used to benefit society. Academia's interest in research impact assessment appears driven by competitive pursuit of government research funding by universities. Government organizations such as the U.S. National Science Foundation (NSF), the UK Higher Education Funding Council for England (HEFCE), and the Australian Research Council (ARC) are responsible for oversight of federally funded research. These oversight agencies have implemented programs to determine how best to allocate federal funding across academic research organizations. These oversight programs include research impact assessment methodologies that are used as input to decision processes on allocating research funding.

Academic research organizations want to tap into the government sponsored research funding pipelines, so they have led in developing research measures that can be used to quantify the value and impact of their research portfolios. These measures include both quantitative and qualitative metrics. Fields such as scientometrics, bibliometrics, and altmetrics, which are discussed in more detail in this chapter, are advancing knowledge of quantitative impact metrics. Qualitative impact measures such as technology transfer, knowledge transfer, and collaboration are also addressed in the literature, but to a lesser degree than the quantitative metrics.

Researchers in the biomedical, health, and energy sciences, which have significant and mature government funding pipelines, have led in the development of research impact assessment frameworks (Grant, 2006). The majority of research impact assessment frameworks reviewed in the literature include a mix of both quantitative and qualitative measures.

The literature discusses research impacts that are internal and external to the research community. External research impacts include economic, environmental, social, health, and cultural benefits (Denicolo, 2014). Impact can also be internal to the research community with contributions to the body of knowledge, vectoring of researchers and research threads, and benefits to the researchers and research sponsoring organizations. For federally funded research, impact is largely focused on transitioning research outcomes to government operational use and/or to commercial industry for direct application to government missions (Salasin, Hattery, & Ramsay, 1980).

FFRDC Role in Research

Because the data for this study were collected at an FFRDC, an explanation of the FFRDC role in federal research is warranted. The U.S. Congress created not-for-profit FFRDCs in the 1940s to augment government laboratories trying to solve the country's most critical national defense challenges. FFRDCs provide technical support and research and development (R&D) for their government sponsors; unlike those sponsors, they are free from conflicts of interest and political pressures. Branscomb (1993) differentiated FFRDCs from government laboratories in that: (1) FFRDCs are not hampered by government bureaucracy and administrative regulations; (2) the government has the statutory authority to create new FFRDCs as needed to support emerging needs; and (3) FFRDCs can form independent positions and recommendations without political pressure and influence. According to Branscomb (1993), FFRDC operations are more efficient and effective as a result of this relative autonomy and flexibility.

Today, the use of FFRDCs has expanded beyond national security to other sectors of government. FFRDCs do not develop products for sale and cannot compete with industry. While FFRDCs are privileged with a sole-source contracting relationship with the government, the U.S. Congress legislates funding caps on the centers, thus limiting their growth. This encourages the proper use of FFRDCs by government agencies and reduces the potential of FFRDCs being used for work more appropriate for commercial industry (Branscomb, 1993; Shahidi & Xue, 1994).

While independence from government bureaucracy is a core principle of the FFRDC construct, it also contributes to the lack of transparency and oversight of the FFRDCs' research portfolios. The review of the literature revealed no work specific to federal research impact assessment or process improvement. This study will help to fill that gap. The remainder of this literature review will document the relevant work on research impact metrics, measures, and methodologies that will contribute to this study's objective to enhance the achievement of research outcomes and impacts in the federal research environment.

Research Impact Metrics

The criteria for measuring research impact have evolved considerably over many decades. Technology has played, and continues to play, a key role in this evolution by making research impact data more comprehensive and accessible. Since the days of Galileo, the diffusion of research knowledge has been accomplished through publication of research discoveries. Citations of published works provide measures of influence and impact on subsequent research. Over time, the comprehension of the commercial value of intellectual property has led to government implementation of legal frameworks for patents and licensing, resulting in additional quantitative measures of research impact. These quantitative measures were selected and used by researchers *subjectively* to make claims on the usefulness of their research (Gingras, 2014). This led to the emergence of bibliometrics, which is aimed at adding broad *objective* value to the metrics by aggregating and linking data on publications, patents, and their related citations within scientific disciplines.

Bibliometrics

Bibliometric data provide quantitative statistical indicators used by some scientists to evaluate the quality and scientific impact of research projects, research journals, research organizations, and even individual scientists. The sources of data for bibliometric analysis include publications (journal articles, books, reports), patents, and their associated citations. Before computerized databases, bibliometric data were collected manually, primarily by librarians, within small specific scientific communities. Today, comprehensive automated databases such as the Science Citation Index (SCI), the Web of Science (WoS), Scopus, and Google Scholar are used by researchers to perform bibliometric analysis. The scientific community has used this data to develop bibliometric indexes to measure, for example, the number of published articles from an author which have 10 or more citations. This is called the h-index and is meant to measure the scholarly output of a scientist (Gingras, 2016).

Another example of the use of bibliometric data for the measure of research impact is that of the journal impact factor. The impact factor uses the citation count of the articles published in a journal as an indicator of that journal's impact on its target academic domain. The impact factor of a journal is calculated for a specific year by totaling the number of citations that the articles published in that journal received across the previous two years, and then dividing by the total number of articles in the journal over the same time period. This quantitative measure has become very influential in the global journal publishing business that includes tens of thousands of publications covering hundreds of research domains. Gingras (2016) warned however that the short two-year timeframe of the impact factor calculation is skewed in favor of scientific journals and discredits social science and humanities journals "because the temporality of research in the social sciences and humanities is longer than that in the natural and biomedical sciences" (p. 45). Seglen (1997) studied the international uses, and apparent misuses, of the journal impact factor as an indicator of a researcher's scientific achievement and for general use in research evaluation. Seglen listed 21 problems associated with the use of the journal impact factor and concluded that “citation impact is primarily a measure of scientific utility rather than of scientific quality, and authors' selection of references is subject to strong biases unrelated to quality” (1997, p. 502).

Narin and Hamilton (1996) studied the use of bibliometric performance measures for meeting Government Performance and Results Act (GPRA) reporting requirements on research outputs and outcomes. They validated the use of bibliometrics for responding to two categories of GPRA questions: 1) is the work being conducted by an agency good science and 2) is it important from a technological viewpoint? Their study also highlighted the increased value of citation linking across patents and publications. Narin and Hamilton cautioned that with bibliometric data, “virtually every distribution of scientific productivity or impact is highly skewed, with a small number of highly productive scientists, hot areas, research institutions, etc., and a relatively large number of institutions and producers of much smaller impact” (1996, p. 295). They stressed the importance of taking this skewness into account in any comparisons made using bibliometric data. Kostoff also warned that cross-discipline comparisons of bibliometric data may lead to skewed results and suggested that the data be normalized to enable comparisons among different types of programs and fields (1997a; 1997b).

Scientometrics

Scientometrics expanded the narrower field of bibliometrics to a more comprehensive study of the quantitative measures of scientific information in the attempt to better understand research activities (Donovan, 2008; Vinkler, 2010). Practitioners of scientometrics build complex quantitative research measures in an attempt to reveal past performance, present potentials, and trends in science. They consider, compare, and correlate factors such as the aging of data, the diversity of research domains/fields, data grouping (e.g., multi-author papers, research organizations, and countries), research/human capacity (number of research personnel in an organization), investments in research organization instrumentation, and research funding in the quest for deeper understanding (Vinkler, 2010). However, like bibliometrics, the practice of using singular scientometric measures, and/or the use of scientometric measures alone to evaluate research quality and impact is criticized in the literature (Harnad, 2008; Kostoff, 1997a; Martin, 1996; Vinkler, 2010). Harnad (2008) stated that "scientometric measures…are individual 1-dimensional metrics…none of these metrics can be said to have face validity: they still require objective validation" (p. 105). Kostoff (1997a) provides sage guidance for the use of scientometric data with his conclusion that "metrics have a useful role to play in the evaluation of research…however, when used in a stand-alone mode, metrics can be easily misinterpreted and result in misleading conclusions…metrics should be an integral part of a more comprehensive approach to research evaluation" (p. 117).

Altmetrics

The proliferation of Internet technology and social media has further evolved the research impact measurement field by adding measures such as contributions to open source software, open innovation, and a complex measurement of social media research discussion topics called altmetrics (Schillo & Kinder, 2017). Erdt, Nagarajan, Sin, and Theng (2016) studied the emergent science of altmetrics, which is attempting to apply usage metrics such as downloads and view counts, the number of web links, and social media posting data to the assessment of scholarly impact. Their findings validated the use of altmetrics for measuring research impact, but their study also acknowledged the challenges related to the technique's immaturity, and the dubious trustworthiness of the social media data. Heather Piwowar (2013) states that recent changes in NSF funding policy directing research principal investigators (PIs) to list research products rather than publications in the biographical sketch section of the grant application represent a sea-change in how research and researchers are evaluated and opens the door to the use of altmetrics. She states that "altmetrics give a fuller picture of how research products have influenced conversation, thought and behavior" and will "speed the shift by publishing diverse research products in their natural form, rather than shoehorning everything into an article format" (p. 159).

Research Impact Measures and Indicators

The research measures and analytic practices described above have been developed, used, and critiqued primarily by the academic community. The literature shows an awareness of these measures by federally funded researchers, but very few examples of the use of the measures to assess research impact. A common theme in the literature across bibliometrics, scientometrics, and altmetrics is the warning against the use of single metrics from any of these practices to assess the quality and impact of research. Ben Martin concluded in his study of basic research evaluation that "all quantitative measures of research are, at best, only partial indicators…the most fruitful approach is likely to involve the combined use of multiple indicators" (1996, p. 351).

Table 1 provides an overview of the research measures and performance indicators found in the literature that could apply to the analysis of federally funded research impact. The literature is heavily focused on the quantitative bibliometric and scientometric metrics. The qualitative performance indicators are less represented in the literature but are relevant to the assessment of federally funded research. A more detailed look at a selection of these measures and performance indicators follows.

Table 1. *Research Measures and Performance Indicators*

Name	Description	Type	References
Publication Count	The number of peer reviewed journal publications that result from research project activities.	Quantitative	Gingras, 2016; Kostoff, 1997b; Narin & Hamilton, 1996; Salasin et al., 1980
Patent Count	The number of patents filed as a direct result of a research project.	Quantitative	Cheah, 2016; Dodgson & Hinze, 2000; Gingras, 2016; Kostoff, 1997b; Salasin et al., 1980
Citation Score	The number of times a research paper or patent has been cited in peer-reviewed journals or patents.	Quantitative	Carroll, 2016; Hamilton, 1996; Kostoff, 1997b; Martin, 1996; Narin & Seglen, 1997; Panaretos & Malesios, 2009; Salasin et al., 1980;
Technology Transfer	The transfer of technology output from research to applications external to the research (e.g., industry, government, commercial, society).	Qualitative	Bozeman, 2000; Brown, 1996; Cunningham et al., 2016; Estep, 2017; Estep & Daim, 2016; Kingsley et al., 1996; Kostoff, 1997b; Reisman, 2004; Schillo & Kinder, 2017; Shahidi & Xue, 1994
Knowledge Transfer	The diffusion of knowledge as a result of participation in a research project.	Qualitative	Bozeman, 2000; Salasin & Cedar, 1982
Awards	The recognition and honors a researcher and/or research receive from evaluative bodies within or across research disciplines.	Quantitative and Qualitative	Brown, 1996; Kostoff, 1997b
Collaboration	The extent that research is performed in partnership with other research organizations.	Qualitative	Brown, 1996; Kostoff, 1997b

Journal Publication Counts – The number of peer reviewed journal publications that result from research project activities is a common measure of research output. Publication counts alone have limited utility in assessing research outcomes and impacts because the measure is a simple count of published papers from a researcher or organization. Also, these counts can be misleading since some researchers publish multiple articles about the same research project thereby skewing bibliometric indicators (Narin & Hamilton, 1996; Kostoff, 1997b; Gingras, 2016). For the federally funded research community, some research may occur in science and technology areas that do not have mainstream journals to publish in, or researchers may simply choose not to publish. Additionally, some government sponsored research has security classifications that preclude publishing (Salasin et al., 1980).

Patent Count – The number of patents filed as a direct result of a research project is another commonly used measure of research output. This metric has limitations: not all research output is patentable, some researchers do not pursue patents due to legal complexities, and some researchers are not interested in patent protections (Dodgson & Hinze, 2000; Cheah, 2016). Also, like journal publication counts, patent counts alone have limited use in assessing research impact but do provide a more tangible indicator of scientific contribution than do publication counts (Salasin et al., 1980). Kostoff (1997b) suggests using patent citation analysis to track the diffusion of research information but acknowledges that more research is required on the approach.

Citation Score – The citation score is the number of times a research paper or patent has been cited in peer-reviewed journals or patents. Salasin et al. describe citation score as a direct measure of influence on further research work (1980). However, they and other authors caution against using citation data to make conclusions on research impact. They make the case that citation data can be used as indicators of research output, but that the approach needs deeper analysis to identify activities and linkages that surface the impacts (Salasin et al., 1980; Martin, 1996; Narin & Hamilton, 1996; Kostoff, 1997b; Seglen, 1997; Panaretos & Malesios, 2009).

Carroll (2016) conducted a study to test the feasibility of creating a "citation profile" that would provide a context aware citation metric reflecting the impact a research paper was having within the research community. The citation profile is determined by analyzing the sections of the citing papers (e.g., background, methods, and results) in which the citations occur. A citation in the methods section may be more significant than a citation in the introduction or background sections, according to Carroll. The hypothesis is that the frequency of a citation within a paper, and the section in the paper that the citation is made, might provide a measurable, unambiguous metric of the impact a paper is having on the research community, thus providing greater depth and context than the commonly used citation count.

Technology Transfer – Technology transfer is a performance indicator of research that has been prominently used in both academia and the federal government. Technology transfer from research is pursued very deliberately by federally funded research organizations due to its tangible evidence of research return on investment and its value for achieving and communicating impact success to research sponsors and the public (Barbur, 2018; Schillo & Kinder, 2017).

Technology transfer is a heavily represented indicator of research impact in the literature, and even has a dedicated journal—the *Journal of Technology Transfer*—to help promote research in the area. The transfer of research output is a tangible event that is highly useful for research organizations to evidence and communicate the impact of their research programs. Transferring research outputs to application is the primary objective of conducting applied research. While a tangible activity, technology transfer does not readily lend itself to quantifiable measures. As such, much of the literature focuses on studying technology transfer with qualitative methods such as case study.

Kingsley, Bozeman, and Coker performed an analysis of 31 research project case studies in 1996 to explore theoretical explanations of technology transfer processes and the factors contributing to research impact. They explored technology absorption in parallel to technology transfer in the study. Technology absorption is differentiated from transfer in that transfer is the use of research output by entities external to the research project, while absorption is use of the research output by those who participated in the research project. Their study found that the technology transfer process is not unitary. It is instead "multiple sets of activities within multiple processes" (Kingsley et al., 1996, p. 990).

Bozeman (2000) also highlighted the complexities of technology transfer. He explores another aspect of technology transfer: *knowledge* transfer. Bozeman stated that "when a technological product is transferred or diffused, the knowledge upon which its composition is based is also diffused" (2000, p. 629). His study includes a table of technology transfer effectiveness criteria (see Table 2) that could be adapted for federal research technology transfer assessment.

Table 2. *Technology Transfer Effectiveness Criteria*

Effectiveness Criterion	Focus
Out-the-Door	Based on the fact that one organization has received the technology provided by another, no consideration of its impact.
Market Impact	Has the transfer resulted in a commercial impact, a product, profit or market share change?
Economic Development	Similar to Market Impact but gauges effects on a regional or national economy rather than a single firm or industry.
Political Reward	Based on the expectation of political reward (e.g., increased funding) flowing from participation in technology transfer.
Opportunity Costs	Examines not only alternative uses of resources but also possible impacts on other (than technology transfer) missions of the transfer agent or recipient.
Scientific and Technical Human Capital	Considers the impacts of technology transfer on the enhanced scientific and technical skills, technically-relevant social capital, and infrastructures (e.g., networks, users groups) supporting Scientific and technical work.

Note: Adapted From "Technology Transfer and Public Policy: A Review of Research and Theory," by B. Bozeman, 2000, *Research Policy*, *29*(4), p. 638.

Reisman (2004) also acknowledged the complexities of technology transfer and describes the literature on the topic as "disjoint and disparate" (p. 199). His contribution to the body of knowledge on technology transfer is a comprehensive taxonomy of 173 independent attributes. He argues that with the taxonomy, researchers across many fields will have a "systematic, objective and user-friendly framework for doing integrative research reviews of any subject involving technology transfer" (p. 200). While perhaps too specific and detailed for research impact analysis, the taxonomy could be distilled down to an appropriate level.

Cunningham, Menter, and Young performed a study of the case methods used in technology transfer research between 1996 and 2015. They concluded that the case study method is optimal for technology transfer research but is still in an emergent state. They encourage further work blending qualitative and quantitative measures of technology transfer assessment to produce greater insights into technology transfer impact (2016).

Estep and Daim (2013) studied the process of successfully transferring technology from research to application to help researchers identify the barriers to achieving technology transfer. Estep followed that work with a study that developed and piloted a process for calculating a technology transfer score that could be used to inform research proposal funding decisions (2015). Two additional Estep studies furthered the development of the technology transfer score process by identifying 22 success attributes across four perspectives (i.e., organizational, technological, social, and market), all of which contribute to successful technology transfer. A technology transfer decision model/framework was developed and validated using an expert panel. The validated framework was then used in a case study of three research proposals to calculate their technology transfer score and determine what changes in attributes contributed to improving the scores. The line of study concluded that successful technology transfer is primarily about building and maintaining an effective relationship between the researcher and the technology recipient. It also provided evidence that the success attributes necessary for technology transfer are being only peripherally addressed by research organizations as part of their proposal evaluation processes (Estep & Daim, 2016; Estep, 2017).

Technology transfer is a key criterion for assessing federal research impact. This is evidenced by the many federally funded research organizations with Technology Transfer Offices (TTO) and TTO websites highlighting technology transfer successes. Technology transfer expert Vicki Barbur stated that "there is currently a mass of untapped technical potential and IP [intellectual property] sitting on the shelves within the federal laboratory ecosystem that has been funded by federal agencies" (2018, "Conclusion," para. 38). The research technology outputs from the federal laboratories, such as FFRDCs, that do transition "have compelling impacts, solve national and global problems, provide a catalyst for greater success by industry alone, and drive the economy and GDP of the country," according to Barbur (2018, "Conclusion," para. 38). Table 3 provides a partial list of FFRDCs and the types of technology transfer information provided on their corporate web sites. Some FFRDCs use terminology such as technology deployment and technology licensing to label the transfer of research outputs to organizations external to the FFRDC.

Table 3. *FFRDC Technology Transfer Web Sites*

FFRDC	Web Site Technology Transfer Information
The MITRE Corporation	Technology transfer office information on licensing, patents, open source software, and collaboration. Also highlights of successful technology transfer to government and industry.
Sandia National Labs	Information on Technology Deployment Centers for the Department of Energy and for access by external users.
Aerospace	Technology transfer information for sharing intellectual property with industry.
Argonne National Lab	Information on technology commercialization, partnerships, and their Collaboration Centers.

FFRDC	Web Site Technology Transfer Information
Los Alamos National Lab	Information on technology opportunities and their intellectual property including patents and software tools.
Oak Ridge National Lab	Information on technology licensing.
National Renewable Energy Lab	Information on technology deployments world-wide with examples of impacts on the global energy marketplace.

Additionally, Table 4 provides a partial list of organizations dedicated to enabling technology transfer between federal research organizations, academia, and industry.

Table 4. *Technology Transfer Support Organizations*

Technology Transfer Organization	Description
Association of University Technology Managers	Core purpose is to support and advance academic technology transfer globally.
Licensing Executives Society	Global leader in standards development, education, and certification in promoting IP commerce.
National Council of Entrepreneurial Technology Transfer	Membership organization of Fortune 500 and universities. Mission is to create, develop, and fund the world's most transformative start-ups that align with corporate business needs from university and federal lab research.
Alliance of Technology Transfer Professionals	Promotes and maintains global standards in knowledge and technology transfer for knowledge transfer and commercialization in universities, industry and government labs.
TechConnect	Provides strategic technology prospecting and commercialization services through the largest network of active innovators world-wide. Each year TechConnect prospects, vets, and connects thousands of emerging technologies for industry, investment, and government clients.
Federal Laboratory Consortium	Initiated in 1974 and formally chartered by the Federal Technology Transfer Act of 1986 to promote and strengthen technology transfer nationwide. More than 300 federal laboratories, facilities and research centers and their parent agencies make up the FLC community.
American Council for Technology – Industry Advisory Council	A 501(c)3 non-profit organization established to improve government through the effective and innovative application of technology. This public-private partnership is in the government technology community and is an example of how government and industry can work together.
IP Business Conference	Addresses issues at the cutting edge of IP value creation and management. Facilitates the exchange of ideas and experiences. Sponsored by IAM - acknowledged as the world's leading IP business media platform.

Technology Transfer Organization	Description
Association of American Universities	Promotes activities to improve university technology transfer through providing a forum through which information about institutional policies and best practices is shared to move ideas from the laboratory to the marketplace.
TechLink	Develops partnerships between DoD and industry to develop, transfer and transition technologies.

Technology Transition - While the literature focuses heavily on technology transfer, there is an important distinction with technology transition, an activity that takes place in Department of Defense (DoD) organizations adapting new technologies into their operational environments. Within the DoD, transfer is the movement of technology from the federal research community to the commercial sector. Technology transition is defined as “the process by which technology deemed to be of significant use to the operational military community is transitioned from the science and technology environment to a military operational field unit for evaluation and then incorporated into an existing acquisition program or identified as the subject matter for a new acquisition program” (Dobbins, 2004). Technology transition is a much more complex, time-consuming activity than transfer. It is the preferred outcome of federally funded research. Like transfer, however, measures for assessing technology transition are sparsely studied (Bozeman, 2000; Spivey, Munson, Nelson, & Dietrich, 1997).

Research Impact Methodologies

As has been evidenced above in the review of research impact measures, the literature forcefully warns against misusing quantitative metrics to assess research impact. Kostoff (1997a) concludes that metrics bring insight to the complex challenge of assessing research impact but can be misinterpreted and thus mislead assessors if used exclusively. The literature decisively rejects the use of single metrics to make impact conclusions. Martin (1996) concludes that a “multidimensional set of ratings or a profile” of measures is critical for effectively assessing research impact to ensure that the process or act of measuring does not influence researchers towards producing outputs just to improve an impact score (p. 360). Penfield et al. reinforce this point and add that “if metrics are available as impact evidence, they should, where possible, also capture any baseline or control data” (2014, p. 29).

To address these concerns, the research community has developed research assessment methods and frameworks that combine quantitative and qualitative measures (Salasin et al., 1980; Grant, 2006). A review of the literature finds mention of over twenty research assessment methods, most focused on specific sectors such as health and energy. Studies from Greenhalgh et al. (2016), Penfield et al. (2014), Milat et al. (2015), and Rivera, Kyte, Aiyegbusi, Keeley, & Calvert (2017) extensively review the literature to compare and contrast the models and frameworks that are in use or being piloted. Many models and frameworks modify a core set of foundational work such as the Payback Framework developed by Martin Buxton and Stephen Hanney at the UK Health Economics Research Group (HERG) to assess research impact in the health sector (1994).

Individual counties and trade-related unions (e.g., the European Union) have also developed frameworks to systematically assess the impact of their government funded research programs. Driving the development of such frameworks is the need to show the research funders and the taxpaying public the value of government research investments, and to provide insight on how to improve the value of future research. These government sponsored frameworks are often implemented as part of a research allocation process that includes research impact assessment information in the funding decision equation.

Table 5 provides an overview of the most mature and studied frameworks found in the literature that could apply to assessing federal research impact. They all use mixed-methods approaches to collecting research impact indicators employing both quantitative and qualitative measures. The use of the case study method is prominently employed by most of the research impact frameworks reviewed in the literature. A more detailed look at a selection of these frameworks follows with highlights of their origination, objectives, and assessment approach.

Table 5. *Research Impact Assessment Frameworks*

Framework Name	Methods	Measures	References
Research Impact Framework (RIF)	Literature review, interviews, case study.	Publications, patents, outputs, awards, collaboration.	Greenhalgh et al., 2016; Milat et al., 2015
Payback Framework	Self-reported and peer review questionnaires, case studies, interviews, bibliometrics, logic modelling, document review	Publications, journal impact factor, citations, collaboration, linked research, knowledge transfer, outputs, economic benefits	Donovan, 2008; Grant et al., 2009; Greenhalgh et al., 2016; Milat et al., 2015; Penfield, 2014; Wooding et al., 2007
Canadian Academy of Health Services (CAHS) Framework	Case study, document review, citation analysis.	66 indicators mapped to impact categories.	Greenhalgh et al., 2016; Milat et al., 2015
Research Impact Logic Model	Logic model tailored to inputs, outputs, and outcomes. Data from NIH databases. Bibliometric data.	Input indicators: budget data. Activity indicators: awards, collaboration, PIs. Output indicators: publications, curricula, outreach material. Outcome indicators: citations, patents, legislations, collaborations.	Milat et al., 2015
UK Research Excellence Framework (REF)	Case study, panel assessments, survey.	Citations, publications, reach, significance, collaboration, contracts, patents, legislation, outputs.	Grant et al., 2009; Greenhalgh et al., 2016; Milat et al., 2015; Penfield, 2014

Framework Name	Methods	Measures	References
Australian Research Quality and Accessibility Framework (RQF)	Pioneered the case study approach. Peer review, benchmarking. Impact rating scale across social, economic, environmental, and cultural categories.	None required. Potential indicators include licenses, citations, collaborations.	Donovan, 2008; Grant et al., 2009; Penfield, 2014
European Union Framework Programme (FP)	Questionnaire, macroeconomic modelling, interview and case studies, cost-benefit analysis, peer review.	Bibliometrics, altmetrics, collaboration, knowledge transfer.	Arnold, 2012; Grant et al., 2009
Netherlands Evaluating Research in Context (ERiC)	Focuses on quality and relevance using a mix of qualitative and quantitative data. Bibliometrics, survey, interviews.	15 indicators including publications, citations, collaboration, and patents.	Grant et al., 2009

Payback Framework

The Payback Framework was developed by Martin Buxton and Stephen Hanney in the mid-1990s at Brunel University's Health Economics Research Group (HERG) to help measure and assess the impact, or 'payback,' of research in the health services domain (Buxton & Hanney, 1994). The framework has been adapted for use beyond health services to biomedical research, social science research, and other domains. According to Grant and Wooding (2010), the Payback Framework is "one of the most comprehensive and widely adopted frameworks (p. 7). In their 2016 review of 110 research impact assessment studies, Greenhalgh et al. found that the Payback Framework "remains the most widely used approach" for performing research impact assessments (p. 4).

Despite its name, the framework does not measure the monetary benefit from research. Instead, it is a methodology for collecting and analyzing data associated with the impacts of research throughout the research process. The framework consists of two elements: 1) a logic model of the research process that can be used to organize the measurement of impacts; and 2) a multidimensional categorization of research impacts to help identify and capture the diverse, and sometimes ambiguous, impacts at all stages of the research process (Donovan & Hanney, 2011). Used together, the two elements can provide a repeatable and common structure for capturing the impacts of multiple research projects, thus enabling analysis and comparison of the impact data across the projects.

The Payback Framework logic model (Figure 4) consists of seven stages and two interfaces that depict the research process from conceptualization of the research topic/idea to final outcome. The logic model may have been influenced by Brown and Svenson's 1988 work depicting the R&D laboratory as a system (Figure 2). All the components of that earlier work are found in the logic model. The logic model expands on those components to enable a more comprehensive exploration and identification of influences on and impacts from the research process. It adds a representation of the body of knowledge that both contributes to and is expanded by the research activity. The model also depicts the interactions between the research process and the external political, professional, and industrial environment, including the wider society. The process flow through the seven stages is not linear. Instead, there are multiple feedback paths depicting the cycle of knowledge creation and application within and external to the research process.

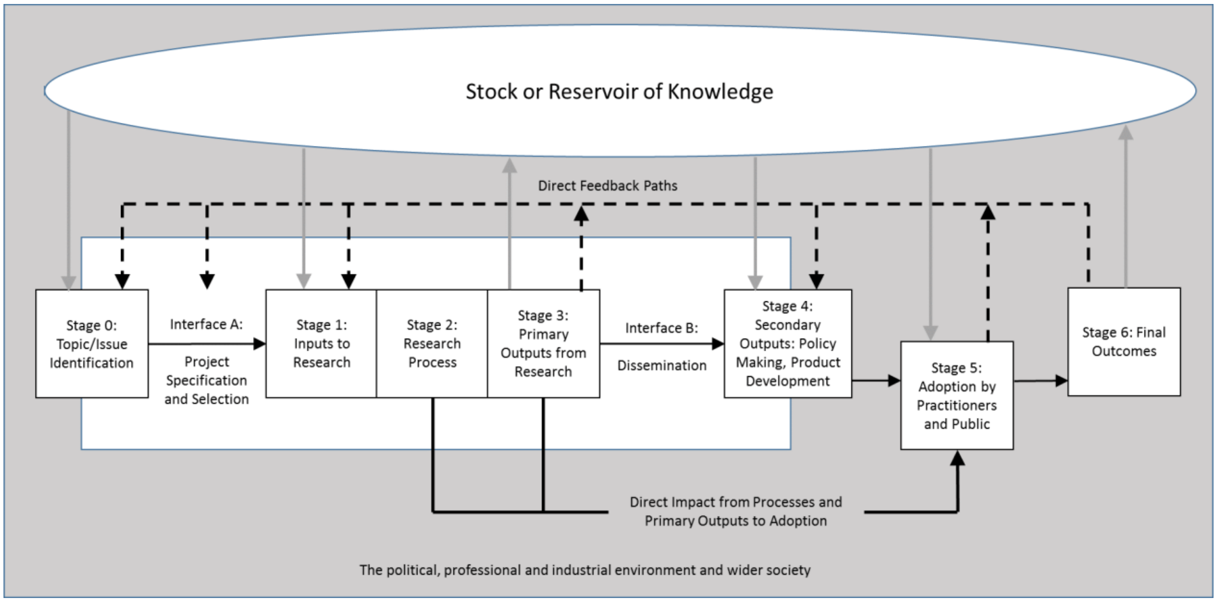

Figure 4. The Payback Framework. Adapted from "The 'Payback Framework' Explained," by C. Donovan and S. Hanney, 2011. *Research Evaluation, 20*(3), p. 182. Adapted with permission.

The Payback Framework defines five main categories of research impact. Table 6 lists the five categories and their definitions. The categories do not tie directly to specific stages in the logic model but do have strong correlations in some cases. These correlations are included in Table 6. According to Donovan and Hanney (2011), the first two categories are "more traditional academic benefits of knowledge production and research capacity-building…the next three categories constitute wider benefits to society" (p. 181).

Table 6. *Payback Framework Categories*

Category	Definition	Logic Model Correlation
Knowledge	• Journal articles • Conference presentations • Books and book chapters • Research reports	Stage 3 – Primary Outputs from Research
Benefits to future research and research use	• Better targeting of future research • Development of research skills, personnel and overall research capacity • A critical capacity to absorb and appropriately utilize existing research including that from overseas • Staff development and educational benefits	Stage 3 – Primary Outputs from Research

Category	Definition	Logic Model Correlation
Benefits from informing policy and product development	• Improved information bases for political and executive decisions • Other political benefits from undertaking research • Development of pharmaceutical products and therapeutic techniques	Stage 4 – Secondary Outputs
Health and health sector benefits	• Improved health • Cost reduction in delivery of existing services • Qualitative improvements in the process of delivery • Improved equity in service delivery	Stage 6 – Final Outcomes
Broader economic benefits	• Wider economic benefits from commercial exploitation of innovations arising from R&D • Economic benefits from a healthy workforce and reduction in working days lost	Stage 6 – Final Outcomes

Note. Adapted from "The 'Payback Framework' explained," by C. Donovan and S. Hanney, 2011, *Research Evaluation*, *20*(3), p. 182. Adapted with permission.

The popularity of the Payback Framework has been attributed to its flexibility, adaptability, and support for a range of data collection methods. It can be applied to single, multiple, and/or a portfolio of research projects. The framework supports triangulation through documentary and archival review, survey data collection organized according to stages of the logic model and categories, and case studies. The most common approach to applying the Payback Framework in the literature is through multiple-case study. The case studies use a mixed-method approach collecting both qualitative and quantitative data using semi-structured interviews including detailed questions on the interactions between researchers and the user community. Bibliometric analysis is often used to verify the impact information provided by the researchers (Milat, Bauman, & Redman, 2015). The analysis of the case studies is organized and presented according to the stages of the logic model (Wooding, Hanney, Buxton, & Grant, 2005).

UK Research Excellence Framework (REF)

The REF is a process, first implemented in 2014, for UK higher education funding bodies to provide evidence of the benefits of public research investment, to provide benchmarking information for UK academic research organizations, and to inform the selection of research funding based on non-academic impact (i.e., societal benefits). Planning for REF by the Higher Education Funding Council for England (HEFCE) began in 2007 and was the catalyst for numerous academic studies on research impact assessment measures and methods. The development of the REF started with an assessment of international best practices for assessing research impact. Four frameworks were evaluated from an initial list of 14 research impact frameworks in use internationally at that time. The four selected were the Australian Research Quality and Accessibility Framework (RQF), the UK RAND/ARC Impact Scoring System (RAISS), the US Program Assessment Rating Tool (PART), and the Dutch Evaluating Research in Context (ERiC) (Grant et al., 2009). Table 7 provides a description of each of these four frameworks.

Table 7. *Research Impact Assessment Frameworks Evaluated for REF*

Framework	Country	Description
Research Quality and Accessibility Framework (RQF)	Australia	• An example of measuring impact in a higher education context. • Takes the form of a case study approach in which research disciplines submit examples and evidence of research with high-impact. • Tested and found applicable to capture impact but was not implemented due to a change of government.
RAND/ARC Impact Scoring System (RAISS)	UK	• A first step towards an indicator-based approach. • Takes the form of a questionnaire (to be filled in by researchers) to capture over 150 potential research impacts. • Used to capture the impact of research grants for the Arthritis Research Campaign (ARC).
Program Assessment Rating Tool (PART)	U.S.	• A self-evaluation approach used to assess program performance across the federal government.

Framework	Country	Description
		• Takes the form of a questionnaire. It asks programs to assess themselves against their own strategic (impact) goals. • Used to assess the impact and efficiency of over 1000 federal programs.
Evaluating Research in Context (ERiC)	Netherlands	• Assesses research impact with a focus on 'societal quality' in the Dutch higher education system. • Combines several evaluation approaches: self-evaluation, an indicator-based approach, and stakeholder analysis.

Note: Adapted From "Capturing Research Impacts: A Review of International Practice," by J. Grant et al., 2009, *RAND Corporation*, p. v.

The evaluation of the four research impact assessment frameworks concluded that the RQF provided a "promising basis for developing an impact approach for the REF" (Grant et al., 2009, p. v.). According to Penfield et al., the RQF was the "first attempt globally to comprehensively capture the socio-economic impact of research across all disciplines" and "pioneered the case study approach to assessing research impact" (2014, p. 24). The catalyst for Australia's development of the RQF was twofold: 1) the Australian academic community's desire for government research funding to be allocated to academic research organizations based on peer review of research quality rather than the quantitative metric formulas in use at that time, and 2) the government's need to show how its research investments were benefiting industry and society (Donovan, 2008). The assessment approach used during the RQF pilot in 2005 involved research groups from the Australian Technology Network of Universities submitting verifiable evidence of impact from their research projects as determined by self-conducted case study. The case study information was then tested and verified by an international assessment panel to determine "whether research had led to reciprocal engagement, adoption of research findings, or public value" (Penfield et al., 2014, p. 24). The conclusion from the assessment of 200+ impact case studies was that “sound qualitative and quantitative evidence was readily available to be drawn on in the case study submissions” (Duryea, Hochman, & Parfitt, 2007, p. 8).

The REF approach adopted much from the RQF using peer review panels to assess case studies of completed research projects. The case studies measured and evaluated impact across social, cultural, economic, environmental, public policy, and quality of life categories using a mix of qualitative and quantitative methods (Smith et al., 2013; HEFCE, 2014; Jones, Manville, & Chataway, 2017). The HEFCE conducted a pilot study for the REF in 2009-10 with 29 UK research institutions and, like the RQF pilot, found that case studies were a valid method of assessing research impact (Penfield et al., 2014). In 2011, the HEFCE began the implementation of REF across 154 UK higher education research institutions. The first iteration of the REF process completed in 2014. Submissions from the higher education institutions were assessed by 36 review panels that were aligned with a specific unit of assessment (UOA). UOAs were created for research discipline areas such as Public Health, Computer Science and Informatics, Law, and Philosophy. The review panels assessed the submissions across three elements using a similar profile as shown in Table 8 for each element: 1) the quality of research outputs; 2) the social, economic, and cultural impact of research; and 3) the research environment. The scores across the three elements were weighted with output at 65%, impact at 20%, and environment at 15%. A research quality profile was provided for each participating institution with the result of the review panels. The quality profile included a percentage rating for the institution’s aggregate submission per the quality levels in Table 8.

Table 8. *REF Quality Profile Definitions*

Quality Level	Definition
Four Star	Quality that is world-leading in terms of originality, significance and rigor.
Three Star	Quality that is internationally excellent in terms of originality, significance and rigor but which falls short of the highest standards of excellence.

Quality Level	Definition
Two Star	Quality that is recognized internationally in terms of originality, significance and rigor.
One Star	Quality that is recognized nationally in terms of originality, significance and rigor.
Unclassified	Quality that falls below the standard of nationally recognized work. Or work which does not meet the published definition of research for the purposes of this assessment.

Note. Adapted from "*Research Excellence Framework 2014: The results*," HEFCE, p. 60.

The review panels found "a wide range of outstanding and very considerable social, economic and cultural impacts" (HEFCE, 2014, p. 3). REF 2014 was the first time in UK history that research impact was considered in a review of higher education research quality.

The next iteration of the REF has been initiated by the HEFCE. The process has been refined based on REF 2014 lessons learned and will complete in 2021.

Research Impact Automation Support

Kostoff (1997b) wrote extensively in *The Handbook of Research Impact Assessment* about the need for development of a database, or a federation of databases, to collect and store the impact measures of federally funded research. He stated that in order to track the diffusion of information from federal research, multiple public and private organizations would need to collect data at all evolutionary stages of the research, including years beyond the completion of the research project. He described the potential use of software-based algorithms to make connections within the database of research impact data. Kostoff was ahead of his time in forecasting the requirement for and value of data analytics to show the full picture of research impact.

Fifteen years later, Merrill and Olson (2011) published a summary of a workshop titled *Measuring the Impacts of Federal Investments in Research* held in April 2011 and hosted by the National Academy of Sciences, the National Academy of Engineering, and the Institute of

Medicine. The workshop explored the question of whether the impacts and practical benefits of research to society could be measured either quantitatively or qualitatively. Experts from the research community (i.e., academic researchers, R&D government and industry managers, and research sponsors) made presentations at the workshop covering aspects and perspectives on the topic, including national security. Methodological differences across fields of research were explored. Training of early career scientists was identified as one of the most important benefits of research. Other observations included the following: measurement imposes cost, resource, and time overhead on the research community; single measures can be misleading; multiple measures are needed; the act of measuring can perturb the research being conducted; and the benefits of research results are different across disciplines thus requiring sector-specific analysis. The workshop also produced a call for implementation of a comprehensive capability to automatically capture research input, output, and impact data stating that doing so would demonstrate the "long-term and diffuse but tremendously important impacts of science" and reduce the reporting requirements imposed on research organizations (Merrill & Olson, 2011, p. 81). Penfield et al. came to the same conclusion in their 2014 study on research impact assessment stating "the development of tools and systems for assisting with impact evaluation would be very valuable…capturing data, interactions and indicators as they emerge increase the chance of capturing all relevant information" (pp. 30-31).

High Impacts Tracking System

Even while the aforementioned workshop was calling for research impact assessment automation, two systems were being launched to provide such a capability. Drew, Pettibone, and Ruben (2013) wrote about one such effort within the U.S. National Institute of Environmental Health Sciences (NIEHS) called the High Impacts Tracking System (HITS). HITS is a direct result of the increasing demand from the U.S. Congress for accountability and stewardship of federal research investments. HITS extends and leverages multiple databases and tools developed by NIEHS over the past decade to track and collect data on research efforts. HITS is a "Web-based application intended to capture and track short-and long-term research outputs and impacts" (Drew et al., 2013, p. 309). The primary functions of HITS are to enable federated searching across the NIEHS research data, to display the search results, to add output and impact information, and to add summaries of reports. HITS implements 29 categories (Table 9) that researchers can use to describe their research outputs and impacts. Defining a fixed set of research output and impact categories, called tags in the HITS application, supports detailed analysis of the data, including the future development of data analytics (Drew et al., 2013).

Table 9. *HITS 29 Research Output and Impact Categories*

Category	**Description**
Award	Honored for research or service
Biomarker	Identified a new biomarker for an exposure or health outcome
Clinical Impact	New treatment or other patient-related impact
Collaboration	Collaboration between research partners
Community Partnership	Formed a new partnership with community members
Congressional Briefing	Presented data to Congress to inform decision-making
Curriculum	Created or revised a set of teaching instructions
Data Available	Data made publicly available for others to use
Data, Software, Models	Developed databases, software, or statistical models
Economic Impacts	Impact on health care costs, remediation or income
Fact Sheets, Materials	Created documents to communicate findings
Gene Identification	Identified genes associated with exposure susceptibility
Leadership	Researcher nominated to a significant leadership position
Measurement Tools	Developed new tools to measure exposures
Media Coverage	Coverage of research findings in mass media or social media
Meetings of Workshops	Hosted meetings or workshops to discuss findings
Meta-Analysis	Conducted meta-analysis of environmental health findings
Methodology	Created a new process for analyzing exposures
Model System	Created a new model system
Patent	Awarded a patent for a new innovation
Policy, Regulation	Research informed a policy, regulation or legislation
Publications	Significant publication, like the cover story of *Nature* or *Cell*
Public Health	Implemented an intervention that improved public health

Category	Description
Remediation	Improved environmental remediation methods
Scientific Finding	Major scientific finding that moves the field forward
Success Stories	Stories that demonstrate success and achievement
Subsequent Research	Additional funding from NIH or others to continue research
Training	Conducted training for stakeholders, also mentoring
Translational Research	Bridging of research from one translational area to another

Note. Adapted from "Greatest 'HITS': A new tool for tracking impacts at the National Institute of Environmental Health Sciences," by C. Drew, K. Pettibone, and E. Ruben, 2013, *Research Evaluation, 22*(5), p. 311.

Researchfish

Hinrichs, Montague, and Grant (2015) assessed a second major initiative focused on automating the collection and tracking of research impact data. Researchfish.com is a Web-based capability designed for research funders and researchers to capture, monitor, analyze, and communicate the activities, outputs, and impacts of research. Researchfish, like HITS, spawned from a government transparency and accountability initiative. For Researchfish, that initiative was the United Kingdom's (UK) Research Excellence Framework (REF) highlighted earlier in this chapter. Planning for REF began in the 2007 timeframe and was the catalyst for numerous studies and tool development associated with assessing research impact. Researchfish evolved from a series of such studies into a for-profit service run by a UK-based private firm. It is used almost exclusively by academic research organizations within the UK to communicate and evidence the impact of research portfolios to their funding sponsors, and for providing input to the REF process. Data collection in Researchfish is framed around 16 research outcome/impact focused categories with 175 sub-categories/questions. The 16 categories are listed in Table 10. The sub-categories/questions can be found in Annex A of Hinrichs et al. (2015). To date, the Researchfish database contains over 100,000 projects representing more than $53 billion of research investment from 79 research funding institutions. However, Greenhalgh et al. (2016)

warn that the business model of Researchfish limits data capture to only those organizations willing to pay the membership fee, potentially resulting in gaps in the research impact picture.

According to Hinrichs et al., the challenge facing Researchfish is gaining value from the vast warehouse of research impact data (2015). The four main challenge areas identified in the study are: 1) data analysis and sharing; 2) analytical capability and capacity; 3) data integrity; and 4) data connectivity within the world-wide research community (Hinrichs et al., 2015).

The long-term value of systems such as HITS and Researchfish.com have yet to be determined.

Table 10. *Researchfish 16 Research Output and Impact Categories*

Category	Description
Publications	Publications attributed to the research
Collaborations and Partnerships	Collaboration and partnerships attributed to the research
Further Funding	Funding received beyond the base to advance the research
Next Destination and Skills	Information on the general movement and advancement of the research team
Engagement Activities	Efforts by the research team to engage with special interest groups and the general public to inform them about the research
Influence on Policy, Practice, Patients & the Public	Significant impact on policy or professional practice
Research Tools & Methods	New research tools or methods which have been created or commissioned by the research team
Research Databases and Models	New research databases and models which are making, or have the potential to make, a significant difference to the research
Intellectual Property and Licensing	Intellectual property attributed to the research
Medical Products, Interventions and Clinical Trials	Medical products/interventions and any related clinical trials attributed to the research
Artistic and Creative Products	Significant artistic and creative output from the research
Software and Technical Products	Software and other technical products attributed to the research
Spin Outs	Establishment, development, or growth of new private sector organizations attributed to the research
Awards and Recognition	Awards and other significant forms of regional, national, or international-level recognition received by the research team

Category	Description
Other Outputs and Knowledge	Any other research outcome attributed to the research
Use of Facilities and Resources	Use of any shared national or international research facility by the research team

Note. Adapted from "*Researchfish: A forward look*," by S. Hinrichs, E. Montague, and J. Grant, 2015, King's College London, pp. 45-53.

Academic Social Networking Sites

The rapid rise and popularity of on-line social networking has spread to the professional and academic domains. The literature and current on-line offerings show the creation, failure, and merging of a dozen social networking sites dedicated to academic research over the past 15 years. These sites are referred to in the literature as either Social research network sites (SRNS) or academic social networking sites (ASNS). ASNS are defined as a "web-based service that allows individual researchers to 1) construct a public or semi-public profile within a bounded system (identity), 2) articulate a list of other researchers with whom they share a connection and communicate (communication), 3) share information with other researchers within the system (information) and 4) collaborate with other researchers within the system (collaboration)" (Bullinger, Hallerstede, Renken, Soeldner, & Moeslein, 2010, p. 3). ASNS is similarly described as including five services including 1) collaboration, 2) online persona management, 3) research dissemination, 4) documents management, and 5) impact measurement (Espinoza Vasquez, Caicedo Bastidas, 2015). The aforementioned altmetrics are the primary driver of the impact measurement category in the ASNS. Henceforth in this report, these sites are referred to as ASNS. The ASNS most frequently mentioned in the literature are ResearchGate, Academia.edu, LinkedIn, Mendeley, and Impactstory.

The uses of ASNS by academic researchers have been found to be "mainly for consumption of information, slightly less for sharing of information, and very scantily for interaction with others" (Meishar-Tal, Pieterse, 2017, p. 1). This is reinforced by a study of users of Mendeley that found that "participants did not engage with social-based features as frequently and actively as they engaged with research-based features" (Jeng, He, Jiang, 2015, p. 1). The primary appeal for academic researchers to use ASNS are for reputation management and the ability to amplify and accelerate the peer-review process (Ovadia, 2014). However, the literature on ASNS is still in its nascent stage. A study of 80 research articles on ASNS between 2004 and 2014 found the "field of study lacks methodological, theoretical and empirical coherence" (Kjellberg, Haider, Sundin, 2016, p. 232).

Research Impact Challenges

Certain challenges associated with research impact analysis are intrinsic to the research process. Most of these challenges are associated with the effects of time on research impact. Table 11 provides an overview of the challenges found in the literature that could apply to analyzing federally funded research impact. Jones and Grant state that the "challenges must be acknowledged and, where possible, addressed in measuring research impact" (Dean, Wykes, & Stevens (Eds.), 2013, p. 28).

Table 11. *Research Impact Challenges*

Challenge	Description	References
Time Lag	The time it takes for research to transition from academia into government, industry, commercial, and/or societal impacts/benefits.	Dean et al. (Eds.), 2013; Milat et al., 2015; Penfield et al., 2014; Wooding et al., 2007
Impact Evolution	Impact evolves over time. It can be temporary or long-lasting, may increase or decrease, and may be positive or negative. For example, a new drug may initially be considered revolutionary but years later be determined to be harmful.	Kostoff, 1997b; Penfield et al., 2014
Attribution	Tracing benefits back to a specific research project, output, and/or researcher is not	Dean et al. (Eds.), 2013; Duryea et al.,

Challenge	Description	References
	straightforward. Impacts can be derived from unanticipated findings, luck, and complex interactions, making attribution difficult.	2007; Greenhalgh et al., 2016; Milat et al., 2015; Penfield et al., 2014; Wooding et al., 2007
Knowledge Creep	Knowledge from research diffuses into the pool of academic knowledge and/or into government and public policy over time without recognition of the research contribution.	Kostoff, 1997b; Penfield et al., 2014; Wooding et al., 2007
Gathering Long Term Data	The research community has not adopted the discipline of collecting research impact evidence to support short- and long-term research impact assessment.	Grant & Wooding, 2010; Greenhalgh et al., 2016; Kostoff, 1997b; Penfield et al., 2014

Another area of challenge for research impact analysis is associated with the research culture. While a majority of the literature on research impact is focused on advancing the field, there is also an undercurrent of discontent. At the extreme end of this discontent are research stakeholders that have organized around stopping the use of bibliometric measures in research assessment frameworks, especially those frameworks mandated by government research oversight organizations. For example, in 2013, a group of researchers, research funders, and journal editors published the San Francisco Declaration on Research Assessment (DORA), which protests the use of journal impact factors in frameworks such as the UK REF (Rafols & Wilsdon, 2013). DORA reflects the warnings found throughout the literature regarding the use of single quantitative metrics to assess research and researcher impact. Much of the concern revolves around the potential corruption of the scientific process by changing the focus of researchers away from their research objectives and more towards increasing their impact metrics, a risk termed “chasing impact” by Geoff Rogers (Clappison, 2013, p. 1). A related concern is that researchers will trend away from basic research and toward applied research that is more conducive to showing short-term impact (Penfield et al., 2014; Greenhalgh, 2014; Chubb & Watermeyer, 2016; Clear, 2016).

Summary

The body of evidence from the review of the literature indicates that governments will continue to pressure federally funded research organizations world-wide to demonstrate return on investment of public funded research. Government sponsored research assessment programs such as the UK REF, the Australian RQF, the European Union Framework Program, and the NSF Broader Impacts are continuing to evolve within the government/academic community. However, the body of evidence supports the premise of this study that further research is needed to determine how to extend and apply the current measures and methods used in the existing frameworks toward enhancing research impact through changes to the research process. Increasing the transparency of federal research could result in a database of discoverable research inputs, outputs, outcomes, and impacts that could make it possible to infer short- and long-term common factors and threads (Grant & Wooding, 2010). Doing so enhances researchers' ability to collaborate with stakeholders of the research. It would also enhance research organizations' ability to communicate the impact of their research portfolios, reduce risk to their federal research funding pipelines, and perhaps increase the return on investment by promoting higher impact research. However, changes to the research process should acknowledge and address the reality that impact is not static, and can be temporary or long-lasting (Penfield et al., 2014). Finding an approach that integrates research analysis constructs seamlessly within the research process may alleviate most of the concerns found in the literature and drive cultural acceptance, and ultimately diffusion, of the discipline within the federal research community.

The measures and methods of research impact analysis identified in this review of the literature are used in the chapters to follow to determine those most applicable to federal basic and applied research. Chapter 3 identifies and explains the research process analysis methodology used in the data collection and analysis phase of the study. Chapter 3 also provides details of the data collection and analysis approach taken in the study and details how the selected research process analysis framework was used.

Chapter 3: Methodology

The purpose of this study was to understand the contributors and limiters within the research process to achieving outcomes and impacts in federal research. The mixed-methods case study design with a convergent approach was selected to achieve the study purpose due to its strength in identifying appropriate cases for comparative analysis (Creswell & Clark, 2018).

This chapter starts with a detailed description of the research impact assessment framework that was selected from the literature review and adapted for use in this study. That is followed by an overview of the mixed-methods case study design used to frame the data collection and data analysis approach. The data collection approach is detailed with a full explanation of the survey instruments used in the study including a description of the reliability and validity testing conducted. The chapter concludes with a description of the data analysis approach and how each research question was addressed.

Federal Research Impact Assessment Framework (FRIAF)

In their University of Exeter essay on methodologies for assessing and evidencing research impact, Jones and Grant stated that "the inconvenient truth is that searching for a universal framework is, perhaps, unhelpful…the reality is that disciplines require different approaches to the assessment of research impact" (Dean, Wykes, & Stevens (Eds.), 2013, p. 34). Jones and Grant specified the "disciplines" that require different approaches to impact assessment to be inclusive of natural science, health, social sciences, and the humanities. It follows logically that the federal laboratory, UARC, and FFRDC science and engineering discipline requires its own research impact assessment framework.

Based on this and other similar conclusions from the review of the literature, an assessment framework readily adaptable for the federal research environment was selected for use in this study. The Payback Framework has been widely adapted for use beyond the health services domain over a 20-year timeframe. As such, a modified version of the Payback Framework, henceforth called the Federal Research Impact Assessment Framework (FRIAF), was created and used for step 3 of this study. The Payback Framework logic model required only minor modifications to represent the federal research process and environment. Figure 5 depicts the FRIAF process model that was used in the data collection phase of this study. The modifications include: minor label name changes to represent federal research sponsors, stakeholders, and transition organizations; the addition of government, academia, and industry collaboration partners; and recognition of unanticipated and ambiguous impacts such as changing the course of a researcher's career path, developing questions that spawn new research, and raising the prestige of a research organization that attracts investment and talent. The FRIAF process model was used within this study as a guiding framework for the data collection instruments and to help the survey and case study participants understand the stages of research being explored. The seven stages in the process model enabled the creation and association of data collection questions within each of the stages, thus providing a consistent and comprehensive structure for collecting and analyzing the survey and case study data.

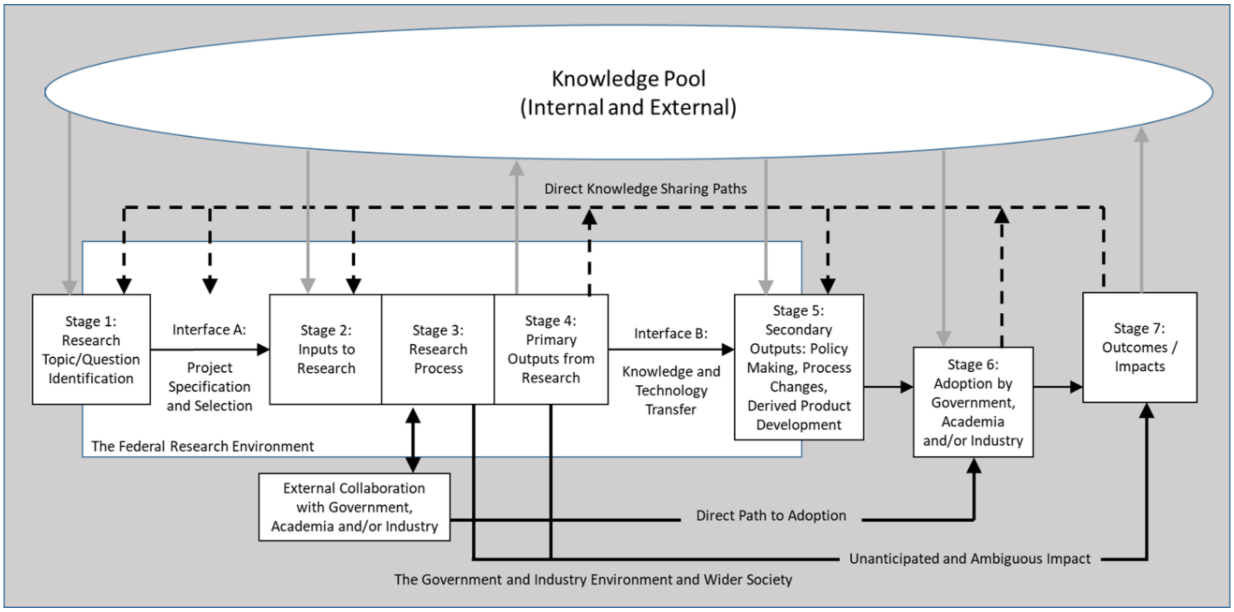

Figure 5. Federal Research Impact Assessment Framework (FRIAF) process model. Adapted from "The 'Payback Framework' Explained," by C. Donovan and S. Hanney, 2011. *Research Evaluation, 20*(3), p. 182. Adapted with permission.

The multi-dimensional categorization of impacts in the Payback Framework were developed for use in the health services domain. This categorization was used for theme development during data analysis. The Payback Framework impact categories were adapted for the federal research environment as follows:

<u>Academic Oriented</u>

- Knowledge production – publications, patents, conference presentations, knowledge transfer
- Future research, capacity building – skills and knowledge development, career influence, research offshoots, research collaborations

<u>Mission Oriented</u>

- Informing policies – process changes, influencing legislation and public policy, improved information bases for government decisions

- Building government capability and capacity – prototypes, hardware, software, technology transfer, cost savings, efficiency improvements, effectiveness improvements
- Broader economic benefits – commercial application, public safety improvements

Research Design

This study used the mixed-methods case study design with a convergent approach. The process started with two parallel data collection and analysis efforts, one for quantitative data and another for qualitative data. The results of the two efforts were merged and used to identify multiple case studies. The process culminated in a comparative analysis and interpretation of the converged and integrated findings from the multiple case studies (Creswell & Clark, 2018). Penfield et al. concluded in their study of research impact that “the mixed-method case study approach is an excellent means of pulling all available information, data, and evidence together, allowing a comprehensive summary of the impact within context” (2014, p. 30). Werner and Souder (1997) conducted a review of the literature of R&D performance measurement techniques covering 1956 to 1995 and stated that “integrated metrics that combine several types of quantitative and qualitative measures were found to be the most effective, but also the most complex and costly to develop and use” in the assessment of research impact (p.1). This study confirmed Werner and Souder’s finding.

The choices leading to the selection of mixed-methods were anchored in authoritative research theory and practice. Saunders, Lewis, and Thornhill (2009) created the research ‘onion’ shown in Figure 6 as a systematic categorization of research to help researchers structure their research design. Saunders et al. defined five categories of research theory and practice: philosophies, approaches, strategies, choices, and time horizons. These categorical choices are layered in an onion diagram that lead the researcher to a core set of data collection and data analysis techniques and procedures. The research design choices for this study are circled in Figure 6 and described as follows.

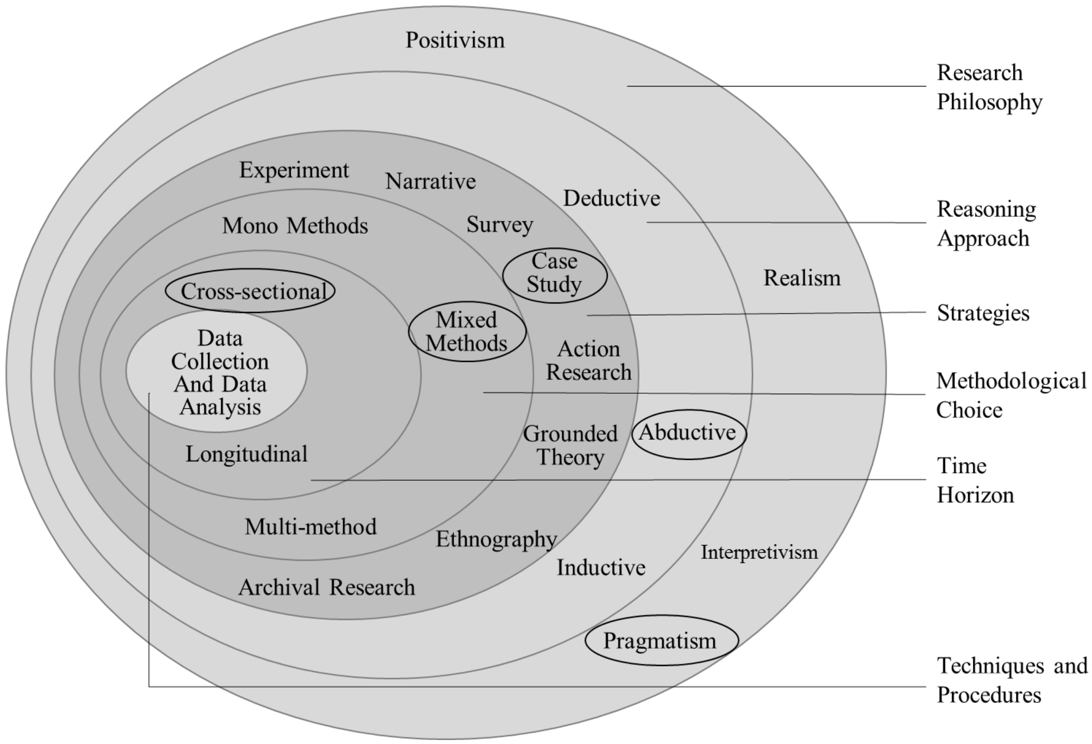

Figure 6. The research onion with the addition of abduction. Adapted from "Research methods for business students" by M. Saunders, P. Lewis, and A. Thornhill, 2009, Prentice Hill.

Research Philosophy

Researchers adopt particular research philosophies, which reflect their world views. These views chart distinctive paths through the academic research process. According to Saunders and Tosey (2013), the selected path reflects the researcher's "personal view of what constitutes acceptable knowledge and the process by which this is developed" (p. 58). This study used the pragmatic world view. Creswell (2013) writes extensively on the benefit of researchers' taking a pragmatic view by focusing on answering the research questions instead of on a particular research method such as quantitative or qualitative. The pragmatic approach guides researchers toward using all available methods to understand the research problem, which this study did.

Reasoning Approach

Saunders et al. (2009) highlight two core reasoning approaches for research, deductive and inductive. The deductive approach starts with the researcher selecting a general or universal premise and conducting research to test it. Inductive reasoning involves collecting and analyzing data based on what is known or observed in a specific instance towards the formation or generalization of a conclusion. Bryman and Bell (2015) suggest a third choice for researchers that is based on the pragmatist perspective: the abductive approach. They suggest that "abduction starts with a puzzle or surprise and then seeks to explain it…abduction involves the researcher selecting the best explanation from competing explanations or interpretations of the data" (Bryman & Bell, 2015, p. 27). The pragmatic nature of this study and Bryman and Bell's explanation of abduction suggests an abductive reasoning approach. However, the close inter-relationship between the three types of reasoning required deeper consideration before coming to that conclusion. Charles Sanders Peirce, an America philosopher, logician, mathematician, and scientist, conceived the concepts of pragmatism and abductive reasoning. About abduction, Peirce states that it "makes its start from the facts, without, at the outset, having any particular theory in view, though it is motived by the feeling that a theory is needed to explain the surprising facts" (1992, p. 106). In contrast, Peirce states that "induction seeks for facts…the study of the hypothesis suggests the experiments which bring to light the very facts to which the hypothesis had pointed" (1992, p. 106). Peirce continues this discussion with perhaps the most insightful statement of relevance to the reasoning approach for this study: "that the matter of no new truth can come from induction or from deduction, we have seen. It can only come from abduction; and abduction is, after all, nothing but guessing" (1992, p. 107), albeit guessing within a context.

The objective of this study was to answer the research questions and propose a set of recommendations. It sought facts, perhaps surprising ones, to explain the puzzling current state of federal research impact awareness and understanding. The study did not start or end with any general or universal premise and, as such, was not framed by deductive or inductive reasoning; however, instances of both these forms of reasoning were embedded within the study process. Because this study sought new truths formed through a sound, academically-rooted, and data-driven scientific process, i.e., "educated guessing," the reasoning approach was an abductive journey.

Strategies of Inquiry

The next two layers of the research onion, strategies and choices, are core to the research design. The researcher chooses between quantitative, qualitative, or mixed-methods designs. The selected design should be best for answering the research question(s). Quantitative research is focused primarily on numerical data and analysis, often using longitudinal survey data collection over time to study trends (Creswell, J.W. & Creswell, J.D., 2018). Qualitative research is focused on narrative data collected by interviewing and observing to establish patterns or themes (Creswell, 2013). The mixed-methods design, the newest of the three designs (circa 1989), is a mix of both quantitative and quantitative methodologies. Creswell and Clark (2018) describe mixed-methods as a set of four key components that go into the design and conduct of a mixed-methods study: 1) collecting and analyzing both qualitative and quantitative data to address the research question or hypotheses; 2) integrating, mixing, or combining the two forms of data and their results; 3) designing the method of inquiry and data collection/analysis procedures for conducting the study; and, 4) framing the procedures within theory and philosophy (p. 5).

This study used the mixed-methods design because neither a quantitative or qualitative data source alone was sufficient to answer the research questions. Creswell and Clark (2018) state “qualitative research and quantitative research provide different pictures, or perspectives, and each has its limitations” (p. 8). Qualitative research often studies a small number of individuals thereby limiting the ability to generalize. Quantitative research studies a large number of individuals, limiting the ability to personalize the data. This study took the convergent approach to the mixed-methods case study design. Quantitative and qualitative data, in the form of a survey, was first collected and analyzed. Based on an analysis of that data, research projects were selected for case study to explain, elaborate, and expand on the survey results (Ivankova, Creswell, & Stick, 2006). This approach supported a comprehensive (i.e., a micro and macro level) analysis and understanding of the federal research process and enabled the formation of answers to the research questions.

Time Horizon

Saunders et al. explain time horizons in research as the period of time the study will focus on (2009). The cross-sectional time horizon is a snapshot of a particular time, often the time the data is collected, to study a phenomenon. The longitudinal time horizon is defined as a series of snapshots over a period of time supporting the study of changes and trends. This study used a cross-sectional time horizon with the collection of data focused on the federal research environment in 2018.

Techniques and Procedures

At the core of the research onion are the data collection and data analysis techniques and procedures. Figure 7 depicts the four-step mixed-methods data collection and analysis process used for this study. The process is based on best practices documented in Creswell and Clark in *Designing and Conduction Mixed Methods Research* (2018). The four steps are detailed in the following sections.

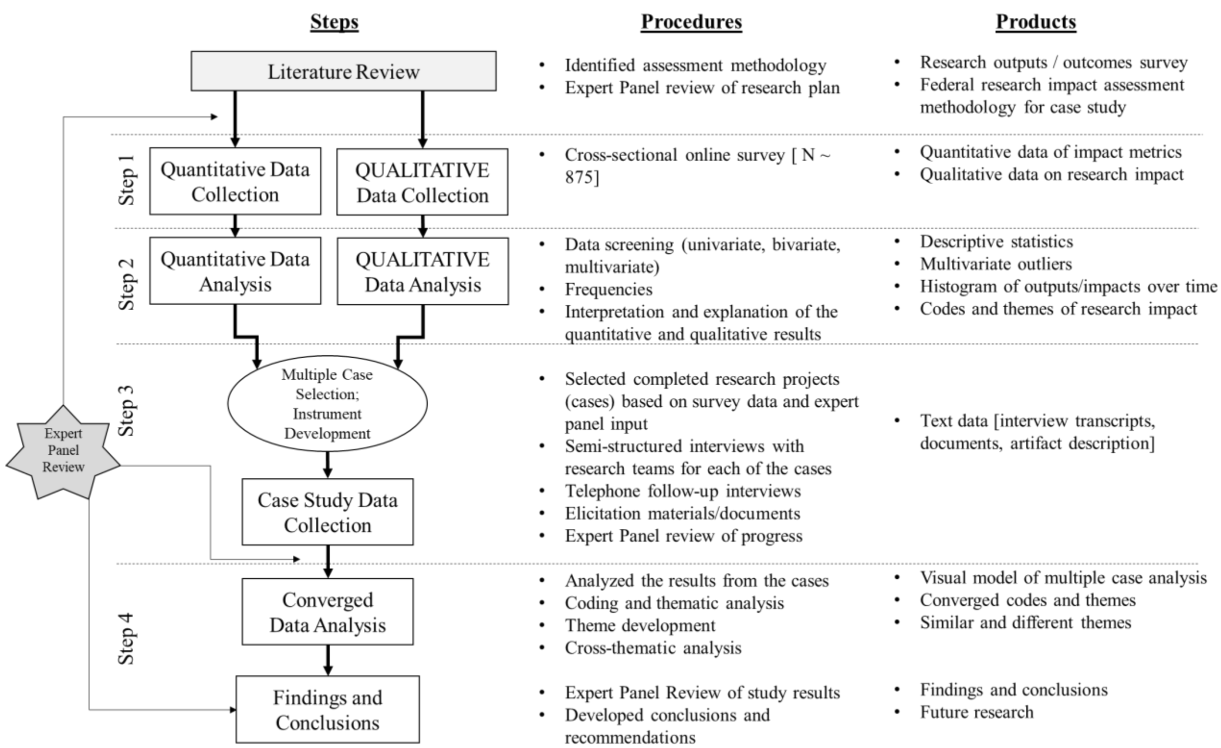

Figure 7. Process model for mixed-methods convergent case study procedure. Adapted from *"Designing and Conduction Mixed Methods Research*," by J. Creswell and V. Clark, 2018, Sage Publications, p. 119.

Expert Panel

Based on the practice and positive findings of the use of expert panels in the REF and RQF case study processes, an expert panel was formed to review, validate, and provide input to this study. Members of the expert panel were selected based on their subject matter expertise and experience with research within and external to the federal research environment. All seven panel members held senior positions at the MITRE Corporation, and five brought extensive experience and insight from previous government and industry positions. The panel included the Chief Technology Officer (CTO), senior Ph.D. members of the CTO office, and senior level Ph.D. engineers who have published on the topics of research impact and technology transfer. One panel member changed employment during the study but remained active on the panel.

The expert panel was convened three times during the study as indicated in Figure 7. At the first session, the panel reviewed the study purpose, research questions, and methodology. The panel validated the FRIAF and the data collection plan and provided input into the selection of completed research projects to include in the multiple case study. At the second session—not originally in the study plan but requested by the panel during the first session—the expert panel was interviewed individually. Each panel member reviewed and provided feedback on the progress made and the findings from the initial analyses of the survey and multiple case studies. At the third and final session, the expert panel reviewed, validated, and provided feedback on the study conclusions and recommendations.

The primary purpose of using an expert panel was to add trustworthiness and credibility to the study results and reduce biases on the part of the author. Details of the expert panel sessions are provided in Chapter 4.

Mixed Methods Step 1: Quantitative and Qualitative Data Collection

A conclusion from the University of Exeter DESCRIBE Project found that "the real challenge for assessing and evidencing research impact is in understanding what kinds of impact categories and indicators will be most appropriate, and in what contexts" (Stevens et al., 2013). To address this challenge and gain the needed understanding of the impact categories and indicators within the federal research environment, a survey was conducted that collected data on federally funded research projects completed prior to 2018. The survey included quantitative and qualitative questions on outputs, outcomes, and impacts determined as relevant to federal research organizations. The questions were derived from the review of the literature, discussion with subject matter experts, and feedback from the first expert panel session. Reliability and validity testing of the survey instrument also contributed to development of the questions (details below). Additional qualitative data was collected in the form of a transcript from the first expert panel session.

Population and Sample

The study population of principal investigators (PIs) across federal laboratories, UARCs, and the 42 FFRDCs is estimated to be above 10,000 (no data were found in the literature to confirm this estimate). The sampling framework of PIs at the seven MITRE FFRDCs who completed research projects prior to 2018 and were still employed at the organization was estimated at 875. Some of these PIs had led multiple research projects over the survey period. The survey was sent to the 875 PIs as a sample set of federal researchers. The author had full access to the PIs and the support of the organization’s CTO to collect the data.

The analysis of the survey data did not include statistical probability calculations such as margin of error. As such, the sampling approach described above uses nonprobability sampling consistent with the guidelines provided by Daniel (2012), which allow for ad hoc rule-of-thumb conventions. The convention applied to the sample size for this study’s survey was for 200 to 1,500 participants in a population size over 400 (Daniel, 2012).

Data Collection Procedure

An email was sent to the identified 875 PIs explaining the objective of the study and requesting their completion of an on-line survey focused on one or more of their completed research projects. Reminder emails were sent on a weekly basis for three weeks. The survey consisted of 26 quantitative questions focused on research impact metrics such as bibliometrics, patents, licenses, copyrights, trade secrets, technology transfer, knowledge transfer, collaboration, awards, recognition, and publicity. The survey also included three qualitative questions on additional impacts achieved that were not covered in the quantitative questions, the impacts the project had on the careers of the researchers, and the PI's general feedback on the topic of research impact.

From the 875 email requests, 147 completed survey responses were received representing 144 unique research projects and 126 unique PIs. Three projects were duplicates due to having co-PIs and were removed from the results pool. Some PIs submitted separate survey responses for more than one of their research projects. The response rate was below the 20-30% expected rate of return for emailed surveys (Nardi, 2014), but not unexpected considering the length and complexity of the survey.

Instrumentation

The survey was developed based on the review of the literature. The selected measurement criteria were heavily influenced by a set of metrics collected annually by the U.S. Army Research Laboratory in response to government research impact accountability requirements (Brown, 1996). The survey instrument was put through reliability and validity testing with PIs and members of the expert panel and revised based on the test results. The survey was also adjusted based on feedback from the first expert panel session.

Mixed-Methods Step 2: Quantitative and Qualitative Data Analysis

Step 2 of the method was designed to support the analysis for research question one:

- RQ1: What are the factors that contribute to or limit the achievement of research outcomes and impacts?

The first expert panel session was held before the survey was launched. The transcripts from the panel session were analyzed for themes that would suggest improvements to the study methodology. One such theme was the introduction of Pasteur's Quadrant (Stokes, 1997) that resulted in the addition of Use Inspired Basic to the category types of research in the survey and case study interviews.

Table 12 defines the data variables that were used in the survey analysis. The variables are linked to the questions in the survey. The variables are either ordinal or coded into nominal values. The survey data were exported to a Microsoft Excel spreadsheet and imported into SPSS for descriptive, frequency, and historical analysis. Statistical analysis was performed to determine the mean, median, range, minimum, and maximum values of the ordinal variables. Frequency, percentages, and histograms were generated for the nominal variables. These statistics were analyzed to help identify the factors that contribute to or limit the achievement of research outcomes and impacts.

Table 12. *Overview of variables from survey instrument*

Variable	Survey Q#	Measurement Value	Levels of Measurement	Description & Coding
Research Type	3	0-2	Nominal	0 = Basic 1 = User Inspired Basic 2 = Applied
Project Start Year	4	Year	Ordinal	1991 – 2016, or Pre-1990
Project Lifespan	5	In years	Ordinal	Length of the research project in years. 1-5, or Over 5
Funding Level	6	$$$	Ordinal	Total funding level over the lifespan of the project: <$100,000 $100,000 - $300,000

Variable	**Survey Q#**	**Measurement Value**	**Levels of Measurement**	**Description & Coding**
				$300,001 - $600,000 $600,001 - $900,000 >$900,000
Primary Output	7	0-10	Nominal	10 = Patent 9 = Software 8 = App/Application 7 = Hardware 6 = Process 5 = Algorithm 4 = Theory 3 = Standard 2 = Peer Reviewed Pub 1 = Prototype Demo 0 = Other
Staff Participation Count	8	0-N	Ordinal	Number of staff gaining skills from participation in research: 1-9 or 10+
Publication Count	9	0-N	Ordinal	Number of published papers by the project team associated with the research project: 0-9 or 10+
Citation Count	10	0-N	Ordinal	Number of citations of project-linked publications: 0 1-10 11-50 50+
Book Count	11	0-N	Ordinal	Number of books or book chapters published: 0 1-5 6-10 >10
Technical Report Count	12	0-N	Ordinal	Number of internal technical reports or conference papers: 0-9 or 10+
Patent Count	13	0-N	Ordinal	Number of registered patents from project: 0-9 or 10+

Variable	**Survey Q#**	**Measurement Value**	**Levels of Measurement**	**Description & Coding**
Government Use License Count	14	0-N	Ordinal	Number of government use licenses granted for project technology: 0-9 or 10+
Commercial License Count	15	0-N	Ordinal	Number of commercial licenses granted for project technology: 0-9 or 10+
Media Article Count	16	0-N	Ordinal	Number of media or trade articles published: 0-9 or 10+
Presentation Count	17	0-N	Ordinal	Number of presentations made at conferences and workshops: 0-9 or 10+
External Award Count	18	0-N	Ordinal	Number of external awards received: 0-9 or 10+
Trade Secret Count	19	0 or 1	Nominal / Dichotomous	0 = No 1 = Yes
Open Source Contribution	20	0 or 1	Nominal / Dichotomous	0 = No 1 = Yes
Government Collaboration	21	0 or 1	Nominal / Dichotomous	0 = No 1 = Yes
Academia / Industry Collaboration	22	0 or 1	Nominal / Dichotomous	0 = No 1 = Yes
Previous Research Linkage	23	0 or 1	Nominal / Dichotomous	0 = No 1 = Yes
Technology Transfer	24	0 or 1	Nominal / Dichotomous	0 = No 1 = Yes
Technology Transfer Level	25	0-3	Nominal	A discrete measure of technology transfer determined as follows: 0=no follow-on; 1= technology acknowledged by sponsor; 2=technology influenced change; 3=technology resulted in measurable efficiencies

Variable	Survey Q#	Measurement Value	Levels of Measurement	Description & Coding
Case Study Participation	26	0 or 1	Nominal / Dichotomous	0 = No 1 = Yes

Mixed-Methods Step 3: Multiple Case Study

The body of evidence in the review of the literature showed that the case study approach provides a compelling narrative of the impact of research (Grant, 2006; Jones, Castle-Clarke, Manville, Gunashekar, & Grant, 2013). Yin (2014) stated that “when you have the choice (and resources), multiple-case designs may be preferred over single-case designs (p.63). He explained that the analytic results benefit substantially from a multiple-case study. The additional data from both the mixed-methods approach and multiple-case study supports triangulation. Creswell and Clark (2018) defined triangulation within mixed-methods research as “convergence and corroboration by comparing findings from qualitative data with the quantitative results” (p. 290). Triangulation and the use of multiple sources of data are critical for a case study approach in order to validate and converge the evidence supporting the findings (Yin, 2014). Yin also highlighted the benefit of using a multiple-case study to enable the replication of a procedure for each case. For this study, the replicated procedure was the use of the FRIAF and associated data collection instrument for each case study.

Step 3 data collection was designed to further support the analysis for research questions one:

- RQ1: What are the factors that contribute to or limit the achievement of research outcomes and impacts?

Population and Sample

For multiple-case study, Creswell (2013) recommended including no more than four or five cases in one study to balance the increased analytical benefits against the added time and resources needed to conduct the cases. The original plan for the study targeted four case studies; however, the findings from Step 3 data analysis and feedback from the expert panel resulted in the selection of twelve completed research projects for case study. Driving this increase in number was the understanding gained of the diversity of research projects across the seven FFRDCs participating in this study including factors such as research type (i.e., basic, use inspired basic, applied), differences in the research cultures, and variation of impact achieved across the research projects. Research projects for inclusion in the multiple case study were identified from recommendations by the expert panel, survey submissions, recommendations from PIs, and PIs expressing interest in participating in the case study. The following categories and associated criteria were used in the selection of projects for case study:

- High-impact applied research projects defined as having transitioned output to government programs, improved government mission capability, gained senior-level government exposure/recognition, and/or resulted in significant outcomes (e.g., trade secret, patent, and license).
- High-impact basic and use inspired basic research defined as having spawned significant applied research or credited as the catalyst/foundation for a new area of basic research, and/or having achieved a high level of publication-based exposure, citations, or collaboration.
- Low-impact research defined as lacking the high-impact criteria but potentially having ambiguous and/or unanticipated impacts.

The principal investigator (PI) and their key research team participants made up the interview population of the case studies. The case study interviews included from one to three researchers from each project team, including the PI. This sampling size is lower than Daniel's (2012) guideline of three to five participants for a case study. This is offset by the larger number of case studies. The lower sampling size is in part the result of research team attrition since some of the selected projects had completed as far back as 20 years prior to this study. Additionally, some projects were selected for case study due to their small team makeup in order to analyze the challenges associated with that factor in achieving research impact.

Data Collection Procedure

Data collection for the case study projects came from multiple data sources including interviews, document review, and other related artifacts (e.g., media articles, research project summaries, award write-ups, and CTO research program data collections). The data collection techniques used for the case studies were group or individual semi-structured interviews with the research team, based on participant availability and willingness. The group interview format was encouraged because of its behavioral dynamic of enhancing recall as the research team reminisced together on their shared experience, which in some cases took place up to 20 years earlier. Issues such as group think and peer pressure that are often experienced in focus groups were not a factor in the group interviews of this study due to the objective of surfacing past events and facts regarding the case study research projects instead of personal feelings and opinions.

Each case was approached separately, i.e., each group interview included a research team from only one research project. Follow-up telephone interviews with one or more of the research team also were conducted after the face-to-face interviews when additional or clarifying information was deemed necessary during data analysis.

The procedure used to collect the case study data started with an email to the research teams notifying them that their project was selected for case study and requesting their participation. The email explained the intent of the study and how the collected data would be used. Interview sessions were then scheduled with each of the teams. Prior to the interview, the PIs were asked for documentation on the project including original proposals, in-process reviews, final reviews, papers, and technical reports. Following the interview, a literature review was conducted on the project to search for additional outputs, outcomes, and impacts through published papers, patents, citations, and other sources.

Instrumentation

The case study interview questions were developed based on the review of the literature. They repeated some of the questions from the survey in order to validate the survey data and collect detailed contextual information. The questions were structured based on the seven stages of the FRIAF process. Thirty-eight questions were focused on the seven stages of the research process, and four were focused on research process improvement.

Reliability and Validity

Bibliometric analysis was used to verify the impact information provided by the researchers (Milat et al., 2015). The bibliometric data were collected from online sources such as Google Scholar, Google Patent, and the CTO office.

The FRIAF research impact assessment methodology was reviewed by the expert panel and validated. The expert panel was asked to suggest and validate case study research projects as representative of the federal basic and applied research portfolio. Feedback from the first expert panel session was used to adjust the study approach, the survey instrument, the selection of projects for case study, and the case study interview protocol.

Mixed-Methods Step 4: Converged Data Analysis

The data analysis plan was designed to answer the two research questions. The survey instrument was designed to collect the data necessary for the partial analysis of RQ1. The FRIAF was used to structure the case study interview protocol. The results of the survey data analysis were used to improve the case study interview protocol. The case study and survey data were converged for the analysis of RQ1. The RQ2 data analysis used the findings of the RQ1 analysis in combination with information from the literature review and expert panel feedback to develop recommendations for enhancing federal research impact.

The converged case study data analysis process used in the study is depicted in Figure 8. Four general strategies identified by Robert Yin (2014) were considered for analyzing the case study evidence: 1) relying on theoretical propositions; 2) working data from the ground up; 3) developing a case description; and 4) examining plausible rival explanations. Because the analytical path was not driven by a theoretical proposition but instead by poring through the data, Yin's (2014) strategy of *working the data from the ground up* was used. Patterns in the data suggested useful concepts that contributed to answering the research questions as well as concepts that went beyond the research questions. In some cases, *plausible rival explanations* of factors influencing achievement of research outcomes and impacts surfaced and were tested. The mixing of the two analytic strategies is supported by Yin with his statement that "you can use any of them in any combination" (2014, p. 136).

Four forms of data analysis were considered based on Creswell (2013) including 1) categorical aggregation, 2) direct interpretation, 3) cross-case synthesis, and 4) naturalistic generalizations. These were compared and contrasted with Yin's (2014) five analytic techniques of 1) pattern matching, 2) explanation building, 3) time-series analysis, 4) logic models, and 5) cross-case synthesis. The type, quantity, and quality of the data collected led to the selection of a combination of these analysis techniques. Pattern matching, categorical aggregation, cross-case synthesis, and naturalistic generalization were used to complete the analysis.

The data analysis process used in this study is depicted in Figure 8. The diagram shows the three research questions driving the development of the FRIAF. The FRIAF framed, standardized, and categorized the data collection across the case studies. For each case study, iterative coding and theme generation was performed.

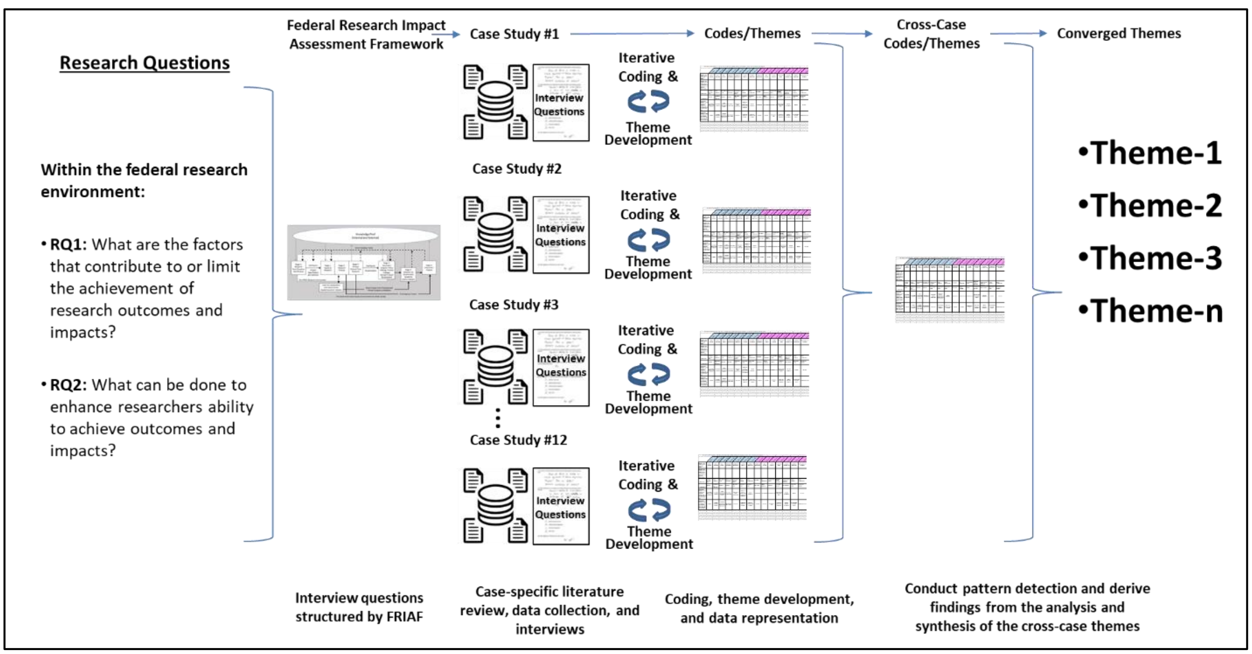

Figure 8. Case study data collection and analysis process.

The process followed Creswell's (2013) case study data analysis and data representation approach shown in Table 13. Coding involved coding the text data for each question in the interviews (transcribed from audio recording) into small categories of information, seeking evidence for the code from the collected data, and then assigning a label to the code. The next step was the identification of themes from broad units of information that consisted of several codes aggregated to form a common idea. The codes and themes were entered into a Microsoft Excel spreadsheet. Pattern detection was then conducted to look for correlations between two or more themes to reduce the number (Stake, 1995). From the distilled themes, findings were generated. Naturalistic generalization (Stake, 1995) was used to interpret the findings from the author's personal experiences with the FFRDC research program. Yin's (2014) technique of *working the data from the ground up* was also employed to increase the probability of uncovering unexpected findings that supported the research questions.

Once the data analysis process was completed for each case study, a cross-case analysis was performed to compare and contrast the individual case codes and themes. The result of the cross-case analysis was used to develop findings and recommendations.

Table 13. *Case study data analysis and representation approach*

Data Analysis and Representation	Case Study Approach
Data Organization	Create and organize files for data
Reading, memoing	Read through text, make margin notes, form initial codes
Describing the data into codes and themes	Describe the case and its context
Classifying the data into codes and themes	Use categorical aggregation to establish themes or patterns
Interpreting the data	Use direct interpretation; Develop naturalistic generalizations of what was learned
Representing, visualizing the data	Present in-depth picture of the case (or cases) using narrative, tables, and figures

Note. Adapted from "*Qualitative Inquiry & Research Design: Choosing Among Five Approaches*," by J. Creswell, 2013, Sage Publications, pp. 190-191.

Data Analysis for RQ1

RQ1: What are the factors that contribute to or limit the achievement of research outcomes and impacts?

Using the survey data, a descriptive statistical analysis was performed to determine the mean, median, range, minimum, and maximum values of the ordinal variables. Frequencies and percentages were generated for the nominal variables. The statistics were used to identify factors associated with achievement of research outcomes.

During the case study phase, interview participants were asked for clarifying and expanding information on the factors associated with achievement of research outcomes from their projects. This supplemented and validated the survey data collected for their project and helped in the understanding of the realized and potential relevance of the factors within the federal research environment.

The survey data were collected from completed research projects prior to 2018. The review of the literature showed that research impact evolves over time and that some impacts take years to manifest. For example, the older a publish date gets for a peer reviewed paper, the more citations it should have. The literature also indicated the challenge associated with collecting retrospective research impact data over time. This analysis provided insight on how impacts evolved within the federal research environment over time and the atrophy of data availability over that same time period.

Data Analysis for RQ2

RQ2: What can be done to enhance researchers' ability to achieve outcomes and impacts?

Data were collected during the case study interviews on the contributors and limiters within the research process to achieving research results and impacts. Best practices found in the literature and options for augmenting the research process to increase impacts were discussed with the interview participants to gain their perspectives and insights. The themes uncovered through analysis of the data were used in a search of the literature for applicable solutions. Findings and recommendations for changes to the research process were then generated.

Validation of Findings and Recommendations

The validation approach for Step 4 of this study consisted of both internal and external components. The internal component focused on ensuring that the biases of the author did not invalidate the data collection, analysis, findings, or recommendations. The external component focused on use of research best practices to ensure valid findings and recommendations.

Bracketing

To minimize the effects of investigator bias, bracketing was implemented during the study. Bracketing "is a method used by some researchers to mitigate the potential deleterious effects of unacknowledged preconceptions related to the research and thereby to increase the rigor of the project" (Tufford & Newman, 2010, p. 81). It is a deliberate and transparent method used by the researcher to set aside views, biases, and preconceived notions about the research topic. This requires reflexivity in the author, that is, an ability to self-evaluate. Creswell (2013) warned that "bracketing personal experiences may be difficult for the researcher to implement because interpretations of the data always incorporate the assumptions that the researcher brings to the topic" (p. 83). With that in mind, the investigator implemented bracketing by documenting recognized biases in a bracketing journal during the study and discussing these biases with the study advisor, the case study participants, and the expert panel. Doing so transformed preconceptions into rich discussion and data collection topics.

External Validation

The external components of the validation approach included:

- Triangulation that made “use of multiple and different sources, methods, investigators, and theories to provide corroborating evidence” (Creswell, 2013, p. 251). Data from the survey, interviews, case study document search, literature review, and expert panel were used to triangulate findings and recommendations.
- Member checking in which “the researcher solicits participants’ views of the credibility of the findings and interpretations” (Creswell, 2013, p. 252) were implemented. This included validating the findings and recommendations with the case study participants, federal research experts, and the expert panel.
- Creswell (2013) stated that “reliability can be addressed in qualitative research…if the researcher obtains detailed field notes by employing a good-quality tape for recording and by transcribing the tape…to indicate the trivial, but often crucial, pauses and overlaps” (p. 253). The interviews and expert panel sessions were audio recorded and transcribed to insure reliable data for analysis.

Upon completion of the data analysis, the initial findings and recommendations from the study were reviewed with the expert panel. Feedback from the panel is included in Chapter 4.

Confidentiality of Participants and Data

Before the data collection began, an application to conduct the survey and case studies was approved by both the MITRE Corporation and Robert Morris University (RMU) Institutional Review Boards (IRBs). The personal information collected in the course of this study was handled confidentially. Survey and interview data in all forms (e.g., digital, paper, and audio recordings) were protected by encryption and/or physical locks. No participant names, research project names, or otherwise identifying information was included in this study. Participation was voluntary.

Limitations

The major limitation of the study was the sample of research projects coming from a single research program across seven FFRDCs. The MITRE research program may not be representative of other FFRDCs or the federal research community.

Another limitation is the lack of user participation in the survey and case study. A user in this context would be a receiver of the research output, for example a government sponsor of the federal research. The perspective of the user would add insight into the impacts of the research. User input was not pursued due to time and access challenges.

Summary

Chapter 3 presented and justified the academic methodology used in this study. Mixed-methods is a highly complex undertaking that requires deliberate planning, thorough data collection, and comprehensive analysis. The academic and theoretical roots for the research approach were laid out and supported with evidence. The critical risks and limitations of the study were identified and addressed. A plan was presented to ensure that biases were minimized, and the quality of data collection and analysis was maximized. This included the implementation of bracketing, triangulation, member checking, and audio recording of participant engagements.

The chapter started with a detailed description and justification of the research impact assessment framework selected from the literature review for use in this study. The Payback Framework was found to be highly adaptable for use in case study of federal research in a standardized, structured, and comparable manner. The Federal Research Impact Assessment Framework (FRIAF) was adapted from the Payback Framework to organize and structure the data collection, analysis, and findings of this study.

A four-step data collection plan was diagramed and described in this chapter. The plan started with a survey collecting quantitative and qualitative data. This was followed by a multiple-case study of completed research projects. The survey and case study instruments were tested for validity and reliability and refined based on expert panel review. The data analysis process that converged the quantitative and qualitative data was also diagramed and described. The multi-case study data collection and analysis process was shown to culminate in findings and recommendations that would lay the groundwork for answering the research questions. The process concluded with the findings and recommendations being presented to the expert panel for feedback and validation.

Chapter 4: Results

This chapter presents the results of the study framed by the four steps of the data collection and analysis process model depicted in Figure 7. The chapter begins with an overview of the first expert panel session including the recommendations from the panel and actions taken in response. The results from the steps #1 and #2 quantitative and qualitative data collection and analysis are then presented including highlights from the survey and derived findings. The results and findings from the step #3 case study data collection are segmented into the seven stages of the federal research process model depicted in Figure 5. The model was used to frame the case study interview questions and as a visual aid during the interview sessions. The case study results are followed by a summary of the second expert panel session held as one-on-one interviews with each of the seven panel members. Finally, the step #4 section includes the results of the converged case study analysis depicted in Figure 8 and presents answers to the research questions:

- [RQ1] What are the factors that contribute to or limit the achievement of research outcomes and impacts?
- [RQ2] What can be done to enhance researchers' ability to achieve outcomes and impacts?

Expert Panel Session #1

Before quantitative and qualitative data collection began, the expert panel was convened to review the study objectives, research questions, and approach. The seven members of the panel participated in the 90-minute meeting held via video teleconference at two locations with one member participating through teleconference. The panel validated the study objectives and stated, “it has deep potential value” and “would be huge in terms of helping do our work going forward.”

The expert panel session drove considerable reflection on the original objective of the study, which was focused on enhancing research impact through development and implementation of a research impact assessment methodology. This reflection led to the realization that an assessment methodology would be executed at the end of the research process and thus have limited influence on the achievement of research impact. The conclusion was that there would be more potential value in studying the contributors and limiters to achieving research impact within the research process, especially in the early stages where it would be possible to explore and propose improvements to the process that could enhance the achievement of research outcomes and impact. This change in the study focus was reflected in the survey and case study instruments and validated with the expert panel during the mid-study session. The recommendations and guidance from the panel are summarized in Table 14.

Table 14. *Recommendations from expert panel session #1*

Panel Recommendation/Guidance	**Action**
Expand the categories of research beyond basic and applied with the addition of use-inspired basic research from Pasteur’s Quadrant.	Adjusted category of research question in survey to include the three categories from Pasteur’s Quadrant.
Define short-term and long-term in the context of the study.	Revisited language used in writing and verbal presentation of study to eliminate ambiguity and relative terms such as long-term and short-term in the context of research impact.
Perform literature review on the differentiations of research programs at FFRDCs [and government labs].	This information was collected during the study and considered in the conclusion and recommendations.
Consider not doing original research this broadly.	Data collection was narrowly focused on seven FFRDCs. The findings, recommendations, and conclusions of the study were generalized taking this guidance into account.

Panel Recommendation/Guidance	Action
The approach to managing the research program might be a factor in achieving impact.	This point came out in the case studies and evolved into a key theme.
Consider the hypothesis that generating Intellectual Property increases the probability of having impact.	Intellectual property surfaced as a sub-theme in the case studies; however, the hypothesis was not directly addressed in the study.
Increase the number of case studies [from the originally proposed four] in order to cover the diverse types of research projects across the seven studied FFRDCs, the project selection criteria, and time ranges.	This was found to be sage advice. In the course of developing the case study selection criteria, the conclusion was made that twelve case study projects were necessary to represent the wide diversity of research across the seven studied FFRDCs.
Engage the expert panel at mid-study to provide them the opportunity for further review and guidance.	One-on-one interviews were held with each expert panel member at the completion of case study data collection and during the converged data analysis. The one-on-one format was selected over the group session to afford a deeper discussion with each and avoid the effects of group dynamics.

Step #1 & #2: Quantitative and Qualitative Data Collection and Analysis

Steps #1 and #2 of the data collection and analysis process for the study were implemented via a survey instrument. The web-based survey was hosted on QuestionPro and open for four weeks. Weekly reminders were sent to the non-responding survey population. The survey provided a broad understanding of the characteristics and outputs of federally funded research projects and the approaches used by the principal investigators (PIs) in the execution of their projects. The information gained was used to develop the case study interview instrument. The survey was sent to 875 PIs within seven FFRDCs that were believed to have completed internally funded research projects prior to 2017. The Office of the Chief Technology Officer (CTO) for the seven FFRDCs provided a list of PIs and their funded projects starting from 2011, which is when the office began capturing the data. The CTO-provided data were later found to contained non-PI staff in addition to PIs. Email announcements and other sources of research awards prior to 2011 were used to identify PIs from as far back as 1999 with some gap years.

Year-end reports of the research program were found on-line for some years which provided PI and descriptive research information (i.e., research project name, PI contact information, project description, and project results), but the information was not centrally managed and unlocatable for some years.

From the 875 email requests, 147 completed survey responses were received representing 144 unique research projects. An additional 17 research projects provided partial responses to the survey. The 144 projects were submitted by 126 unique PIs as some filled out separate surveys for more than one of their completed research projects. Because the survey data were used for descriptive purposes, the partial responses were included in the analysis. The lack of accurate PI data resulted in a survey completion rate of 17% which was lower than expected. Preparation of the PI survey email list also uncovered attrition of PIs due to factors such as retirement and change of employment. In some cases the attrition of PIs was found to be correlated with attrition of research information related to their projects.

As seen in Figure 9, the projects represented in the survey had start dates ranging in time from pre-90s (1987 was the earliest) to 2017. The majority of the projects (63%) started post-2010. The difficulty in identifying past PIs, locating historical research information, and the low project representation in the survey prior to 2011 led to the following findings:

- Finding 1: There is an atrophy of research information over time.
- Finding 2: PI attrition results in loss of research information.

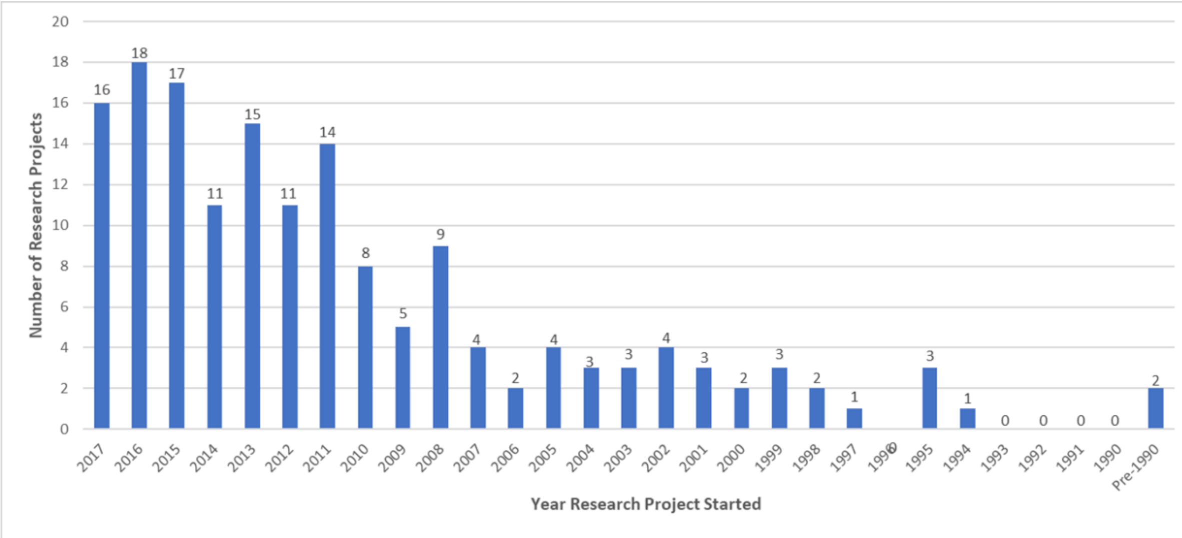

Figure 9. Survey results of year research project started

Figure 10 depicts the number of years that each research project was funded and Figure 11 the range of total funding that each research project received. As might be expected, a Spearman's rank-order correlation found that there was a strong, positive correlation between the number of years the project was funded and the total project funding, which was statistically significant ($n = 161$, $r_s = .690$, $p < .001$). This indicates that as the number of years a research project is funded increases, the total project funding also increases. Interest in other correlations surfaced in the case study interviews as well as during the one-on-one mid-study sessions with the expert panel members. The specific questions raised during the interviews were whether the analysis of the data indicated a decreasing level of funding for research projects over the time period of data collection and if the number of years a project was funded was decreasing over the time period of data collection. These questions were repeatedly raised due to a perception of a trend toward increasing the number of awarded projects but with smaller funding levels than in past years. Due to the *project start year* being questionable as a true continuous variable, no time-related correlations were performed. As such, no findings on changes in project award numbers or funding behavior over time could be made. This is an area for future study.

The findings from the analysis of these data are:

- Finding 3: 89% of the surveyed research projects were funded for 1 to 3 years.
- Finding 4: 43% of the surveyed research projects were funded at or below 1 full time equivalent (FTE), defined as the annual hours of a full-time employee.

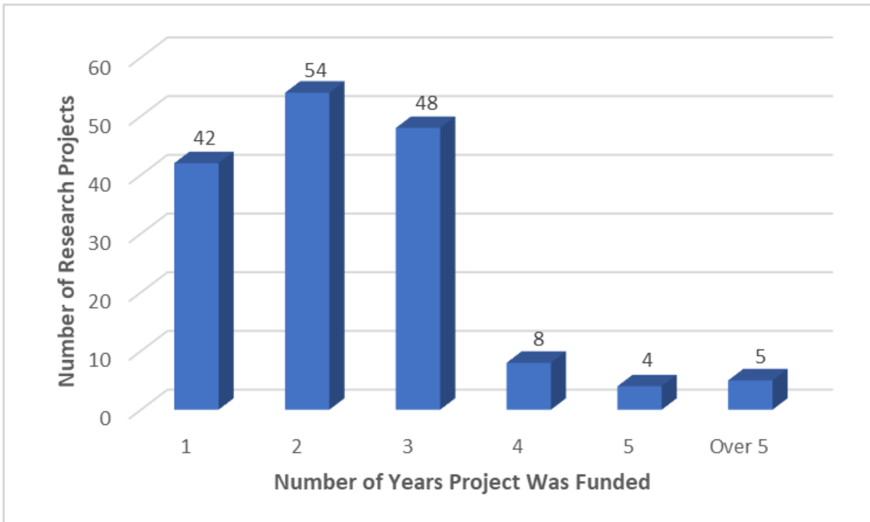

Figure 10. Survey results of number of years project was funded

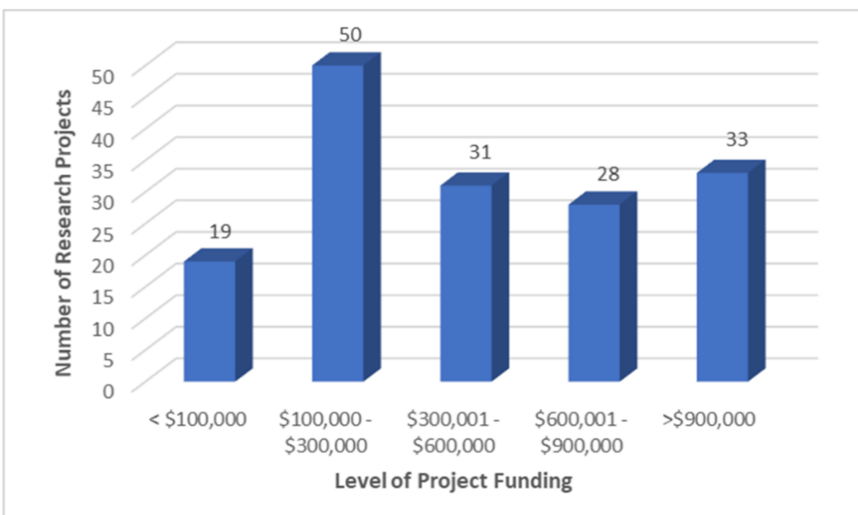

Figure 11. Survey results of the level of project funding

Based on the recommendation of the expert panel, the PIs were asked in the survey to self-categorize their research project as Pure Basic Research, Use-Inspired Basic Research, or

Applied Research. The results in Figure 12 indicated a majority focus on applied research (51%) and use-inspired basic research (45%). Basic foundational research was only identified in 4% of the represented research projects. This led to the following finding:

- Finding 5: The mission-focused charter of the federal research organization is reflected in the research program.

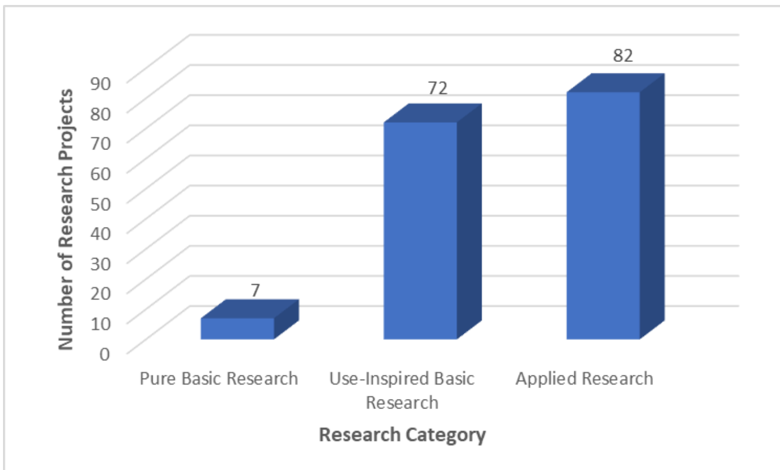

Figure 12. Survey results of project research category

The survey participants were asked to identify the primary output of their research project. Feedback on this question from some PIs was that they had multiple outputs and would have liked to have provided that information. However, the question was designed specifically to force a selection of only one to determine what they considered their most important output. The results in Figure 13 show that a prototype demonstration was the most prevalent (34%) research output.

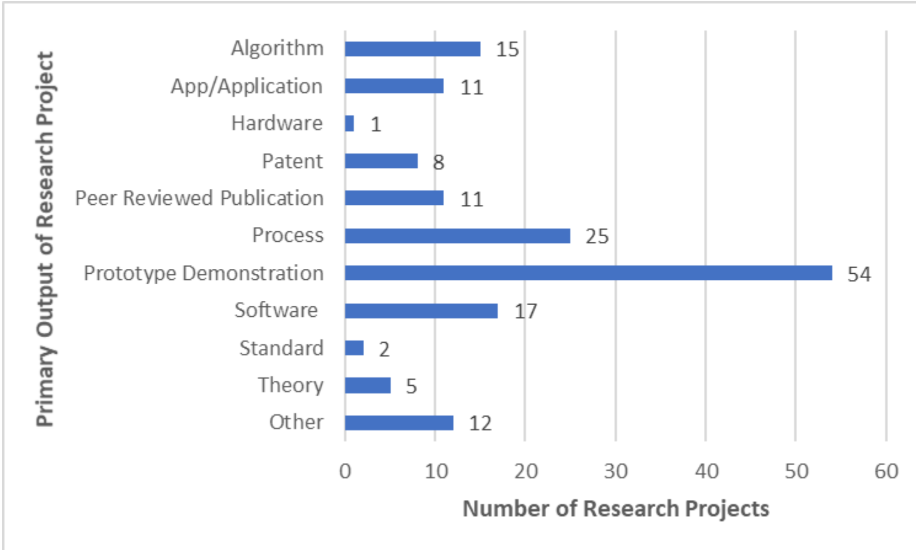

Figure 13. Survey results of primary output of research projects

The survey included two questions on the characteristics of the research teams. The first question asked for the number of staff that participated in the research with the qualifier that those counted should have gained knowledge from the research activity. The results in Figure 14 show that most projects involved more than the PI alone with an average of 5.366 staff participating in some material way. Twelve percent of the projects reported having 10 or more staff participate and gain knowledge from the research activity. As would be expected, a Spearman's rank-order correlation found that there was a strong, positive correlation between the number of staff participating on a project and the total project funding, which was statistically significant ($n = 161$, $r_s = .549$, $p < .001$). This indicates that as the number of staff participating on a project increases, the total project funding also increases. A statistically significant, strong, positive correlation was also found between the number of staff participating on a project and the number of years the research project was funded ($n = 161$, $r_s = .504$, $p < .001$). This indicates that as the number of staff participating on a project increases, the number of years a research project is funded also increases.

The second question was open ended and asked, “How did the research experience impact the careers of the participants?” Common responses described research participation as: developing subject matter expertise in the field of study; the catalyst for career advancement/promotion; contributing to the completion of advanced degrees (i.e., Masters and Doctoral); attracting new hires interested in the research field; providing a catalyst for recognition and awards; increasing staff visibility and reputation; and growing staff networks and collaboration skills.

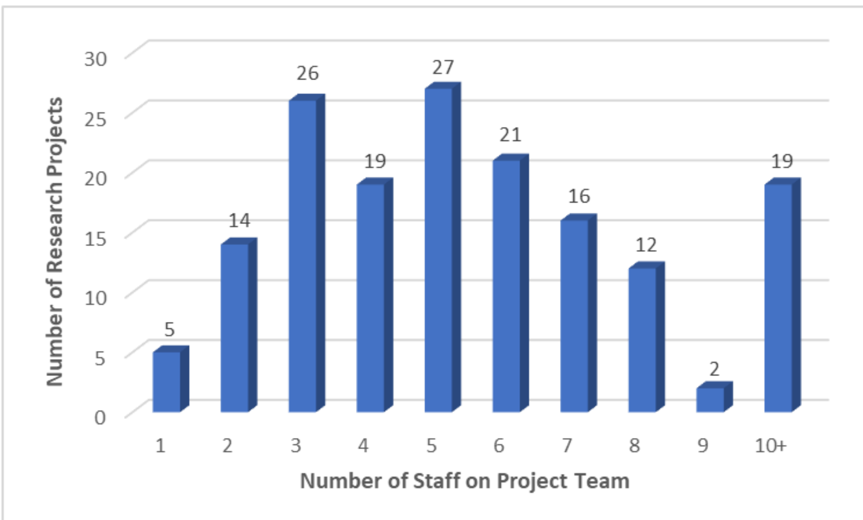

Figure 14. Survey results of number of staff on project teams

The remaining survey results are captured in Table 15. The survey data were included in the converged analysis with the case study results. The three survey topics that were prevalent in a majority of the surveyed projects were participation in conferences and workshops, technology transfer to the government, and the publishing of technical reports for conferences and internal use in the research organization. These represent the primary dissemination vehicles of research information and results by the surveyed research projects.

Table 15. *Survey results summary*

Survey Topic	Yes	No
Conference and Workshop Participation	84%	16%
Technology Transitioned to Government	62%	38%
Technical Reports Published	60%	40%
Peer Reviewed Papers Published	32%	68%
Research Built Upon Previous Research Project	29%	71%
Formal Collaboration/Partnership with Academia/Industry	29%	71%
Trade and Media Articles Published	25%	75%
Patent Applications Registered	18%	82%
Formal Collaboration/Partnership with a Government Lab	15%	85%
Software Made Available Through Open Source	15%	85%
External Awards	13%	87%
Government Licenses Granted	11%	89%
Books or Book Chapters Published	11%	89%
Trade Secret Declared	10%	90%
Commercial Licenses Granted	9%	91%

Step #3: Multiple Case Study Results

Selection of the 12 case study projects was influenced by suggestions from the expert panel, analysis of the survey responses, requests from PIs, and the authors' familiarity with the research program. Selection was based on a representative distribution across three categories: 1) research category (i.e., Applied and Use-Inspired Basic); 2) high and low-impact; and 3) year of project start. Basic research was not included as a category in the project selection due to its low (4%) representation in the survey results. The determination of high and low-impact was based on known results of the selected research projects and verified during the case study interviews. No attempt was made in this study to determine a measurement approach for research impact; instead, projects were categorized using the following criteria:

- High-impact use-inspired basic research – The project was the catalyst for high-impact applied research or a new area of basic research. Project resulted in a high level of publication-based exposure/citations/collaboration.

- High-impact applied research – The project led to significant direct work, improved sponsor mission capability, senior-level government exposure/recognition, and/or a brand promoting outcome (e.g., trade secret, patent, license).
- Low-impact research – The project lacked the high-impact criteria but potentially had ambiguous and/or future unanticipated impacts.

The assignment of a high or low-impact designation to a project was intersubjective. Figure 15 depicts the distribution of the 12 case study projects across the three categories. Individual projects are referred to in chapters four and five by their code in the table.

Research Category	1989	1995	1998	2002	2007	2009	2012	2013	2014	2017
High Impact Use-Inspired Basic Research	HB1		HB2	HB3		HB4	HB5			
High Impact Applied Research				HA1	HA2			HA3	HA4	
Low Impact Use-Inspried Basic Research		LB1								LB2
Low Impact Applied Research								LA1		

Year Research Project Began

Figure 15. Distribution of case studies across research categories

Interview sessions were held with the PI of each case study project. In some cases, additional staff from the research team participated. In total, 19 researchers participated in the interview sessions. Interview sessions ranged from 60 to 120 minutes. Each session was audio recorded and transcribed. In total, 15.5 hours of transcripts were documented.

The case study instrument was used in each session to guide discussion. Each interview session walked through the seven stages of the research process using the federal research process model shown in Figure 5. The case study instrument, which included the research process diagram, was provided to the interviewees at least one day prior to the interview to help them prepare. The instrument included 38 questions framed within the seven-stage research process. An additional three questions were aimed at exploring research process improvements. The final question asked for any additional information the interviewee wanted to share. The interview questions were not covered in their entirety at every interview session. The results from each question, segmented by the associated research stage, are summarized below.

Stage 1 Results: Research Topic/Question Identification

The overall experiences described by the case study participants regarding the formation and selection of their research topic were wide ranging. The results are summarized in Table 16. The following findings surfaced as significant factors in the research topic selection of high-impact projects.

- Finding 6: The selection of a research topic that was rapidly ascending or high on the emerging technology hype curve was a contributing factor to some high-impact projects.
- Finding 7: The selection of a foundational research topic that developed deep and unique talent, capability, capacity, and knowledge (core competency) in a high-need area was a contributing factor to some high-impact projects.
- Finding 8: The selection of a research topic that was derived from a discovery in a previous or on-going research project that the PI was a part of was a contributing factor to some high-impact projects. In some cases, the PI was involved in the previous research project at another company.

Table 16. *Stage 1 case study results*

Stage:Q#	Question	Highlighted Results
S1:1	How did the research idea and questions originate?	• Previous research finding • Discovery of a mission gap during PI support of a government initiative • PI interest in emerging hot topic area • Externally generated challenge area

Stage:Q#	Question	Highlighted Results
S1:2	Describe the original objectives of the research.	These were unique to each of the case studies. The question was useful in getting the PIs to tell their story.
S1:3	Do you consider the research to be pure basic, use-inspired basic, or applied?	Survey results were depicted in Figure 12. All high-impact use-inspired basic projects either transitioned to applied status or spun off new applied research projects.
S1:4	Explain the literature review process used to formulate the research questions.	This was unique to each case study. Some projects benefited from extensive literature review having been conducted within previous research projects. Other projects did no formal academic research and instead relied on mission-related knowledge and experience from the operational environment.

Stage 2 Results: Inputs to Research

The *Inputs to Research* stage was defined for the case study participants as the knowledge, experience, talent, equipment, objectives, and plans that were in place by the initiation of the project. The results are summarized in Table 17. The following findings surfaced as significant factors contributing to or limiting the achievement of outcomes and impacts.

- Finding 9: The projects that spun off from recent or still on-going research benefited from having access to knowledgeable and experienced staff in the research domain and had well defined outcomes. These projects also had well established collaboration, partnering, and technology transfer/transition opportunities identified or even pre-staged. As a result, these projects were able to hit the ground running.
- Finding 10: High-impact projects were associated with having addressed collaboration and technology transition/transfer opportunities at the initial stage of research. Low-impact projects were not.

Table 17. *Stage 2 case study results*

Stage:Q#	Question	Highlighted Results
S2:1	Did the research build upon one or more previous specific research projects?	Five of the 12 case study projects had pedigree from previous research.
S2:2	How was the research team formed?	Most of the case study projects formed research teams from previous established networks and relationships. In some cases, external experts were hired specifically for the research.
S2:3	Were collaboration opportunities pursued at the formative stage of the project?	All high-impact case study projects established collaborative relationships with government, academia, and/or industry at the initial stages of their research. The low-impact case study projects did not.
S2:4	Were technology transition/transfer opportunities identified at the formative stage of the project?	All high-impact applied case study projects had technology transition/transfer opportunities identified at the initial stages of their research. The high-impact use-inspired basic projects evolved their technology transition/transfer opportunities at later stages in the research process. The low-impact projects did not address technology transition/transfer until the completion of their research.

Stage 3 Results: Research Process

The *Research Process* stage was defined for the case study participants as the execution of the research project during the period of time it was funded. The results are summarized in Table 18. The following findings surfaced as significant factors contributing to or limiting the achievement of outcomes and impacts.

- Finding 11: High-impact research teams actively engaged with the research domain community of interest.
- Finding 12: High-impact projects benefited from being allowed to revector the research plan and outcome(s) based on early findings/realizations and/or based on feedback from stakeholders.

- Finding 13: The combination of active community of interest engagement, presentations at conferences and workshops, and use of a prototype demonstration were prevalent in high-impact case study projects.
- Finding 14: Collaboration, whether formal or informal, is prevalent in high-impact projects.
- Finding 15: Research competition sometimes inhibits collaboration. This was attributed by interviewees as inherent to the competitive nature of researchers and the fear of having their research ideas co-opted.
- Finding 16: Some research situations may warrant limited or no external collaboration during execution of the research. For example, research on a foundational topic may benefit from developing a core competency first before sharing results with the domain community of interest.

Table 18. *Stage 3 case study results*

Stage:Q#	Question	Highlighted Results
S3:1	How was knowledge transferred during the project?	This question was not addressed specifically during the interview sessions. The question was deemed too vague and redundant being that answers came through discussion on other questions. Knowledge transfer was determined to occur at each stage of the research process and through both tacit and explicit means.
S3:2	Did you present the research at conferences and workshops?	Engagement within the research domain community of interest was a dominant behavior in high-impact projects. The exception was with foundational research in which engagement was delayed until after gaining the core competency to demonstrate thought leadership. Low-impact projects either did not engage with the community of interest or did so minimally to help gain additional year research funding.
S3:3	Was research performed under a collaboration/ partnership agreement	The survey found only 15% of the represented projects had formal agreements. The case study

Stage:Q#	Question	Highlighted Results
	with a DoD or government lab?	projects had no formal agreements and only two cases of informal partnerships with government labs.
S3:4	Was research performed under a collaboration/ partnership agreement with academia or industry?	The survey found only 29% of the represented projects had formal agreements. Three high-impact case study projects had formal agreements: two projects with academia and one project with multiple industry Non-Disclosure Agreements.
S3:5	Did the research go down any unanticipated paths?	Eight of the high-impact case study projects indicated the importance of their projects having the agility to revector their outputs and outcomes based on unanticipated discoveries or external feedback from government sponsors and/or the domain community of interest. One high-impact project attributed its conception to its parent project exploring such an unanticipated path. The low-impact case study projects did not exhibit this behavior.
S3:6	Were the research objectives achieved?	Ten of the case study projects indicated achieving their research objectives. Three high-impact projects indicated "far exceeding" their objectives. One low-impact project partly met objectives and another did not but hoped to if given more time.

Stage 4 Results: Primary Outputs from Research

The *Primary Outputs* stage was defined for the case study participants as the tangible outputs produced from the research and the approaches used to both share and protect those outputs. The results are summarized in Table 19. The following findings surfaced as significant factors contributing to or limiting the achievement of outcomes and impacts.

- Finding 17: The prototype demonstration is a key output of mission-focused research. The high-impact projects that produced and used a demonstrable capability in their engagements with the domain community of interest gained significant advancement towards their outcomes in doing so.
- Finding 18: Conference papers are more prevalent than peer reviewed papers.

- Finding 19: PIs of both high- and low-impact projects expressed the view that publishing research results in paper format should be mandated for all projects.
- Finding 20: Engagement in domain community of interest conferences creates opportunities for media coverage.
- Finding 21: Social media was used as a highly effective approach to sharing research results and for rapidly building a user base. For example, one of the case study projects used Twitter to rapidly build a stakeholder community world-wide.
- Finding 22: The research organization's Public Release process can be an inhibitor to researchers if not designed for review of deeply technical and academically focused papers. If the public release process is considered inconsistent, arbitrary, or difficult, some researchers will not seek the sharing of research results.

Table 19. *Stage 4 case study results*

Stage:Q#	Question	Highlighted Results
S4:1	What were the tangible outputs/ contributions?	This question linked with the survey question that asked the PI to select their primary research output. The results in Figure 13 heavily favored Prototype Demonstrations at 34%. The case study participants were given the leeway to discuss all their research outputs. Seven of the 12 case study projects highlighted the significance of having a demonstrable capability, whether a mock-up, proof-of-concept, or fully operational system. Four of the 12 had software output, two producing algorithms, and one each producing a standard and a simulation process.
S4:2	Did you publish in peer reviewed journals?	Only two of the 12 case study projects, both high-impact, published their research results in peer reviewed journals. Six of the 12 indicated being held back by government sensitivities or security classification concerns.
S4:3	What other papers/reports/briefings were produced?	Eleven of the 12 case study projects documented their research results in one or more formats inclusive of conference papers, books, briefings, and internal organizational reports. The high-impact projects were strongly represented in this category. One low-

Stage:Q#	Question	Highlighted Results
		impact project did not publish results, another only internal organizational briefings, and the third submitted a conference paper to support additional year funding.
S4:4	Did you file patent applications?	Five of the 12 case study projects, each high-impact, filed patent applications. One project had two patents awarded, three projects are still awaiting decision, and one project's application was rejected. Two high-impact projects did not pursue a patent stating that their output was not appropriate for a patent. Two high-impact projects did not pursue a patent due to security classification concerns. None of the low-impact projects pursued a patent with one stating that the application process was too "daunting."
S4:5	Were trade and media articles pursued?	Six of the 12 case study projects, each high-impact, used trade and/or media articles to share information on research results. Security classification concerns held back three projects from seeking media attention.
S4:6	Was any software made available through open source?	None of the case study projects made software available through open source. The primary reasons for not pursuing open source release in the case study projects that had software outputs were security classification concerns and pursuit instead of patents and licensing.

Stage 5 Results: Secondary Outputs

The *Secondary Outputs* stage was defined for the case study participants as the benefits and influences the research had on informing policy, improving mission processes and data, and improving government decision making. The results are summarized in Table 20. The following findings surfaced as significant factors contributing to or limiting the achievement of outcomes and impacts.

- Finding 23: Improvements to government processes and mission data are prevalent outcomes of high-impact mission-focused research.

Table 20. *Stage 5 case study results*

Stage:Q#	Question	Highlighted Results
S5:1	What were the secondary outputs/contributions?	This question was not addressed directly in the case study interviews as the details were discussed in the stage 5 questions below.
S5:2	Did the research influence any government process changes?	All high-impact case study projects reported influencing government process changes. Seven of these projects introduced changes to mission operations. One project influenced changes through standards development. Another project influenced changes through simulation experimentation. None of the low-impact projects influenced process changes.
S5:3	Did the research influence legislation or public policy?	Only two of the high-impact projects reported influencing legislation. In both cases the government mandated use of the research output which in one case was a standard and in the other case a taxonomy service.
S5:4	Did the research impact the quality or quantity of government data?	All high-impact and one low-impact case study project reported improving the quality or quantity of mission data.
S5:5	Did the research improve government decision making?	Six high-impact projects reported improving government decision making. Two high-impact projects suspected doing so but lacked certainty.
S5:6	Did the research result in a trade secret?	None of the case study projects resulted in an organizational trade secret.

Stage 6 Results: Adoption by Government, Academia and/or Industry

The *Adoption* stage was defined for the case study participants as the research outputs and knowledge that was transferred or transitioned to an external stakeholder inclusive of government users, academia, and/or industry. The results are summarized in Table 21. The following findings surfaced as significant factors contributing to or limiting the achievement of outcomes and impacts.

- Finding 24: Researchers want more help achieving transfer and transition objectives from their line management, chief engineers, and research program leadership.

- Finding 25: Transition and transfer of research output is important but should not be the only measure of successful research.
- Finding 26: The cost of transferring and transitioning research outputs can be larger than the research budget supports.
- Finding 27: There is a perception in some researchers that licensing of research output has too high a focus from the research program leadership and inhibits the open sharing of research and research collaboration.

Table 21. *Stage 6 case study results*

Stage:Q#	Question	Highlighted Results
S6:1	Was technology transfer or transition achieved?	The survey found that 62% of the represented projects transitioned research output and knowledge to a government sponsor with 43% of those reporting having impact on the sponsor mission. Seven of the nine high-impact case study projects reported having significant impact (L3) on the sponsor mission. Two of the three low-impact projects reported having impact (L1/2), but narrowly focused on a single sponsor organization.
S6:2	Did the research produce a capability that was fielded for operational use?	Five of the nine high-impact case study projects provided output that was used for a time in the operational sponsor mission environment. In each case the research output was associated with a prototype demonstration.
S6:3	Were commercial licenses granted?	Only three of the 12 case study projects generated commercial licenses, each a high-impact project. Two of those projects had over ten licenses each granted, one through commercial licensing and another through government use licensing.
S6:4	Did the research result in spin offs of commercial products?	The three projects granting licenses in S6:3 also resulted in spin offs of commercial products. Five of the other case study projects reported having influence on a commercial product spin off.

Stage 7 Results: Outcomes / Impacts

The *Outcomes and Impacts* stage was defined for the case study participants as the short and long-term results of the research project. Outcomes were defined as achievable objectives in the mission environment planned at the beginning of the project. Impacts were explained as often being unanticipated and realized over time post-research. The results are summarized in Table 22. The following findings surfaced as significant factors contributing to or limiting the achievement of outcomes and impacts.

- Finding 28: The common impact characteristics of research projects regarded as highly successful include having long-term (over 10 years in some cases) effects and influences, industry or domain-wide effects and influence, spawning direct work programs with government sponsors, and benefiting the reputation of the research organization.
- Finding 29: PIs were not aware if their research had influenced derivative research in most cases.
- Finding 30: Having participated in the research program was found to be highly positive and attributable to promotion, awards, and becoming recognized as a subject matter expert in the field of study.

Table 22. *Stage 7 case study results*

Stage:Q#	Question	Highlighted Results
S7:1	What were the outcomes and impacts?	The specific outcomes and impacts of the case study projects were widely varied due to the diversity of research domains represented. The generalized impacts of the high-impact projects had common characteristics including having long-term (over 10 years in some cases) effects and influences, industry or domain-wide effects and influence, spawning direct work programs with government sponsors, and benefiting the reputation of the research organization. The low-impact projects lacked clear impacts, but two of the three low-impact projects may still achieve impacts over time.
S7:2	How long did it take for outcomes and impacts to be realized?	In each case study project that realized impacts, those impacts were achieved after the outcomes were completed (i.e., impacts followed outcomes). Two

Stage:Q#	Question	Highlighted Results
		high-impact projects realized impacts within the first year following the outcome. Five projects reported between 2-5 years for impacts to be realized. The high-impact project that developed foundational core competency reported 10 years for impacts to be realized but are still having impact 30 years later.
S7:3	Is there still interest from external or internal stakeholders?	Only two of the 12 case study projects reported no continuing interest from stakeholders. Both these projects took place in the 1990s and have become obsolete by technology advancement.
S7:4	What do you predict will be the future impacts?	This question was not addressed in most case study interviews. The four projects that did address it had highly speculative responses focused on potential evolutions of the research area.
S7:5	Was your research the catalyst for any other research?	Only one high-impact project provided a specific response to this question naming one spawned research project and 13 research proposals that referred to it. The other case study projects were unable to provide an answer.
S7:6	Did your participation in the research change your career path?	Five researchers in the case study interviews stated that participation in the research project had a profound influence on their career path. Three researchers reported promotions attributable to the success of the research project. Two other researchers attributed career path decisions to their participation in the research program.
S7:7	Did the research project impact the careers of any other participants?	Seven of the interview sessions provided responses to this question. They reported that researchers on their teams gained valuable domain subject matter expertise that has benefited their careers. Others became PIs of their own research. Examples were collected of researchers using their participation in research projects to fulfill thesis and dissertation requirements in the purist of graduate degrees. Examples were also collected of researchers recruited by other companies as a result of the expertise gained in the research.
S7:8	Did the research win any industry, government, or other external awards?	Only three of the case study projects reported receiving external industry or government awards.

Research Process Improvement Results

The *Research Process Improvement* questions were explained for the case study participants as a postulation that online services providing research transparency, discoverability, and accessibility would increase collaboration and engagement with stakeholders inclusive of researchers, potential government users, academia, and industry, all of whom would have access to the portal. The online service was described as a portal for PIs to register their research projects from the early stages of the research process and to keep the information updated with progress, results, outcomes, and impacts over time. The results from questions I1-I6 are summarized in Table 23. The following findings resulted from the discussions and additional literature review that was spawned from those discussions.

- Finding 31: Online services for researchers are prevalent on the Internet providing various functions including collaboration, researcher persona management, research information dissemination, research document management, and research impact measurement. Additional domain specific online services exist as well as online services internal to research organizations.
- Finding 32: The online services for researchers are focused on academic research and not the federal research environment.
- Finding 33: A good online data source of federal research activity, outputs, outcomes, and impacts would make long-term analytics feasible.

Table 23. *Research process improvement case study results*

Stage:Q#	Question	Highlighted Results
I:1	Is there value in measuring and assessing research ROI?	This question was only addressed in the first of the 12 case study interviews. The feedback received highlighted the complexity and highly subjective nature of the topic.

Stage:Q#	Question	Highlighted Results
I:2	Will increased transparency and discoverability of research activities and results throughout the research process increase collaboration and outcomes/impacts?	Questions I2-I6 were discussed as a collective during the case study interviews. The topic of automation support for researchers was discussed in 10 of the 12 case study interviews. The focus of these discussions was on what such a service would provide and its utility. Six of the 10 interview teams indicated support for the concept but with concerns on implementation including public release issues, researcher willingness to share, and proper incentives for participation. Four of the interview teams expressed skepticism for the concept raising concerns that such a service already exists (e.g., ResearchGate, Mendeley, and LinkedIn), it would add more administrative overhead for researchers, it would not add value, and it would be difficult to represent the research results and impacts in a way that would support efficient and effective discovery.
I:3	Would you use such a service in the formation of future research proposals?	
I:4	Would you share your research objectives at the start of a research project?	
I:5	Would you share your research outputs, outcomes, and impacts at the completion of a research project?	
I:6	If asked on a periodic basis, say annually, would you provide updates regarding the impact from your research?	

Miscellaneous Topics

The final question in the case study interviews asked the interviewees if they had any additional related comments. This generated a high level of diverse responses in three primary categories: research team skills, research program management, and research culture.

- Finding 34: High-impact research teams included or were provided guidance and help from someone with operational experience in the target user domain.
- Finding 35: People that come up with a good research idea may not have the skills to execute the research. Some proposers of federal research are not trained researchers (i.e., lacking a doctoral degree).

- Finding 36: Good researchers may not have the skills or operational connections to transition or transfer the research outputs.
- Finding 37: Seasoned researchers desire to mentor and coach junior researchers.
- Finding 38: There is a perception that the number of research projects being funded is increasing leading to lower funding for the projects and thus making it harder to achieve their outcomes and have impact. Data were not available to validate the perception that the number of projects being awarded is increasing over time.
- Finding 39: The PI role is perceived as becoming a part time role to the detriment of good research due to lower funded projects and requirements for larger teams. The perceived requirement for larger teams is based on the belief that proposed research projects with team representation across multiple organizational divisions will be more likely to be funded. Data were not available to validate the perception of project funding level trends.
- Finding 40: There is a perception that research sponsors are focused on a relatively small set of strategic problems that research proposals must address in order to get funding and that this inhibits innovative ideas outside that scope that could benefit government missions.
- Finding 41: There is confusion among researchers on the appropriateness of pursuing commercial licenses for the sharing of federally funded research outputs due to the not-for-profit status of FFRDCs and UARCs.

Summary of Findings

The consolidated findings from each research process stage are provided in Table 24. The findings are referred to by their number in remainder of Chapter 4 and in Chapter 5.

Table 24. *Summary of study findings*

Process Stage	Finding #	Finding
#1: Topic ID	1	There is an atrophy of research information over time.
	2	PI attrition results in loss of research information.
	3	89% of the surveyed research projects were funded for 1 to 3 years.
	4	43% of the surveyed research projects were funded at or below 1 full time equivalent, defined as the annual hours of a full-time employee.
	5	The mission-focused charter of the federal research organization is reflected in the research program.
	6	The selection of a research topic that was rapidly ascending or high on the emerging technology hype curve was a contributing factor to some high-impact projects.
	7	The selection of a foundational research topic that developed deep and unique talent, capability, capacity, and knowledge (core competency) in a high-need area was a contributing factor to some high-impact projects.
	8	The selection of a research topic that was derived from a discovery in a previous or on-going research project that the PI was a part of was a contributing factor to some high-impact projects. In some cases, the PI was involved in the previous research project at another company.
#2: Inputs	9	The projects that spun off from recent or still on-going research benefited from having access to knowledgeable and experienced staff in the research domain and had well defined outcomes. These projects also had well established collaboration, partnering, and technology transfer/transition opportunities identified or even pre-staged. As a result, these projects were able to hit the ground running.
	10	High-impact projects were associated with having addressed collaboration and technology transition/transfer opportunities at the initial stage of research. Low-impact projects were not.
#3: Research Process	11	High-impact research teams actively engaged with the research domain community of interest.
	12	High-impact projects benefited from being allowed to revector the research plan and outcome(s) based on early findings/realizations and/or based on feedback from stakeholders.
	13	The combination of active community of interest engagement, presentations at conferences and workshops, and use of a prototype demonstration were prevalent in high-impact case study projects.
	14	Collaboration, whether formal or informal, is prevalent in high-impact projects.
	15	Research competition sometimes inhibits collaboration. This was attributed by interviewees as inherent to the competitive nature of researchers and the fear of having their research ideas co-opted.
	16	Some research situations may warrant limited or no external collaboration during execution of the research. For example, research

Process Stage	Finding #	Finding
		on a foundational topic may benefit from developing a core competency first before sharing results with the domain community of interest.
#4: Outputs	17	The prototype demonstration is a key output of mission-focused research. The high-impact projects that produced and used a demonstrable capability in their engagements with the domain community of interest gained significant advancement towards their outcomes in doing so.
	18	Conference papers are more prevalent than peer reviewed papers.
	19	PIs of both high- and low-impact projects expressed the view that publishing research results in paper format should be mandated for all projects.
	20	Engagement in domain community of interest conferences creates opportunities for media coverage.
	21	Social media was used as a highly effective approach to sharing research results and for rapidly building a user base. For example, one of the case study projects used Twitter to rapidly build a stakeholder community world-wide.
	22	The research organization's Public Release process can be an inhibitor to researchers if not designed for review of deeply technical and academically focused papers. If the public release process is considered inconsistent, arbitrary, or difficult, some researchers will not pursue the publishing of research results.
#5: Secondary Outputs	23	Improvements to government processes and mission data are prevalent outcomes of high-impact mission-focused research.
#6: Adoption	24	Researchers want more help achieving transfer and transition objectives from their line management, chief engineers, and research program leadership.
	25	Transition and transfer of research output is important but should not be the only measure of successful research.
	26	The cost of transferring and transitioning research outputs can be larger than the research budget supports.
	27	There is a perception in some researchers that licensing of research output has too high a focus from the research program leadership and inhibits the open sharing of research and research collaboration.
#7: Outcomes / Impacts	28	Common impact characteristics of research projects regarded as highly successful include having long-term (over 10 years in some cases) effects and influences, industry or domain-wide effects and influence, spawning direct work programs with government sponsors, and benefiting the reputation of the research organization.
	29	PIs were not aware if their research had influenced derivative research in most cases.

Process Stage	**Finding #**	**Finding**
	30	Participation in the research program was found to be highly positive and attributable to promotion, awards, and becoming recognized as a subject matter expert in the field of study.
All Stages	31	Online services for researchers are prevalent on the Internet providing various functions including collaboration, researcher persona management, research information dissemination, research document management, and research impact measurement. Additional domain specific online services exist as well as online services internal to research organizations.
	32	The online services for researchers are focused on academic research and not the federal research environment.
	33	A good online data source of federal research activity, outputs, outcomes, and impacts would make long-term analytics feasible.
	34	High-impact research teams included or were provided guidance and help from someone with operational experience in the target user domain.
	35	People that come up with a good research idea may not have the skills to execute the research. Some proposers of federal research are not trained researchers (i.e., lacking a doctoral degree).
	36	Good researchers may not have the skills or operational connections to transition or transfer the research outputs.
	37	Seasoned researchers desire to mentor and coach junior researchers.
	38	There is a perception that the number of research projects being funded is increasing leading to lower funding for the projects and thus making it harder to achieve their outcomes and have impact. Data was not available to validate the perception that the number of projects being awarded is increasing over time.
	39	The PI role is perceived as becoming a part time role to the detriment of good research due to lower funded projects and requirements for larger teams. The perceived requirement for larger teams is based on the belief that proposed research projects with team representation across multiple organizational divisions will be more likely to be funded. Data was not available to validate the perception of project funding level trends.
	40	There is a perception that research sponsors are focused on a relatively small set of strategic problems that research proposals must address in order to be awarded funding and that this inhibits innovative ideas outside that scope that could benefit government missions.
	41	There is confusion among researchers on the appropriateness of pursuing commercial licenses for the sharing of federally funded research outputs due to the not-for-profit status of FFRDCs and UARCs.

Categorization of the findings took place during the quantitative and qualitative analysis resulting in five preliminary themes: Positive Result Factors, Talent, Management, Research Culture, and Automation Services. These preliminary themes were used to frame the findings during the expert panel one-on-one review sessions.

Expert Panel Session #2

At the completion of the quantitative and qualitative data collection and analysis, one-on-one interviews were held with each expert panel member. The one-on-one format was selected over the group format to afford a deeper discussion with each panel member and avoid the effects of group dynamics. The interview sessions ranged from 60-90 minutes each. The material reviewed included an overview refresher of the study purpose, objectives, and methodology, and then a detailed review of the findings from both the survey and case study interviews. The feedback from the panel members was positive and validated the findings. Additional insight on the findings was collected during the interviews and used in the converged data analysis towards development of contributors, limiters, themes, and recommendations.

Step #4: Converged Data Analysis Results

Preliminary themes began to emerge during the analysis of the previous three steps. The grouping of the findings into these preliminary themes was reviewed and discussed with the expert panel in the one-on-one interviews. The final analysis of the converged results involved looking for common concepts across the results, comparing the quantitative and qualitative results for each preliminary theme, determining in what ways the results confirmed or conflicted, and interpreting and resolving the differences (Creswell, Clark, 2018). Eight final themes emerged from this analysis: Research Topic Selection, Research Team, Collaborative Behavior, Research Achievement, Research Culture, Research Program Management, and Research

Automation Services. The mapping of the findings across these eight themes and across the research process stages is shown in Table 25. This mapping is used in the detailed discussion below of each of the final themes.

Table 25. *Theme mapping to findings across research process stages*

Process Stage / Theme	#1: Topic ID	#2: Inputs	#3: Research Process	#4: Outputs	#5: Secondary Outputs	#6: Adoption	#7: Outcomes / Impacts	All Stages
Research Topic Selection	6,7,8	9						
Research Team		9					30	34,35,36
Collaborative Behavior		10	11,13,14, 15,16	20,21				41
Research Program Management	3,4,5		12	22		24,25, 26, 27		35,36,37, 38,39,40, 41
Research Achievement					23	24,25, 26, 27	28,29	
Research Culture				19		25,27	30	41
Research Automation Services								31,32,33
Research Knowledge Management	1,2			17,18, 19,21			29	37

Theme 1: Research Topic Selection

Selection of the research topic was a major focus of discussion during the case study interviews. This was the only theme that corresponded directly to one of the research process stages. As such, three of the four associated findings (i.e., #6, #7, and #8) mapped to the *Research Topic/Question Identification* stage. Finding #9, which mapped to the *Inputs to*

Research stage, was also associated with the research topic selection theme since the benefits realized in that stage were derived from selection of the research topic as a spin-off from a past project. Of the projects represented in the survey, 29% were identified as spin-offs from past research projects.

The research teams discussed the various factors involved in the selection of their research topics. One common thread was the importance of understanding the mission domain and the operational gaps that needed the attention of the research community. One PI reinforced this notation:

> The ideas for the research did not come from just sitting at a desk and thinking about what's the hard problems here? It really came from working on cutting edge, admittedly, but real systems. Grappling with the problems that real systems have with carrying out their missions. Getting a good understanding of that should be a critical piece of what we try to get. (HB4)

The associated findings identify major contributors to the achievement of research project outcomes and impacts. These contributors included selecting research topics in hot technology areas as indicated in finding #6, foundational research areas as indicated in finding #7, and spin-offs from current or past high achieving projects at indicated in finding #8. These contributors alone do not guarantee high achievement for a research project; instead they need to be combined with other contributors. A relevant observation from the interviews is that the hot topic research areas are by their nature highly visible in the domain community while foundational research areas are often recognized by a very few experts in the domain. This makes establishing foundational research areas harder to do. However, when foundational research areas are established, long lasting benefits and impacts are often realized. One case study participant discussed the role that hot topics play in the research program:

> We're tech watching, we're paying attention, or at least that's the way I viewed my role, was to know what … was hot. Gardner talks about the hype curve and the buzz words. We are … watching that hype curve, and when the terms first show up, we start wanting to know, well, is there a there there [sic]? What is that idea about? Is it just about a renaming of something? Or is there really something novel and different? What is cloud computing? What is big data computing? What is peer to peer computing? These things all kind of start off somewhere on that hype curve. We see them, because we're reading people talking about the buzz. Many of the ideas that I've had funded research around started like that. (LB1)

A foundational researcher described his experience:

> I saw this as an opportunity to go back and build a very strong theoretical technical foundation that then could be used for a set of practical applications. The research was basic, but it was inspired by the fact that we knew there were applications out there that could benefit from it. And we hoped that if we had this rigorous theoretical foundation it would help us be smarter in the applications. (HB1)

Another foundational researcher described the experience:

> I think this developed a set of core competencies and knowledge that could not be found anywhere else, so that put us in a very unique position that allowed us to participate and influence, and continue to grow and build that competency, which kept the value proposition. (HA2)

Theme 2: Research Team

The Research Team theme evolved from a preliminary theme focused on talent. Two sub-themes prevalent during the case study interviews were the benefits of participation in the research program and the importance of having the right mix of skills on the research team.

Finding #30 was derived from the Benefits of Participation sub-theme and was mapped to the *Outcomes/Impacts* research process stage because of the impact participation had on the individual research team members' careers. This is indirectly associated with finding #9, which highlighted the benefits that an experienced research team contributes to achieving outcomes and having impact. These combined findings surface an important contributor to the achievement of research outputs and impacts: having researchers on a team that have had past research success and are highly motivated. One PI evidenced this in speaking about having had positive impact on a government mission, declaring, "That is the best feeling in the world. When you've had a taste of that, that's want you want to do for the rest of your career" (HA2).

The Skillset sub-theme related to the research team highlighted the importance of having the right skillset and experience on the team. Findings #34, #35, and #36 were associated with this sub-theme and surfaced both contributors and limiters to achieving research outcomes and impacts. These three findings mapped across all stages of the research process. Two premises echoed throughout the case study interviews were that 1) the people who come up with a good research idea may not have the skills to execute the research, and 2) good researchers may not have the operational connections to transition the results. Some federal research organizations accept research proposals from all levels of the technical staff with no requirement for academic credentials or past research experience. While this benefits diversity of research topic, it can limit a PI's ability to achieve research outcomes if not compensated in the research team makeup. Likewise, even the most highly qualified PIs can be limited in achieving research outcomes and impacts if missing the connections to the operational mission environment they are targeting their research towards. The inverse of this potential limiter was highlighted in finding #34, which found that having strong connections with the operational mission environment contributed to the research team's ability to achieve their outcomes. One PI interviewee described this premise by stating, "Not every PI … has that ability to be both extremely in-depth technically and have the business savvy [referring to connections to the operational environment] to go along with it. We shouldn't select our PIs to have business savvy and tech savvy. We should select them to be good researchers, but they need to have … some sort of mentor who helps them with the other part" (HA2). The survey results indicated an average of 5.366 staff contributing to each represented research project in some material way. As such, forming a research team with the right skills, experience, and connections to the operational environment seems an achievable goal.

Theme 3: Collaborative Behavior

The Collaborative Behavior theme evolved from the Positive Result Factors preliminary theme. Collaborative behavior is demonstrated by research teams that actively engage formally or informally with the domain community of interest in which their research falls. Findings #11 and #14 highlight the importance of this behavior in achieving research outcomes. The mapping of five of nine of the findings associated with this theme in the *Research Process* stage indicate the importance of this behavior throughout research execution.

Participation in domain conferences and workshops was the most common collaborative practice identified in the surveyed research projects (84%). Finding #10 highlighted the importance of establishing collaborative behavior in the formative stage of the research project.

One interview participant stated, “Your first opportunity [for collaboration] is after you push send on your proposal” (HB2). Finding #13 reinforces the notion that combinations of contributing factors are most effective in achieving outcomes and impact. In this case, the combination of active community of interest engagement, presentations of research results at conferences, and use of a prototype demonstration in presenting research outputs were prevalent in high-impact achieving projects. Of surveyed projects, 34% identified their primary research output as a prototype demonstration. The benefits of having and using a demonstration to present output from mission focused research are multifaceted. From the collaborative perspective, it enables the audience to better understand the research topic and how it might transition into the operational environment. Having a tangible demonstration, in comparison to a paper product such as a paper or PowerPoint presentation, increases the interest of academia, potential government users, and/or industry in collaboration, transition, and/or transfer of the research. One PI explained the role the demonstration played in the high-impact project:

> For getting into the transfer for our big license, what happened is . . . went back to that conference and presented our new approach, new tool. Didn't do a demo during the conference itself, but I had all these people lining up afterwards. Everyone's coming up to me like [sic], how do you do that so fast? I had a demo with me at the conference. All these vendors were inviting me up to their private rooms, suites and the hotel to do these. I think this was the most impactful thing that we did. (HB5)

Findings #20 and #21 focused on the use of media to enhance collaboration. Presenting research results and/or activities at domain conferences and workshops has attracted media attention for some projects resulting in write-ups in trade journals and online domain forums. Social media such as Twitter was used successfully in HA4 to create a world-wide user community of the research output. The PI for HA4 stated, "One of the team members had an interesting idea that we should just create a Twitter account. It probably turned out to be one of the most useful mechanisms of outreach that we've had so far."

Finding #16 was an important outlier of this theme. Discussions with research teams that had high-impact projects in foundational areas expressed the importance of first developing a core competency in the research areas before actively engaging with the domain community of interest. Doing so contributed to long term impacts in the domain field.

Findings #15 and #41 raised two limiters in the collaborative behavior theme. The first limiter to collaboration is fear of having the research idea stolen or co-opted. This was found to be a common fear in the researchers interviewed. The PIs with high-impact projects expressed that the benefits of collaboration far outweighed the risk of losing control of the research topic. The second limiter to collaboration was ignorance of the processes, legalities, and appropriateness of using collaborative vehicles such as commercial licenses, government use licenses, non-disclosure agreements, and memorandum of agreements. The confusion and misunderstandings on how these vehicles could benefit the research limits the achievement of outcomes and impacts.

Theme 4: Research Achievement

The Research Achievement theme focused on what research success manifests as in the federal research environment and some of the challenges faced by PIs in achieving or exceeding their research outcomes. Not surprisingly, the seven findings associated with this theme mapped to the final three research process stages (i.e., Secondary Outputs, Adoption, and Outputs/Impacts).

Findings #23 and #28 identified the more prominent success characteristics of high-impact mission focused research that surfaced in this study. These characteristics include improving government processes and mission data, spawning direct work programs with the government (e.g., 29 surveyed projects declared having spawned direct sponsor work), and transitioning and/or transferring technology to the government, academia, and/or industry. The impacts from these projects were in some cases long lasting (i.e., >10 years) and benefited the reputation of the research organization.

The remaining associated findings raised concerns and potential limiters to achieving research outcomes and impacts. Findings #24 and #26 highlighted potential resource limiters for PIs in their efforts to transfer and/or transition technology from their research. Finding #24 was a call from some PIs for more help in transitioning/transferring their research outputs. One example was from a case study participant who stated, “I was naïve about the role that my managers would play in helping me connect my work to government sponsors or to transition opportunities” (LB1). Finding #26 suggested a funding gap for PIs to work the transition/transfer activity. Findings #25 and #27 indicated a perception among some PIs that research success, as measured by the research organization, was too focused on achieving technology transfer/transition and/or licensing of research output. While these potential limiters were derived from both the survey results and the case study interviews, the high-impact case study projects were not limited by the issues in these findings. Finally, finding #29 surfaced an admission by some PIs that they had limited or no knowledge of research projects that had been derived (i.e., spun off) from or influenced by their projects. This was a relevant impact factor for research projects and discussed more in the Knowledge Management theme.

Theme 5: Research Culture

The case study interviews involved a diverse cross-section of PIs and researchers spanning over thirty years of research experience in the federal research environment. Analysis of the study data uncovered cultural perceptions of the research program. The seasoned researchers had strong opinions on research culture that in some cases diverged from early career and less experienced researchers, and in other cases converged. On the positive side, a strong contributor to achieving research outcomes and impacts was identified as being able to attract talent to the research program. Finding #30 indicated a strong cultural perception that participation in the research program carries with it recognized rewards including promotion, prestige, and career opportunities. One seasoned researcher talked about the role the research culture played in coming to the organization stating, "What attracted me was the caliber of the staff, the interest in doing the research. It was very much a research department. I think we had, probably, 80%, 75% Ph.D.s in the department. And I really didn't see anything comparable at the other places I looked" (HB1).

Findings #25 and #27 were highlighted under the Research Achievement theme and finding #41 was highlighted under the Collaborative Behavior theme. These three findings are included in the Research Culture theme due to the cultural limitations they represent. Seasoned researchers seemed to push back on the thrusts to achieve technology transfer and licensing as opposed to the early career researchers that seemed to embrace the success criteria. These findings confirm what the literature affirmed as the potential corruption of the scientific process by changing the focus of researchers away from their research objectives and more towards increasing their impact metrics. This was termed "chasing impact" by Geoff Rogers (Clappison, 2013, p. 1).

Finding #19 reflected a strong belief among surveyed and interviewed researchers that PIs should be required to publish their research results in some form of paper whether peer reviewed journal, conference paper, or research organization report. This requirement includes research projects in the classified security realm that are challenged in their ability to disseminate research results. Classified or not, strong support for mandating the publishing of research results was found in the study. One researcher stated, “Every [research] project should have a paper, a publicly released paper. If it lasts one year, two years, three years, it has to have at least one publicly released paper. We can't do research inside an ivory tower and have impact” (HA2).

Theme 6: Research Knowledge Management

The topic of managing research knowledge surfaced as a critical shortfall and an important opportunity for improvement. Findings #1 and #2 evidenced the atrophy of access to and discovery of research information over time. One survey respondent stated, “It's hard to dig back into the past to give accurate figures” (Survey #21110898). Finding #29 added on to this shortfall noting the lack of awareness PIs had of research derived from their projects. This was a significant limiter considering the missed opportunities for leveraging the linkage information. An example of the scale of research spawning from one of the case study projects found it had become, “a foundation for other research to be built upon and other capabilities to be built upon or to extend. . . . There were 13 or 14 proposals that were referencing [the project] in some way for next year” (HA4). These findings confirmed what the literature affirmed: that the research community has not adopted the discipline of collecting research impact evidence (Grant & Wooding, 2010; Greenhalgh et al., 2016; Kostoff, 1997b; Penfield et al., 2014).

Findings #17, #18, and #21 highlight three primary means that PIs in the study used to capture and disseminate their research knowledge. Finding #17 highlighted the significant benefit gained by high-impact PIs using and delivering a prototype demonstration as part of their research output. Demonstrations were found to be instrumental in transferring research knowledge and understanding to targeted audiences. Finding #18 surfaced the primary use of informal papers (i.e., 60% of surveyed projects) to capture and dissemination research results over publishing in peer reviewed journals (i.e., 32% of surveyed projects). Finding #19 reflects a call from PIs to mandate publishing of research results. Finding #21 indicates use of social media as a potentially high benefit means of disseminating research knowledge and increase collaboration.

As cautioned in the Research Culture theme, the study found a cultural divide between long-term, seasoned researchers accustomed to performing research in the program as it was structured and managed decades ago, and the more recent researchers accustomed to the current research program culture and management process. Finding #37 offers a bridge over this divide in that seasoned researchers expressed their desire to mentor and coach junior researchers. This will be explored further in Chapter 5.

Theme 7: Research Automation Services

The Research Automation Services theme was heavily focused on as a data collection and analysis topic in the study, so it logically surfaced as a primary theme. Kostoff (1997b) wrote extensively twenty years ago about the need for development of a database, or a federation of databases, to collect and store the impact measures of federally funded research. He stated that in order to track the diffusion of information from federal research, multiple public and private organizations would need to collect data at all evolutionary stages of the research, including years beyond the completion of the research project. Finding #31 confirmed the current existence of an extensive set of online research automation services, referred to as academic social networking sites (ASNS) in the literature, that address some of what Kostoff suggested. However, finding #32 showed that these ASNS are focused on the academic research environment and not the federal research environment. As indicated in the literature, Researchfish is a research automation service development specifically for assessing the impact of UK government funded research. Likewise, the High Impacts Tracking System (HITS) is a U.S. National Institute of Environmental Health Sciences (NIEHS) specific online research automation service. Neither government organization chose to use the ASNS.

The limitations caused by the lack of a social networking service for the federal research environment surfaced during the case study interviews. One PI stated, "There's no funding for old project leaders to update their [research] information. There are no receptors, any digital receptors anywhere that, you know, channel people to me" (HB2).

The contributions a social networking service for the federal research environment could make was also a topic of discussion in the case study interviews. The feedback included the following:

- "Making it available to all federal researchers is an interesting idea" (LB1)
- "There should be discoverable artifacts for funded projects, no question. A meta data catalog. It could be an extreme value because it could not only attract collaborators, but you could effectively crowdsource the research because people looking for solutions might in fact contact you through such a service, expose you to their problem and get you to work on their solution with some of their funding" (HB2)
- "If there was a product out there that was scraping all the webpages … and aggregating that information on all the research projects that are out there and

doing that, the answer simply absolutely unequivocally yes [sic]. Connecting to industry may give you the incentivization that you need to get researchers to actually use this. Pairing them [researchers] with small companies maybe even venture capitalist, might be a good model" (LA1)

- "I think there is value in that. Something broader than [the research organization] could be useful. It might be hard to work into the process that people are aware of and actively using" (HA4)
- "There isn't a good way to look at, for lack of a better term, prior art. I would have no problem doing that. The trouble is that we've had a lot of successes, we've had a lot of different types of the successes that we'd have to show, we'd have to somehow articulate how that works" (HB5)

Kostoff (1997b) described the collaborative potential of software-based algorithms possible with a database of research information. Kostoff was ahead of his time in forecasting the requirement for and value of data analytics to show the full picture of research activity, outputs, outcomes, and impact. Finding #33 confirmed Kostoff's forecast echoing multiple statements by interviewed PIs and the expert panel that a good online data source of federal research activity, outputs, outcomes, and impacts would "make long-term analytics feasible."

Theme 8: Research Program Management

An observation made during the case study interviews was that the FRIAF process model diagram (see Figure 5) did not depict the research program management process and that the research program management processes, policies, and procedures could be major factors in research project achievement of outcomes and impacts. While no specific questions on research program management were included in the survey and case study instruments, the topic was discussed throughout the case study and expert panel interviews leading to 16 related findings that converged into this study theme. The research program management approach will be unique to each federal research organization. As such, the results from the analysis of this theme will be generalized to apply to the wider federal research environment.

As might be expected, the findings associated with research program management were represented across each stage of the research process. Finding #5 confirmed the mission-focused charter of the federal research organization in that only 4% of the surveyed research projects self-identified as pure foundational basic research. The clear majority of research projects were seeking use-inspired foundational (45%) or applied (51%) solutions to mission-related challenges.

Finding #40 surfaced a perception of a trend toward awarding research projects within a smaller set of strategic problems. Interviewees raised concerns that this inhibits innovative ideas outside that strategic scope that could benefit government missions. One seasoned PI stated, "I've seen a change in the way that we do research. Today there's a focus on a relatively small set of strategic problems, and you have to fit your research into one of these strategic areas in order to get funding. It's a much less entrepreneurial way to propose research" (HB1). The other findings were grouped into five sub-themes: Project Award Profile, Research Objective Agility, Public Release Process, Research Transition/Transfer Enablement, and Research Team Support.

The Project Award Profile sub-theme covered the results and perceptions related to the number, funding level, and length of research project awards within the research program. Findings #3 and #4 derived from the survey and showed 89% of projects being funded from one to three years, but with 26% of projects only funded for one year. Finding #4 indicated 43% of surveyed projects receiving funding at or below one full time equivalent (FTE). While the data failed to support a trending analysis, the case study interviews did surface trend-related perceptions on the project award profile. Finding #38 surfaced the perception of a trend towards funding more projects at lower funding levels and for less time, making it harder for researchers to achieve their outcomes and have impact. Finding #39 extended that perception to the PI role becoming more of a part time role due to lower project funding and pressure to grow research team size in order to improve the chances of being awarded research funding.

The Research Objective Agility sub-theme identified a significant contributor to achievement of research outcomes and impacts in the high-impact case study projects. Finding #12 showed that projects benefited significantly from being allowed to revector their research plan and outcome(s) based on the early findings/realizations and/or based on early feedback on the research from stakeholders. One case study interviewee stated, “I feel like the research … is way more agile, and responsive to the environment, the operational horizon, the planning horizon of the community industry, and technology, and much more adaptive to feedback. We learn stuff and we adapt” (HA2). None of the low-impact projects in the case study indicated that they had changed the objective of their research during research execution.

The Public Release Process sub-theme found a potential inhibitor for research projects in the process. This is another topic that is highly specific to each federal research organization. Finding #22 surfaced a perception in some researchers that the organizational public release process was not supportive of research and academic publications and in some cases inhibited the sharing of research results external to the organization. This was attributed to a process designed primarily for review and approval of direct sponsor work program related products. The study participants expressed the opinion that the review and approval chain needed to be customized for research and academic publications. One of the survey participants best articulated the issue and potential solution stating,

> Due to the inconsistency, arbitrary nature, and overall difficulty of the internal public release (PRS) process, the work was not approved for public release and this made transition to sponsors nearly impossible. I believe you need to establish a [research program] specific PRS requirement for all deliverables with an accompanying standardized [research program] PRS approval process prior to getting an initial project award. The expectation should be built in upfront that any reports that come out of [the research program] will be publicly released to aid sponsor transition efforts unless the content is deemed FOUO/Classified. The process should permit a hand-selected PRS review panel and exclude those with no knowledge/background in the topical area being discussed. (Survey 20148744)

The Research Transition/Transfer Enablement sub-theme surfaced perceived needs and limiters of the research program in supporting the researchers' efforts to achieve their outcomes. Findings #24, #25, #26, and #27 were highlighted under the Research Achievement theme. The findings are also included under the Research Program Management theme because they are best addressed by the leadership of the organization's research program. Finding #26 suggests some research projects are not being funded enough to cover the cost of work technology transfer/transition. While certainly a potential limiter, finding #10 reflects a behavior by high-impact projects of working transition/transfer opportunities from the initial stage of the research. This behavior could negate the cost issue identified in finding #26 by not waiting until the end of the research process to consider how to achieve transition/transfer and how to pay for it. Findings #25, #27, and #41 speak to the perception of an over-emphasis on technology transition/transfer as a research success metric and the appropriateness of emphasizing the licensing of research output by the research program management. These concerns were discussed in detail with the expert panel and appear to be misconceptions based on a lack of information and understanding of the federal regulations, policies, and expectations regarding transfer and transition of federally funded research output. This information gap was thus identified as a limiter to achievement of research outcomes and impact.

The Research Team Support sub-theme is closely associated with the Research Team theme. The reason for including it under the Research Program Management theme was to address the topic from the management perspective. Findings #35 and #36 established that in the federal research environment, some individual researchers, including PIs, will not have the combination of research execution experience, mission knowledge, and connections in the operational environment. This was highlighted by one case study participation who stated, "We shouldn't select our PIs to have business savvy and tech savvy. We should select them to be good researchers, but they need to have some sort of mentor who helps them with the other part" (HA2). Finding #34 emphasized the importance of this point observing that high-impact research teams included or were provided guidance and help from someone with operational experience in the operational mission environment. Furthermore, finding #24 surfaced the request from researchers for more help in achieving their transfer/transition objectives and suggesting sources of such help being line management, chief engineers, and research program leadership. Finding #37 provided a potential solution for research program management to consider. Seasoned researchers who have navigated the research process and the challenges associated with achieving research outcomes expressed their desire to mentor and coach the junior researchers coming into the federal research environment. These are the same seasoned researchers whose projects have resulted in high-impact. They know what research impact looks like and the factors that go into achieving it. One seasoned researcher expressed this concept with the statement that, "there is a payback that comes from people who go through a career of research, they get better at learning and to learn things from the effort, so that they can pass it on to the next generation, they can mentor the young people, they can teach others. It is a virtuous cycle if we value it right, if we treat it right" (LB1).

Summary of Converged Data Analysis

The final analysis of the converged results involved looking for common concepts across the findings, comparing the quantitative and qualitative results for each preliminary theme, determining in what ways the results confirmed or conflicted, interpreting and resolving the differences, combining the associated findings into sub-theme, and then converging those sub-themes into the final themes. Eight final themes emerged from this analysis: Research Topic Selection, Research Team, Collaborative Behavior, Research Achievement, Research Culture, Research Program Management, and Research Automation Services. A summary of the converged analysis is represented in the joint display shown in Table 26. A joint display "is an approach to show the integration data analysis by arraying in a single table or graph the quantitative and qualitative data" (Creswell, Clark, 2018, p. 228). This table shows the integration of the survey and case study data, their associated findings, and mixed methods comparison results, each mapped to the final eight themes.

Table 26. *Joint display of quantitative and qualitative results*

Theme	**Quantitative Survey Results**	**Qualitative Case Study Results**	**Findings**	**Mixed Methods Comparison**
Research Topic Selection	29% Spin-offs	“build a very strong theoretical technical foundation”, “watching that hype curve”	6,7,8,9	Convergent – identified topic selection contributors to achieving outcomes and having impact
Research Team	5.366 average sized team	“best feeling in the world”, “Not every PI … has that ability”	9,30,34, 35,36	Convergent – led to the understanding of research team limiters and contributors
Collaborative Behavior	84% attend conferences 34% output demos	“first opportunity is after you push send on your proposal”, “had a demo with me at the conference”	10,11,13, 14,15,16, 20,21,41	Convergent – confirmed behavior as key to achieving outcomes and having impact
Research Achievement	62% tech transfer 60% tech reports	“connect my work to government sponsors”, 29 surveyed projects spawned direct funded work	23,24,25, 26,27,28, 29	Convergent – led to the understanding of research achievement; Some divergence in metrics for achievement
Research Culture	N/A	“we can't do research inside an ivory tower and have impact”	19,30,41	N/A
Research Knowledge Management	63% of survey projects start after 2010	“13 or 14 proposals referencing”, “hard to dig back into the past to give accurate figures”	1,2,17, 18,19,21, 29, 37	Convergent – confirmed KM as a current limiter with potential for significant improvement
Research Automation Services	N/A	“There are no digital receptors that channel people to me”, “There should be discoverable artifacts”	31,32,33	N/A
Research Program Management	45% use-inspired basic 51% applied 26% funded for one year 43% funded <= one FTE	“Focus [is]on a relatively small set of strategic problems”, “The research … is way more agile”, “hand-selected PRS review panel”, “need to have some sort of mentor”	3,4,5,12, 22,24,25, 26,27,35, 36,37,38, 39,40,41	Convergent – the case study data enabled an expanded understanding of the survey data and led to identification of limiters and contributors to achievement of research outcomes and impacts

Analysis Conclusions

This study collected a large pool of data through the survey, case studies, and expert panel feedback. The data pool was put through an analysis funneling process that surfaced 41 findings which were further refined into the major themes of the study. The final output of the funneling process was a set of contributors and limiter that answered RQ1, and a set of recommendations that answered RQ2.

- [RQ1] What are the factors that contribute to or limit the achievement of research outcomes and impacts?
- [RQ2] What can be done to enhance researchers' ability to achieve outcomes and impacts?

Table 27 and Table 28 list the key contributors and limiters to achievement of research outcomes and impacts in the federal research environment that were identified in this study.

Table 27. *Contributors to achievement of research outcomes and impacts*

#	Contributors	Associated Findings	Associated Themes
C1	Allowing agility in research execution	12	Research Program Management
C2	Research in a hot topic area	6	Research Topic Selection
C3	Research in a foundational area	7	Research Topic Selection
C4	Research derived from a high achieving research project	8, 9	Research Topic Selection
C5	Team includes experienced researcher	9	Research Team
C6	Team includes operational domain experience	34	Research Team
C7	Collaborative behavior from beginning of project	10, 14	Collaborative Behavior
C8	Recognized awards for participation in research program	30	Research Culture

Table 28. *Limiters to achievement of research outcomes and impacts*

#	Limiters	Associated Findings	Associated Themes
L1	PIs with no research execution experience	35	Research Team
L2	PIs with no operational domain connections	36	Research Team
L3	Fear of competition	15	Collaborative Behavior
L4	Education/knowledge gaps in technology transfer/transition and IP protection approaches	25, 27, 41	Research Program Management
L5	Shortfalls in research knowledge management	1, 2, 29	Knowledge Management
L6	Lack of mandate for PIs to publish research results	19	Research Culture
L7	Public release process not customized to support research and academic publication	22	Research Program Management

The contributors and limiters in the previous two tables provided the foundation from which the answer to RQ2 was constructed. The recommendations in Table 29 can be implemented by federal research organizations to enhance their researchers' ability to achieve project outcomes and mission-focused impacts. Each recommendation references the contributors and limiters that the recommendation was derived from. These recommendations will be discussed in detail in Chapter 5.

Table 29. *Summary of study recommendations*

#	Recommendation	Contributor / Limiter
R1	Research organizations should establish training for new and aspiring researchers on best practices for achieving research outcomes and impacts in the federal research environment	C2, C3, C4, C7, C8, L3, L4
R2	Establish a research mentorship program in which early career researchers can benefit from senior/proven researchers	C5, L1, L4
R3	Include an assessment of research team makeup as part of the project award decision process	C5, C6, L1, L2
R4	Promote agility in research project execution	C1
R5	Mandate formal and/or informal publishing of results for all research projects	L6
R6	Review the organizational public release process to ensure it is designed to support research and academic focused publications	L7
R7	Implement a Federal Research Collaborative Investments and Impacts Tracking and Enhancement Service (FR-CI^{2}TES) for research knowledge management and promotion of collaboration	L5

Expert Panel Session #3

The final step of the study methodology was a review and assessment of the results and recommendations by the expert panel. A 90-minute plenary session was held with the panel members at which the answers to the research questions were discussed including the eight contributors and seven limiters to achievement of research outcomes and impacts, and the seven recommendations for enhancing researchers' ability to achieve outcomes and impacts. The feedback from the panel members was positive and validated the recommendations. Information and insights from the panel were captured and reflected in Chapter 5. The highlights of the final expert panel session are listed below.

- The panel raised a caution regarding the mentoring recommendation (R2) that care must be taken in selecting senior researchers to mentor junior researchers. It was pointed out that some senior researchers will have biases that may be counter to current research program best practices.
- In the discussion of the research team makeup recommendation (R3), the panel stressed the importance of having a strong PI to lead the research team. They stated that selection of the PI is the most critical factor in the success of the research project.
- During the discussion on the recommendation to promote agility in research project execution (R4), the question was raised on whether and how to capture changes in a research project's intended outcome(s) when it is decided to pivot from the original plan and/or outcome(s). The discussion surfaced two paths that a project could take when such a pivot is made: 1) end the project, declare the original research path as disproven, publish those results, and start a new project with the new outcome(s); or 2) continue the project, document the change in vector, and continue the research

toward the new outcome(s). In both scenarios it is critical that the reasons for abandoning the original intended outcome(s) be captured and published for the benefit of future researchers.

- The question was raised as to why the publishing of research results was not listed as a contributor in Table 27 considering that in Table 28 the lack of a mandate for PIs to publish research results was included as a limiter (L6) and the recommendation was made to mandate publishing research results (R5). In response, it was pointed out that the study had found that not publishing research results deprives the knowledge pool of valuable information that could help future researchers. The study did not find, however, that publishing research results contributes to achievement of research outcomes and impacts.

Summary

This chapter presented the results of the study framed by the four steps of the data collection and analysis process model depicted in Figure 7. The survey results and multiple case study results were provided. Forty-one findings from the converged data analysis were presented. These findings were categorized into eight themes. The analysis of these themes led to the identification of contributors and limiters to researchers' ability to achieve their research outcomes and have impact, thereby answering research question #1. Further analysis led to the development and presentation of seven recommendations for federal research organizations to help their researchers achieve outcomes and have impact, thereby answering research question #2.

Chapter 5: Conclusions and Discussion

Using a mixed methods case study design with a convergent approach, this study explored a complex research program spanning seven FFRDCs. This research program consisted of a mix of use-inspired basic research and applied research focused on the mission challenges of major federal organizations inclusive of the DoD, FAA, DHS, and VA. Through the analysis of 41 findings, the study achieved an understanding of the contributors and limiters to the achievement of research outcomes and impacts in the federal research environment. With this understanding, seven recommendations were developed for consideration by federal research organizations to enhance their researchers' ability to achieve research outcomes and have impact. The wide diversity of organizations within the federal research environment mean that these recommendations will resonate differently from organization to organization. It will be highly dependent on the organization.

Reusability of the Federal Research Impact Assessment Framework

The Federal Research Impact Assessment Framework (FRIAF) was adapted from the well-established Payback Framework (Buxton & Hanney, 1994) and used in the case study phase of this study. The FRIAF process model (Figure 5) was very useful in helping the survey and case study participants understand the research process stages and frame their research experiences. The FRIAF process stages were also used to frame the data analysis and was instrumental in the development of the findings.

The FRIAF should be highly reusable across the federal research environment. This study confirmed that the best approach to assessing federal research remains the case study methodology, and that the FRIAF supports case study data collection. As Kostoff and others cited in this study found, the assessment of research impact is too complex to answer with metrics alone. As such, surveys will not provide a complete or accurate picture of research impact. While time and resource consuming, case studies of research projects are the only way to get the qualitative data necessary from the various research stakeholders, including researchers and users of the research, to make a comprehensive impact conclusion. Even then, time will continue to change the impact story.

Continuing Education

A highly experienced and achieved researcher who participated in the case studies stated that "great research requires great researchers" (HB1). While that is arguably true, it takes training and experience to develop great researchers. Many of the great researchers within the federal research environment are retiring. Finding skilled scientists to fill the gaps is a growing challenge. As such, investments in junior or aspiring researchers is critical so as to rapidly develop the next generation of great researchers. This is the basis for recommendation #1:

- Research organizations should establish training for new and aspiring researchers on best practices for achieving research outcomes and impacts in the federal research environment.

Training of early career scientists was identified as one of the most important benefits of research by Merrill and Olson (2011). However, some of these early career scientists are already running their own research projects for the first time. Some are also not trained in the art of research. They have had a great research topic idea, perhaps from an immersive experience supporting their government sponsor's mission, and have been awarded research funding to pursue it, but are novices in research execution.

A related concern are the findings in this study related to researchers' misperceptions and/or a lack of understanding of the federal research environment. This study found diverse research philosophies and principles at play within the multi-generational and multi-cultural research group that participated in the case study interviews. The philosophies and principles of the senior researchers were based on how research used to be conducted in decades past. The concerns of the senior researchers were attributable to changes over time in the research program management approach, structure, and priorities. This study found that many of these research program management changes were responses to external drivers such as legislation, presidential administration initiatives, technology advancement, and the ever-evolving nature of collaborative agreements between government, industry, and academia. Researchers, whether senior, junior, or in between, who lack understanding of the external drivers may form misconceptions about the motivations of research program leadership to make changes to and to set priorities for the research program. This generates antibodies in the research program that reduce research productivity and limit the achievement of research outcomes and impacts.

The good news is that these issues are easily overcome with continuing education for researchers focused on best practices for conducting research in the federal research environment. Such a course should address the findings, contributors, and limiters from this study and be mandatory for federal researchers.

Mentoring Early Career Researchers

The attrition of senior researchers is a challenge for all federal research organizations. All means of maximizing knowledge transfer from this resource to the junior and aspiring researchers should be pursued. This study found a strong desire from the interviewed senior researchers, who understood the attrition situation, to mentor the junior researchers. This was the basis for recommendation #2:

- Establish a research mentorship program in which early career researchers can benefit from senior/proven researchers.

This recommendation is conceptually based on the cognitive apprenticeship model used in university research programs in which apprentices learn under the close supervision of expert mentors, gradually gaining independence and building their own expertise (Collins, Brown, & Holum, 1991). Implementation of the recommendation could take many forms. It could involve the senior researchers teaching the research best practices training class or being a guest speaker at the class. It could be structured as a volunteer program provided as a service to junior researchers. Or it could be more prescriptive, requiring project participation and/or review by senior researchers for PIs lacking a specific level of research experience and/or training.

Research Team Makeup

This study found three common attributes in the profiles of research teams that achieved high-impact. These teams 1) were highly skilled in the technology area of the research; 2) had a deep understanding of the operational mission area the research was working in; and 3) had direct connections to the intended government mission user that the research outcome was targeting. In rare cases, the PI embodied all three attributes. In most cases, a team was necessary to bring together the skills, experience, and connections to cover all three. It may seem odd that a research project PI could be funded who does not have the technical skills associated with the proposed research solution; however, research ideas in the federal research environment sometimes originate from prospective PIs that are supporting the operational mission users and recognize a gap or shortfall needing research. These prospective PIs will need to form a team with the skills necessary in the technology area(s) proposed to fill that gap or shortfall. Likewise, a PI may have deep technical skills in a proposed research solution to an operational mission gap or shortfall but have no direct experience with that mission or connection to the mission users. This study came across multiple examples of these team situations. In all cases, a good PI is required to form a good project team, fill gaps in skillsets and domain knowledge, and execute the project. This was the basis for recommendation #3:

- Include an assessment of research team makeup as part of the project award decision process.

Considering the importance of technology transition as an outcome of federal research, implementation of this recommendation is critical. Technology transition planning, which should be accomplished as early as possible in the research process, cannot be accomplished effectively by a research team without exquisite knowledge of and experience with the operational mission domain. This is analogous to the “Lead User” construct in commercial industry (Von Hippel, 1986). Lead Users forecast a technology innovation path based on their advanced use and need within a technology domain, thereby helping commercial companies develop the next breakthrough product. Similarly, federal research teams need access to mission domain Lead Users to help guide their research down the right path towards impactful mission solutions. Lead Users in the federal research environment could be participants or consultants on the research team who have deep operational experience in the mission domain. Lead Uses could also be government operators in the mission space who help guide the research team towards targeted capability solutions.

If a research team is lacking any of the three common attributes listed above, the missing attributes need to be identified and remedied at the beginning of the research process. Not all research projects will fail to achieve their outcomes if these attributes are not present; however, the risk is considerably higher. One approach is to assign an operational advocate to PIs who lack that attribute in their research team to help guide the PI toward solutions relevant to the operational mission user and make the connections with the operational mission users early in the research process to increase the chances of successful technology transition.

Agile Research

Another common attribute of high achieving research projects found in this study was that they were allowed to adjust their original research plan and outcome(s). This often occurred early in the research process based on discovery of technical and/or operational opportunities that presented an alternative path toward more impactful outcomes. In the studied cases, these adjustments were minor course corrections to the original research but resulted in high-impacts. This was the basis for recommendation #4:

- Promote agility in research project execution.

Implementation of this recommendation comes with caveats. The promotion of agility in research needs to include checks and balances. Any changes in the research project outcomes that were the basis for a funding decision need to be reviewed and approved by some authority in the research program. This can be formal or informal, but such reviews are necessary for the integrity of the research program.

Publishing Mandate

The surveyed PIs in this study reported that 68% did not pursue the publishing of their research results in a peer reviewed journal. This can be explained by the high percentage of applied research and mission sensitive research that may not be conducive to public release. However, the survey also found that 40% of research projects failed to document their research in either formal or informal papers. This was a concern voiced by a majority of the case study participants who have observed an overuse of PowerPoint presentations substituting for research documentation. This was the basis for recommendation #5:

- Mandate formal and/or informal publishing of results for all research projects.

All federal research, whether having achieved outcomes and impacts or not, need to have results captured, documented, and made accessible as part of the knowledge pool for ongoing and future researchers. Research knowledge cannot be managed, transferred, or transitioned if not documented. Documentation should be in a formal or informal paper format that can capture the valuable detail. Extra attention will need to be paid to research projects considered "failed"—a misapplied label, considering that the disproving of a research hypothesis or an inability to achieve a research objective is a successful outcome. There is a propensity to ignore these projects and move on. This robs the knowledge pool of disproven hypotheses and failed research paths that would help steer researchers down other paths more likely to succeed.

Enabling Publishing

Mandating the publishing of research results needs to be enabled by organizational processes and procedures that support the public releasing of the papers. This study found a perception in a minority of the interviewed researchers that the public release process was arduous and arbitrary, dissuading some from pursuing the publishing of their research results. This extended to academic papers from graduate programs sponsored by the research organization that required public release approval. This was the basis for recommendation #6:

- Review the organizational public release process to ensure it is designed to support research and academic focused publications.

Public release processes are critical to preserving and protecting the reputations and intellectual property of the federal research organizations. Changes to such processes should not be taken lightly. However, these processes, and the systems used to support them, need to adapt to changing times and practices, and should be responsive to the needs of researchers and graduate students. This is especially true with the growing use of social online networking that requires the ability to rapidly share information (this will be discussed in detail in the next section).

During the course of this study, the public release process for the seven FFRDCs studied was streamlined to enable authors to select an appropriate technical reviewer for their papers. Previously, the procedure required the authors' line manager to conduct the technical review. This was problematic at times when the line manager had no background in the topic area of the research or academic paper. This change to the technical review portion of the public release process is expected to remove the approval roadblocks and cut the approval processing time by 50%. More importantly, the process change is expected to lead to an increase in organizational publishing that will benefit stakeholders.

Federal Research Collaboration, Tracking, and Discovery Service

A prominent theme throughout this study has been the need for augmentation of research knowledge management using modern on-line services and data science techniques. This was implicit in the author's opening story of his federal research experience and the atrophy of information on the project's outcomes and impacts over time. The theme was explicit in the literature review, which noted Kostoff's calls in the 1990s for capturing research outcomes and impacts in a database or federation of databases (1997b). He stated that in order to track the diffusion of information from federal research, multiple public and private organizations would need to collect data at all evolutionary stages of the research, including years beyond the completion of the research project. More recently, Kostoff's call was echoed in a 2011 workshop titled Measuring the Impacts of Federal Investments in Research hosted by the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. This workshop called for implementation of a comprehensive capability to automatically capture research input, output, and impact data stating the value such data would have on the ability to perform long-term impact assessment (Merrill & Olson, 2011, p. 81). Penfield et al. came to the same conclusion in their 2014 study on research impact assessment emphasizing the high value that having such tools would have for populating the research knowledge pool with relevant data. The findings of this study confirm what the literature affirms. The lack of online tools for capturing and sharing research activity and results is limiting federal research collaboration, technology transfer and transition, and impacts. Additionally, the attrition of researchers, due primarily to retirement, is causing a correlated attrition of research information because knowledge management in research organizations is not receiving due attention. This is the basis for recommendation #7:

- Implement a Federal Research Collaborative Investments and Impacts Tracking and Enhancement Service (FR-CI^{2}TES) for research knowledge management and promotion of collaboration.

The realization of a FR-CI^{2}TES to capture and track research inputs, outputs, outcomes, and impacts would take a deliberate and dedicated campaign to gain advocacy including potentially a legislative mandate. Its implementation would take a concerted effort by the federal research community and its stakeholders. Achieving such a capability would provide an efficient, effective, and affordable approach to research transparency and accountability, as discovered by the HITS and Researchfish efforts. HITS and Researchfish are pathfinders for the federal research community and should be further studied for lessons learned and best practices.

One limitation, however, is that both systems are narrowly focused on the medical research domain. Even so, HITS and Researchfish are excellent models from which to develop the FR-CI^{2}TES. Federal research organizations have a rich set of research inputs, outputs, outcomes, and impacts that are closely associated with those captured and tracked in HITS and Researchfish. As such, federal research organizations can and should build on these examples by establishing similar cultures and KM services. Ultimately, the federal research community will need a globally integrated and interconnected web of organizational research impact knowledge management systems that can track and link inputs, outputs, outcomes, and impacts community-wide. Research impact is, after all, global, versus isolated to any singular community, domain, or organization. Much can be learned in this regard from the current Academic Social Networking Sites regarding the five networking functions: collaboration, online persona management, research dissemination, documents management, and impact measurement.

FR-CI^{2}TES would alleviate the factors that limit technology transfer and transition today: the linear and opportunistic approaches used by federal research organizations to make connections between researchers and potential stakeholders. Approaching federal research as a linear process results in the heavy lifting of knowledge and technology transfer/transition being worked as an outcome once the research project has completed. Additionally, technology transfer and transition are generally approached opportunistically with the researchers and/or Technology Transfer Office (TTO) identifying potential users of the technology by presenting at conferences, publishing papers, filing patent applications, and/or posting significant research outputs on TTO websites. While important, these actions require multiple factors to come together at the right time and place to make a successful connection. FR-CI^{2}TES would enable research stakeholders, including current, past, and future researchers, and potential users of that research, to search for and discover opportunities for collaboration, cooperation, and technology transfer/transition *in the early formative stages of research* when time and resources are available to influence and steer the research toward more impactful outcomes. This has the potential to increase federal research return on investment exponentially.

The first step towards realization of FR-CI^{2}TES is for the federal research community to join the U.S. NIEHS and UK HEIs in implementing research impact reporting programs, processes, and automated knowledge management (KM) capabilities. The most expeditious approach would be for the federal government to implement a whole-of-government research reporting service as a President's Management Agenda (PMA) Cross Agency Priority (CAP) Goal #14 initiative focused on increasing federal research return on investment (ROI). It would also help federal research organizations meet the requirements of the Open, Public, Electronic, and Necessary (OPEN) Government Data Act signed into law in January 2019 as Title II of H.R.4174 - Foundations for Evidence-Based Policymaking Act of 2017. This Act is a transparency measure requiring federal agencies to publish all public data in a machine-readable format, in an open format, and under open licenses.

The following steps are recommended:

1. Establish the FR-CI^{2}TES for collecting federal research input, output, outcome, and impact summary data (based on best practices of HITS and Researchfish.com). The DoD laboratories, FFRDCs, and UARCs should leverage the Defense Technical Information Center (DTIC) research portal that is overseen by the Office of the Undersecretary of Defense (OUSD) for Research and Experimentation (R&E). The iEdison.com site hosted by the U.S. National Institutes of Health (NIH) should also be leveraged. iEdison.com is used by grantees of federal research funding to report

derived inventions, patents, and utilization data to the government agency that issued the funding award. A prototype FR-CI^{2}TES with a phased expansion of participation from federal research organizations over a five-year period should be undertaken as a starting point to collect lessons learned. A kickoff followed by annual stakeholder meetings should be organized to inform, energize, and evolve FR-CI^{2}TES, and to expand federal, academic, and industry collaboration.

2. Amend the GPRA (Government Performance and Results Act) Modernization Act of 2010 to require federal research organizations to use FR-CI^{2}TES. This act already mandates a level of federal research activity reporting, but not to the level being proposed by this study. The PMA CAP Goal #14 initiated the Return on Investment (ROI) Initiative for Unleashing American Innovation in 2018. As lead for the initiative, NIST has been collecting comments from the public on how to increase federal research ROI. In December 2018, NIST released a Draft Green Paper with recommendations on increasing long-term ROI from federal research, but it does not include GPRA amendment recommendations. Instead, it focuses on legislative changes to the Bayh-Dole and Stevenson-Wydler Acts that predominantly deal with ownership of federally funded inventions and federal research organization participation in technology transfer. These proposed changes do not go far enough with their intended extensions to research activity reporting, which focus too late into the research process. Amending the GPRA will enable the promotion of collaborative behavior early in and throughout the research process.

3. Require federally funded researchers to report and update their project inputs, outputs, outcomes, and impacts in FR-CI^{2}TES from the start of the project through at least 5 years from project completion.
4. Require federal research proposals to include a literature review listing past research being built upon. The review should include the results of a FR-CI^{2}TES search. This will enable rapid and accurate retrospective tracing of research impacts.
5. Encourage past and present federal researchers to review ongoing research projects via FR-CI^{2}TES for opportunities to collaborate and leverage their research outputs.
6. Encourage government and industry research stakeholders to use FR-CI^{2}TES to identify potential solutions for mission gaps and shortfalls and engage with the researchers on potential technology transition and transfer opportunities.
7. Develop a taxonomy of a common language for research reporting to inform FR-CI^{2}TES development. As discussed in Chapter 1, Brewer (2011) suggested developing a common conversation about research impact between researchers, research sponsors, and the beneficiaries of the research outputs from which a taxonomy could be derived. This conversational foundation and framework would be critical to implementing the FR-CI^{2}TES. Such a taxonomy would enable researchers to commonly describe and categorize their research objectives, outputs, outcomes, and impacts, which in turn would improve search and discovery accuracy for stakeholders. The tags used by the HITS and Researchfish services listed in Table 9 and Table 10 are a starting point for this taxonomy, but will require generalization from their target user domains.

Recommendations for Further Research

During the expert panel sessions, a number of questions were asked regarding the survey data that could not be answered because the data were either not collected or collected in a form that did not support the necessary statistical analysis. The following topics for further research could be pursued:

- An assertion was made in the study of a trend towards 1) an increasing number of research projects being funded, 2) projects being funded at lower funding levels, and 3) projects being funded for shorter timespans. The combination of these factors was considered a potential limiter for researchers in achieving outcomes and impacts. More detailed data collection and analysis is needed to make conclusions on this topic.
- The challenges with regard to the public release process were not quantified in the study. This could be pursued by organizations prior to considering changes to their processes and procedures.
- The survey results showed a high number of staff (10+) on the research teams of 12% of the surveyed projects. The likely explanation is that the majority of longer running and/or highly funded projects fell into this 10+ category, causing the spike in the data. This anomaly could be further explored for a more detailed explanation.
- The survey results showed that 22% of the surveyed projects presented their research in a high number of conference and workshops (10+). The likely explanation is that the majority of longer running projects fell into this 10+ category, causing the spike in the data. This anomaly could be further explored for a more detailed explanation.

- The study found that 40% of the surveyed projects failed to publish their results either formally or informally. The motivational reasons for this behavior could be explored in further study.

An intriguing hypothesis was suggested by the expert panel that generating Intellectual Property increases the probability of having impact. This study did not collect the data necessary to prove or disprove the hypothesis. Additional study could be pursued.

This study recommended the implementation of a FR-CI^{2}TES that would over time create a valuable data repository of federal research activity, results, and impacts. This data would be ripe for artificial intelligence (AI) based analytics that could surface potential research connections across domain space and time including research that is complementary, duplicative, or disproven. Further study exploring the potential of research-focused AI analytics would be valuable.

Some of the researchers interviewed in this study questioned the viability of the FR-CI^{2}TES concept due to concern that some researchers would not be willing to share their research information, especially early in the research process. The concern was that these researchers would hold back on participation due to fear that their research idea would be stolen or co-opted. Another area of concern regarding the viability of FR-CI^{2}TES was due to the sensitivity of some research, especially with regard to potential government mission applications of the research. These concerns are valid and explain why so much federal research information remains restricted and siloed today. The result is underutilization of the data, hindering advancements in many fields. One potential solution worthy of further study is the utilization of blockchain technology to provide transparency and privacy assurances to users. Blockchain technology could enable federal research organizations to guarantee that data are used only in specific privacy-preserving ways, enabling broader sharing of the data with industry and academia.

Finally, mentioned earlier in this chapter was the need for development of a taxonomy for research reporting to support the FR-CI^{2}TES. The category tags in use by HITS and Researchfish are good starting points for this effort, but further study is needed to customize the tags for the federal research environment.

Concluding Remarks

Federally funded research is a national resource. Such a resource needs to be managed and optimized if the United States is to maintain its technology and innovation leadership in the world. Optimization cannot be achieved if research continues to be performed in isolation and siloes across the federal research environment. Optimization also will not be achieved by only focusing attention on the end of the research process when it is too late to change the course of research towards more impactful outcomes.

The DoD believes that the U.S. can maintain military dominance with multi-domain operations, defined as the ability to employ air, ground, sea, cyber, space and other domains in unison towards achievement of some military objective. The same premise is true for U.S. technology and innovation leadership. In order to maintain leadership in technology innovation, the federal research community needs to pursue multi-domain research enabled by a collaborative capability that provides transparency, discoverability, and accessibility to the diversity of federally funded research for stakeholders. This study provided a small but tangible step in that direction.

Implementing the recommendations presented in this study may help federally funded research organizations realize a higher return on investment and better ford the “valley of death” between promising technologies and their integration into government missions thus benefiting both government sponsors and the public.

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