The Historiography of Technology Since 1950, with a Focus on the Navy

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Introduction

I thank Dr. Mike Crawford and the Naval History and Heritage Command (NHHC) for the honor of its invitation to prepare an essay on the subject of historiography of technology in the Navy in its speaker series, "Needs and Opportunities in the Modern History of the U.S. Navy." Dr. Crawford charged me to consider three broad questions: What has been written? What has not been written? (Or, what has not been deemed important enough to consider in writing histories of naval and Marine Corps technology?) And, what should be written?

Three themes inform my discussion of selected work on the history of technology. First, the end of World War II marks a period in which, as historian Barton Hacker observes, "military authorities have come eagerly to accept or even promote . . . the introduction of new weapons." Military authorities' adoption of the idea that "doctrine might drive and control technological change" makes the post–World War II period very different from the past 200 years of military history.[1] Indeed, the idea that military technological change might be controlled and directed had ample precedent in the development of new industries in the late 19th century organized around telecommunications, photographic, electrical, and chemical technologies that exploited then-recent scientific discoveries. Industrial leaders recognized their dependence on science, and established research components—industrial research laboratories—to routinize scientific research to develop improved processes and products.[2] Post–World War II military leaders applied an existing and proven approach to improving products and processes.

The second theme concerns the post–World War II role of knowledge and analysis in making decisions and policy about public expenditures on inventive activity and technology development. The appropriate perspective on the role of knowledge and analysis in inventive activity concerns the co-evolution of institutions and military, social, political, and economic organizations; not whether a law-like generalization can be offered regarding the role of knowledge and analysis in individuals' efforts to invent or apply technology.[3] This theme echoes the views of prominent military historians. For example, Barton Hacker notes that "the concept of military technology has grown beyond hardware to embrace ideas and institutions; organization, management, and doctrine have become as much a part of the field as weapon development."[4] Alex Roland adds that the

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military is a social institution and it "plays an enormously important . . . complex role in the development of science and technology."[5]

My third theme concerns Frederick Pohl's observation: "A good science fiction story should be able to predict not the automobile but the traffic jam."[6] In other words, insight comes from describing and tracing interactions and contextual relationships—not just the technology itself. Pohl, an acclaimed science fiction writer, implies a better story involves examining interactions among inventions, modes of behavior, cultural history, political and social institutions, military organizations, and legacy stock of equipment, infrastructure, and hardware and social technologies.

Developing a capability—concepts, methodologies, organizations, and working relationships—to examine, assess, and predict "traffic jams" of naval (and, more broadly, military) operations requires overcoming challenges to the many ways the historical and analytical communities interact and work. This difficult task is worth pursuing to make discourse about national security questions more rigorous, and to increase the value to senior leaders of the products produced within the historical-analytical community.

What Has Been Written?

Several contrasts channel this historiography of technology relating to the U.S. Navy and U.S. Marine Corps between 1950 and the present. First, fewer histories of naval technology[7] have been written than general histories of technology and histories of technology related to ground combat.[8] Second, the historiography of naval and Marine Corps technology encompasses many topics. Deciding how to frame this historiography involved a good deal of search and rejection of themes, frameworks, and approaches.[9] I conducted a quick JSTOR digital library search of terms "Navy," "naval," "weapons," and "technology" between 1950 and 2016 and found more than 9,000 essays. I also reviewed every issue between 1959 and 2015 of the Society for the History of Technology's journal, *Technology and Culture*, in what turned out to be a vain hope that a clear theme had been articulated by academics. I flagged more than 300 articles and almost 500 book reviews that piqued my interest and seemed relevant to my topic after I read the first few paragraphs. Alas, these articles offered far too many potential themes to consider each in an essay-length discussion.

I also decided against discussing nuclear weapons technologies for two reasons. First, although many unclassified memoirs, histories, and declassified studies of nuclear weapons technologies are available,[10] detailed information about premises for decisions about specific technologies remain classified. Second, the literature on the development of nuclear weapons technologies provides essentially the same insights on inventive activity and technology development as could be found in unclassified literature on conventional naval and Marine Corps technology programs. I assume that impacts of administrative processes and bureaucratic organization on inventive activity and technology development would be similar for classified and unclassified programs begun at roughly the same time,[11] and therefore, unclassified descriptions of organizations and administrative processes provide useful general insights about management of technology development programs.[12]

For example, Massachusetts Institute of Technology political scientist Harvey M. Sapolsky's *The Polaris System Development: Bureaucratic and Programmatic Success in Government* contains a classic description of the use of a formal management tool to disguise informal and flexible decision-making in planning and managing the development program. The story concerns how Vice Admiral William F. Raborn and key subordinates dealt with ambiguities and various political and technological uncertainties in the development of the fleet ballistic missile (FBM) program. Sapolsky identifies the role of program evaluation and review technique (PERT), a dedicated management and assessment process, in shielding the FBM from Department of Navy and congressional supervision and review. Admiral Raborn (and managerial subordinates) received current program status information by "picking up a telephone and calling the relevant technical group or by ordering tickets and flying to the relevant locations." The PERT management tool was irrelevant to managerial decisions about how to develop the FBM; the use of PERT as an "integrated, uniquely effective management system was a myth."[13]

Several colleagues directed me to look at the discussion of current technology programs, such as the Department of Defense's (DOD) Third Offset program (discussed below). Others suggested a relatively safe approach of reviewing academic disputes about the relationship between science and technology in inventive activity,[14] or assessing policy debates about whether basic or theoretical scientific research precedes inventive activity—a position Vannevar Bush takes in three books published before 1950[15]—to justify the argument that more public funds should be expended on basic research, or examining the sources of technology in terms of the reorganization of labor,[16] use of machines in manufacture, exploitation of manmade materials, and application of new sources of energy.[17] With these thoughts in mind, what follows is an effort to provide context, synthesize, and summarize selected studies concerning technology related to Marine Corps and Navy missions.

The Historiography of Modern Military Technology Begins Before World War II

The historiography of military technology has largely concerned weapons, machinery, fortifications, and associated physical objects. Before World War II, some strands of thinking and research on institutions and social context of warfare complemented attention to physical objects. Sociologist William F. Ogburn proposed the hypothesis of cultural lag to explain a period of adjustment during which people become comfortable with, and learn how to use new technologies.[18] Sir Charles Carter, in his 1982 presidential address to the British Association for the Advancement of Science, argues that British technologists and innovators too frequently attempted large leaps in technology—before the benefits of the new way of doing things became evident. Carter did not cite Ogburn's cultural lag hypothesis, yet Carter's argument broadly re-states Ogburn's thesis and sociologist Arthur Stinchcombe's observations about the "liability of newness"—the period between the introduction of a physical or social technology and acceptance by users."[19] Needless to say, an understanding of the liabilities of newness is crucial to minimizing obstacles to the introduction and wide deployment of new technologies and operational concepts.

The pre–World War II work of two other scholars deserves mention. Historian and philosopher Lewis Mumford and sociologist Robert K. Merton examined social conditions under which technology—physical objects—were conceived, developed, and produced. They argued that technology advanced within a craft tradition, and that rapid technological advance was based on accumulating scientific knowledge.[20]

The Mumford/Merton thesis shaped American World War II science and technology goals for applying knowledge to challenges encountered in combat. In 1941, the Office of Scientific Research and Development (OSRD) was established to mobilize academic researchers to develop weapons and associated technologies. OSRD's efforts focused on the physics and engineering to develop new weapons and technologies and to improve existing technologies, leading to a vast array of devices and machines, many of which are described in more than 70 monographs produced by the OSRD. Some of these monographs discuss operational and technological issues relevant today to the Department of the Navy, including hypervelocity guns, recognition of underwater sounds, and subsurface warfare.[21] Little, Brown and Company published some declassified OSRD monographs in its "Science in World War II" series in 1947 and 1948.[22] Among these, my favorite is Lincoln Thiesmeyer and John Burchard's *Combat Scientists*,[23] which contains a great deal of material directly relevant to "traffic jams" and present and future concerns, such as the diffusion of innovation, long-distance communications and policy coordination, and civil-military relations and cooperation in combat zones.[24]

The notion that engineering and technology were applied science guided policy literature during World War II and especially in the immediate post-war period when OSRD director Vannevar Bush advocated continuing federal support for basic research that would lead to technological advances. He argued for the establishment of the National Science Foundation to provide theoretical research to inform and guide invention, the general development of technology, and refinement of technologies for practical uses. The Manhattan Project was a clear exemplar of this "research push" argument; it was prewar basic research in nuclear fission that guided the design and construction of two types of atomic bombs.[25]

The Historiography of Modern Military Technology Following World War II

In the years following World War II, historians recognized and examined infrastructural and organizational legacies of the conflict and changes in institutional rules, organizations, and conceptual approaches military and civilian leaders brought to problems and challenges of national security. For example, Barton Hacker and Alex Roland provide excellent summaries of academic research through the 1990s (see footnotes 4 and 5). Merritt Roe Smith argues that following World War II, armed forces "promoted, coordinated, and directed technological change and . . . sometimes directly and sometimes indirectly affected the course of modern industry."[26] The essays contained in *Military Enterprise and Technological Change* provide context and examples of the ways in which military requirements constrain and guide the organization and actions of large and small industry.[27] Most of the essays focus on the pre–World War II period. David K. Allison, however, examines post–World War II technology policy technology regarding the Sidewinder missile program and the Navy Tactical Data System in "The U.S. Navy's Research and Development Since World War II."

Comprehensive surveys of naval and Marine Corps technologies include performance characteristics and details about system development and operational use. Norman Friedman (who earned a Ph.D. in physics) and Normal Polmar (who earned a college degree in journalism and history) have provided indispensable and vital contributions to the study of naval technologies. Isaiah Wilson III produced a weapons technology database tailored to questions asked by political scientists.[28] The IHS Jane's yearbooks cover many topics relevant to naval and Marine Corps systems, including *IHS Jane's Fighting Ships* (first published in 1897), *IHS Jane's Defence: Platforms, IHS Jane's Defence: Air and Space*, *IHS Jane's Defence: Sea*, *IHS Jane's Defence: Sea Platforms, IHS Jane's Unmanned Maritime Vehicles, IHS Jane's C4ISR & Mission Systems: Maritime,* and *IHS Jane's Underwater Warfare Systems*. In 1969, the Stockholm International Peace Research Institute (SIPRI), began publishing another important yearbook series*, Armaments, Disarmament and International Security*. The SIPRI yearbook provides an overview of developments in international security, weapons and technology, military expenditure, the arms trade and arms production, armed conflicts, and efforts to control conventional, nuclear, chemical, and biological weapons.

Selected Post–World War II Historical Research on Navy Warfighting Systems

In 1992, the Navy Laboratory/Center Coordinating Group and the Naval Historical Center began to collaborate on developing a comprehensive history of Navy research, development, test, and evaluation (RDT&E) and acquisition of Navy warfighting systems. The purpose of this joint effort was to "record Navy history associated with research, development, test, and evaluation and the acquisition of Navy warfighting systems." The joint effort produced at least three publications on the Navy's in-house technical capability and associated management and policy processes written by History Associates vice president Rodney Carlisle.[29] The first publication of this collaboration effort was *Management of the U.S. Navy Research and Development Centers During the Cold War Era*.[30] This report complements a 1976 Booz Allen Hamilton report that reviewed Navy research and development (R&D) management between 1946 and 1973.[31]

In *Management of the U.S. Navy Research and Development Centers*, Carlisle focuses on reports produced by the Department of the Navy, Department of Defense, Congress, private consulting organizations, and blue ribbon panels of experts on the management of RDT&E centers during the Cold War period between 1973 and 1992, such as the 1969 Office of the Director, Defense Research and Engineering *Project Hindsight*. *Project Hindsight*'s author, Raymond Isenson, surveyed the development of more than 600 then-current weapons technologies and assessed the impact of basic research on each weapon system's cost-effectiveness.[32] He concluded that technological advances in more than 90 percent of the weapons surveyed resulted from mission-oriented R&D rather than basic science. In an extensive review, Karl Kreilkamp argues that *Project Hindsight*'s methodology generated an overly simple and basically inaccurate description the interaction between technology and science.[33]

In response to *Project Hindsight*, the National Science Foundation (NSF) funded *Technology in Retrospect and Critical Events in Science* (TRACES), a two-volume study prepared by the Illinois Institute of Technology Research Institute. TRACES did not apply the same methodology as *Project Hindsight* to identify whether and how technologies were enabled by basic science. The key political outcome of TRACES and *Project Hindsight* was that the NSF lobbied Congress to amend the NSF Act to permit the foundation to fund applied research.[34] Historian Edwin Layton concludes his discussion of *Project Hindsight* by noting that science and technology should be treated as a "complex whole capable of functioning as a working system,"[35] rather than treating either science or technology as primary to the other.

The Relationship of Science and Technology: A Bibliographic Guide is a 40-page selected bibliography comprising more than 150 articles and books.[36] It surveys post–World War II themes, such as World War II origins of U.S. technology policy, panels, and commissions that attempted to anticipate the rate and direction of technological development; historians' views of technology and culture; mutual influences between scientific and technology development activities; establishment of research priorities; and Japanese industrial experience of relating science and technology.

Carlisle's *Navy RDT&E Planning in an Age of Transition* examines impacts on Navy policy and planning of international turbulence in the 1980s and 1990s.[37] His work in this period informed policy discussions of the 1990's Base Realignment and Closure process regarding (1) the existence and character of a link between basic scientific research and technologies developed at Navy laboratories and development centers, and (2) effectiveness of R&D conducted under different organizational arrangements, such as a government-owned facility that conducts research through engineering and maintenance, or contractual relationships that assign components of a research program to industry, universities, and private laboratories.

Two studies of note detail Office of Naval Research scientific and technological research: Ivan Amato's *Pushing the Horizon*[38] and Robert Buderi's *Naval Innovation for the 21st Century*.[39] Then, in *The Sound of Freedom*, Carlisle and James Rife examine the evolution of Dahlgren Laboratory from a naval proof and test facility into a modern research and development center that contributes to many different naval weapons systems.[40] Finally, the U.S. Naval Institute recently released an edited volume, *The U.S. Naval Institute on Naval Innovation*, which contains essays on cyber, unmanned vehicles, and future weapons systems.[41]

Naval History and Office of Naval Research Websites

The Naval History and Heritage Command website lists the three science-technology studies written by Carlisle during the late 1990s, but there are no links to digitized versions of the reports. No studies produced more recently were listed.[42]

The Office of Naval Research website contains interesting material, including the fourth version of the *Naval Science and Technology Strategy*,[43] and a list of 61 Nobel laureates who received Office of Naval Research (ONR) funding support. Twenty-four Nobelists received the prize in physics, 26 in chemistry, nine in medicine and physiology, and two in economic science—Herbert A. Simon and Kenneth Arrow.[44]

National Academies of Sciences, Engineering, and Medicine

The Department of the Navy has sponsored many hundreds of studies performed by the National Academy of Sciences (NAS) since the NAS was established in 1863. Political scientist Harvey Sapolsky provides details of the establishment and early operation of the Office of Naval Research in *Science and the Navy: The History of the Office of Naval Research*.[45] For our purpose of examining the development of technology in the Navy and the Marine Corps, it is enough to note that in 1946, the newly established ONR requested that the NAS establish a standing committee to advise the Navy on submarine design and systems technology. The resulting Committee on Undersea Warfare drew its initial membership from the Subsurface Warfare Section of the World War II National Defense Research Committee. In 1955, the ONR requested that the NAS accept responsibility for the Mine Advisory Committee, which had been established in 1951 to advise the Navy on research to develop mines and effective mine countermeasures.[46]

These two proactive committees, composed initially of scientists and engineers, produced approximately 200 reports in the years between 1946 and 1973. In 1973, the Chief of Naval Operations asked the NAS president to extend the charter of its naval advisory committees beyond undersea and mine warfare and form an advisory organization "to which [the] Navy could turn for advice on any area of its responsibility involving the interplay of science and technology with other national issues." The Naval Studies Board (NSB) was established in 1974 and assumed the missions of the Mine Advisory Committee and the Committee on Undersea Warfare. The board—organizationally located in the National Academies of Sciences, Engineering, and Medicine's Division on Engineering and Physical Sciences—has advised the Navy on the basic and applied science associated with almost every area of the service's overall mission.[47] It conducts studies of technology relevant to the Department of the Navy's missions, such as the status of unmanned underwater vehicles. Other recent studies of interest conducted by the Naval Studies Board explore Navy cyber defense capabilities, naval forces' response to capability surprise, and improving small unit leaders' decision-making abilities.

Defense Science Board

Defense Science Board members are accomplished natural scientists, engineers, and mathematicians. The DSB website lists reports produced by the board from the 1970s to the present. The board considers many issues it believes should be brought to the attention of senior Defense Department and Service leaders, such as weapons systems, machinery, and associated objects, and topics that enable or support development of matériel. For example:

- In 2006, it examined the current adequacy and future needs for specialized skills necessary to maintain, upgrade, and design replacement strategic nuclear and non-nuclear strike systems. The board found that it has been difficult for the DOD to attract the "best and brightest science and engineering" talent; and the industry and government talent base is "marginally thin" in many current systems, and "may not be available for potential next-generation systems." Furthermore, the DSB concluded that exploration of new concepts and technologies for strategic strike of challenging systems in the far term is inadequate and will require access to a new talent base with different skills. Current skills may not be able to cope with unanticipated failures requiring analysis, testing, and redesign, and human capital management systems, and strategies to identify, track, and retain critical skills are not implemented effectively.[48]
- A 2006 joint study of the DSB and the United Kingdom Defence Scientific Advisory Council on critical technologies examined five major transformational technology areas—advanced command environments, persistent surveillance, power sources for small, distributed networked sensors, high performance computing, and defense critical electronic components. The report assessed that commercial off-the-shelf technology is insufficient to meet defense needs, and the two powers' lead in critical technologies is under threat from consolidation of the U.S. defense contractor base, migration off-shore of some critical manufacturing and design capabilities, and reduction in the numbers of personnel with experience in critical areas.[49]
- In 2006, the DSB examined strategic technology vectors in a report comprising four volumes.[50] The board reviewed the range of missions U.S. forces are called upon to perform, including major combat, counterinsurgency, stability and reconstruction, countering weapons of mass destruction, homeland defense, and disaster relief. These missions present different challenges, and the board identified the following four operational capabilities and technologies to deal with the range of missions faced.
    - Capability 1: Apply understanding of behavior of individuals, groups, societies, and nations to conduct of missions. Technologies include immersive gaming environments, automated language processing, and human, social, cultural, and behavior modeling.
    - Capability 2: Observe people in varied environments and preserve data of observations. New suites of sensors enable this capability.
    - Capability 3: Extract actionable information from data.
    - Capability 4: Produce effects—offensive and defensive, kinetic and non-kinetic, lethal and nonlethal.
- In 2008, a joint DSB and Intelligence Science Board task force examined integrating sensor-collected intelligence. The task force proposed improvements to tasking, collecting, processing, data storage, fusion, and the dissemination of information collected by intelligence, surveillance, and reconnaissance systems.

The task force's two primary recommendations were to deploy urgent communications improvements including Transformational Satellite System and to metadata tag sensor-collected data as close to the sensor as possible.[51]

- In 2012, the board examined the role of autonomy in DOD systems, and reported that autonomy technology is underutilized. Contributing factors include poor design, ineffective coordination of R&D across military services, and operational challenges created by the urgent deployment of unmanned systems without adequate time and resources to refine concepts of operations and training. The DSB proposed establishing a "coordinated science and technology program guided by feedback from operational experience and evolving mission requirements."[52]
- In 2013, the board developed a framework to analyze technology and investments to support military capabilities required in 2030. The framework consisted of four categories that support development of technically sophisticated, complex, and expensive systems: coping with parity, achieving superiority through cost-imposing strategies, achieving superiority through enhancing force effectiveness, and anticipating surprise.[53]
- In 2015, the DSB released its report on strategic surprise, in which it examined how information about a potential adversary in eight domains may change DOD priorities and actions, and how DOD might regret its failure to respond. They are: countering nuclear proliferation; ballistic and cruise missile defense; space security; undersea warfare; cyber; communications and positioning, navigation, and timing; counterintelligence; and logistics resilience.[54]

Congressional Testimony, Congressional Research Service, and Government Accountability Office

Testimony provided to House and Senate armed services committees, House and Senate appropriations subcommittees, and House and Senate authorization committees include statements by administration and military services officials, and expert reviews of programs and operations from academia and think tanks. For example, on 9 December 2015, the House Armed Services Committee's Subcommittee on Seapower and Projection Forces received testimony on "game-changing innovations" from Bryan McGrath, Managing Director of The FerryBridge Group, and Jonathan Solomon, Senior Systems and Technology Analyst, Systems Planning and Analysis, Inc. On 12 April 2016, the Senate Armed Services Committee's Subcommittee on Emerging Threats and Capabilities received testimony on the progress of Third Offset Initiative projects from Stephen Welby, Assistant Secretary of Defense for Research and Engineering, William B. Roper Jr., Director, Strategic Capabilities Office, and Arati Prabhakar, Director, Defense Advanced Research Projects Agency.

The Congressional Research Service (CRS) and the Government Accountability Office (GAO) are congressional independent, non-partisan agencies that produce reports and assessments of government programs, including the status of weapon systems programs, and issues related to weapons development. These reports may contain information gleaned from government or contractor sources, as well as empirical information developed by individual researchers. Naval analyst Ronald O'Rourke started working at CRS in 1984, where he writes reports for Congress on issues relating to the Navy. He briefs members of Congress and congressional staffs and has testified before congressional committees. Among the many naval technology topics he has examined include "Lasers, Railguns, and Hypervelocity Projectile," "Navy *Ford* (CVN-78) Class Aircraft Carrier Program," and the "Littoral Combat Ship."[55] O'Rourke updates reports after he receives information relevant to a current congressional discussion.

The GAO supports congressional oversight of federal programs by auditing agency operations, investigating allegations of illegality, reporting on how well government programs meet their goals, and performing policy analyses. Its reports on Defense Department weapons systems programs typically include responses prepared by the Department of Defense Inspector General, and recommendations concerning how shortfalls and other program challenges may be fixed.[56]

In addition to official government sources, and academic articles, monographs, and books, there are think tank and FFRDC sources, too many to review.

What Has Not Been Written?

The question, "what has not been written?" invites a search similar to the one Sherlock Holmes undertook in the short story "Silver Blaze" regarding the "curious incident of the dog in the nighttime"—that is, the dog that did not bark. Historical studies of military technology have mostly ignored questions, approaches, and concepts used by economic historians and social scientists to identify and analyze human-organizational interactions that are critical to the development and deployment of new military technologies.

Since the end of World War II, military and civilian officials and academics—including historians, social scientists, and policy analysts—have been keenly interested in technology related to military operations: how technologies operate, how technologies were developed, acquired, and deployed; and what impact various technologies would have on operations and outcomes. The development of nuclear weapons during World War II inspired additional questions and a large and growing literature. In 2016, the ongoing acceleration of scientific and engineering discovery, invention, and development has raised questions about whether the accelerating rate of invention might generate disruptive new military capabilities. For example, National Defense University analysts Jim Kadtke and Lin Wells argue that convergence of the rapidly advancing fields of biology, robotics, information, nanotechnology, and energy pose extreme national security policy challenges.[57]

The following sections provide examples of research subjects, concepts, and ideas that can inform or provide context for histories of human-machine/technology-organization systems.

Context for Naval and Military Technology: "Path Dependence," Institutions, and Organizations

In *Men, Machines, and Modern Times*, historian Elting E. Morison notes that it is a "poor sort of past that only deals with what has happened."[58] Historians have long known that some events and situations that occurred many years ago continue to exert an influence on the present and future. Military historian Ronald Spector notes, for example, that the struggles and triumphs in establishing the Naval War College continue to influence the entire Navy.[59] Economic historians have proposed the concepts of "path dependence," institutions, and organizations to trace the influence of the past on the present and future.[60] This research presents a necessary empirical corrective to implicit and explicit "rational actor" models of decision-making about weapons development and employment. For instance, during the mid-1950s, Andy Marshall and Joseph Loftus criticized implicit RAND Corporation rational actor analyses of the placement of Soviet long-range bomber bases by citing Soviet military history of placing aircraft bases on the USSR's periphery.[61]

We also can apply path dependence, institutions, and organizations to analyze the success or failure of militaries to alter their competitive positions through technological advancements.[62] Path dependence explains how military systems differ, the extent to which they are sensitive to chance events or "initial conditions,"[63] and how military services have resisted abrupt and discontinuous change. A path-dependence analysis is not a simple extrapolation of current trends. Rather, it focuses attention on the many systemic—and sometimes, dynamic—social or political factors (such as coordination costs in changing an information-processing technology) that structure and constrain choices individuals make in organizations.[64]

To describe initial conditions for particular paths, Nobel laureate in economic science Douglass North distinguishes institutions from organizations. He defines institutions as formal and informal rules that constrain and guide individuals' decision-making in organizations. For example, constitutions and traditions are examples of "institutions"; constitutions are "formal" and traditions are "informal" rules. Institutions set the rules through which organizations and individuals act.[65]

In the context of rapid, accelerating, and converging scientific and technological developments, the key to higher military performance is not technology; it is the relationship between institutional rules and organizations—and the opportunities and challenges they establish for people to learn about the outcomes of their actions; to invent and innovate; to organize production more efficiently; to recruit, select, and promote personnel on the basis of merit; to design, test, and correct operational concepts; and to align means to ends effectively.[66]

Institutions guide the way military organizations evolve, and more broadly determine the kinds of organizations that will arise in society as context for that evolution. For example, the laws and rules that reward productive economic activity created the conditions in the West whereby organizations such as partnerships and firms could emerge and succeed.[67] Such organizations are intimately concerned in the process of military technology development and acquisition. In the words of North, John Wallis, and Barry Weingast, such "organizations distinguish the Western European competition from military competition in the rest of the world."[68] Looking at the U.S. vulnerability to cyber-attacks makes the point. Industry spokesmen have argued that the United States is vulnerable to cyber-attacks not simply because of its dependence on computer systems, but because U.S. institutions—that is, the private-public division of responsibility for the provision of public goods (e.g., electricity) and legal restraints on computer network monitoring—contribute to vulnerability.[69] Countries with closer ties between government and commercial sectors—e.g., the United Kingdom, Germany, Sweden, the Netherlands, and Singapore—have coordinated faster government–business responses to cyber-attacks.[70]

These are not new phenomena. Economic historian Avner Greif found systematic differences in North African Islamic and Venetian trading societies traceable to contrasting beliefs about the role of the individual and institutions in society.[71] Like China, the Islamic world was an early candidate for sustained economic growth. Its people possessed technological, architectural, literary, and scientific skills. At its peak, the Arab Empire exceeded the size of the Roman Empire, remaining a military threat to the West as late as the 17th century. Yet, with only a few exceptions, formal and informal institutions comprising the belief structure of the Islamic world mitigated intellectual evolution.[72] As historian William McNeill writes, "by a curious and fateful coincidence, Moslem thought froze into a fixed mold just at the time when intellectual curiosity was awakening in Western Europe—the twelfth and thirteenth centuries."[73]

In Western thought, we find a convergence of arguments from economics, political science, and philosophy of science regarding the impact on behaviors of individuals and organizations of epistemological assumptions embedded in institutions.[74] The common threads are the long-term effect of institutional rules on individual and social behavior, and on human learning—what is learned and shared.[75] For example, operations research analyst Russell L. Ackoff, and philosopher of science Sir Karl R. Popper separately argue that unconscious assumptions about the growth of knowledge affect conceptions of politics—and designs of governmental organizations and programs.[76]

Describing the role of institutions over time in structuring decisions and decision-making has three implications for understanding the design process for Navy Department technology—and for a naval history research program that captures, documents, and contributes to internal feedback.

First, a set of institutions can generate parallel groupings of organizations and that feature different sets of behaviors, leading to vastly different results. For example, during the interwar period, the Army and Navy operated under identical formal institutional rules—the checks and balances and separation of powers embodied in the U.S. Constitution. Yet, the naval aviation community—but not the naval munitions/torpedo community—was able to exploit these formal institutional rules by creating an interactive relationship among the General Board, the Fleet, the Naval War College, and the Bureau of Aeronautics.[77] The primary effect of this multi-organizational arrangement was that the naval aviation community identified and reduced uncertainties in developing technology and operational concepts for the employment of aircraft carriers. Some early technological-operational options favored by high-level persons were rejected and not locked in, e.g., Rear Admiral William A. Moffett's preference for the use of airships.

In contrast, the Army—not developing aviation and armor with an analogous set of organizations and patterns of interaction—was unable to identify and exploit the potential operational advantages of mechanized warfare and tanks.[78] In noting the failure of *Journal of the U.S. Cavalry Association* editors to pay attention to mechanization, Edward Katzenbach observed, "one cannot help but be impressed with the intellectual isolation" of the U.S. Army in the 1930s.[79]

Second, institutions and organizations can enhance prospects for success or hinder the invention, development, and successful employment of military technologies. Military organizations and patterns of interaction that can identify and exploit potentially revolutionary technologies and operational concepts are rare in the global population of military organizations that deal with acquisition and operations.

Third, the institutions and organizations in play when a potential military innovation appears and is refined for combat exert a powerful influence over the types of knowledge required for its exploitation, the types of knowledge generated from its exploitation, and the subsequent evolutionary path followed by the technology and associated operational concepts.

Technology-Human-Organization Systems: High-Reliability Organization

High-reliability organizations are an example of a topic that I believe has not received attention in military history. Sociologist Charles Perrow's *Normal Accidents* was published in 1984. The book examined major systems failures and system damage that resulted from cascading "normal accidents"—small and random errors in organizations and processes designed to operate interdependently. Organizational processes that operate in a fixed and pre-determined sequence offer few opportunities to recover once an unexpected or unplanned sequence is initiated—errors cascade in time-dependent, interdependent, differentiated (low redundancy) systems and failures emerge elsewhere.[80] Such failures can be costly and deadly. In a study published in 1987, Paul Shrivastava surveyed 20th century industrial accidents involving the deaths of at least 50 people; half of these 28 accidents occurred in the years between 1977 and 1986, which suggests that the number of organizations operating hazardous and dangerous technologies has increased.[81]

To understand how some organizations have performed effectively while safely operating tightly-coupled and interactively complex technologies[82] that present serious risks to operators and the public (or the potential for what Perrow called "normal accidents"), Todd LaPorte, Gene Rochlin, and Karlene Roberts conducted case studies of operations on aircraft carriers *Enterprise* (CVN-65), *Carl Vinson* (CVN-70), and *Theodore Roosevelt* (CVN-71),[83] the Federal Aviation Administration's Air Traffic Control System, and nuclear power operations (Pacific Gas and Electric's Diablo Canyon reactor).[84] Karl Weick, Paul Schulman, and others joined the research team, and additional organizations were studied, including the fire incident command system, and pediatric intensive care units.[85]

These studies emphasized that (1) reliable organizations feature redundant communications pathways, search processes, and means to review and oversee performance;[86] (2) they operate in political and social environments intolerant of error; (3) the technologies individually and collectively are subject to potentially catastrophic error; and (4) the scale of possible consequences—such as nuclear war—precludes incremental learning through trial-and-error experimentation.[87]

A review of "high reliability organizations" case studies identified properties that contribute to extraordinary performance in the use of complex technologies in difficult task environments,[88] including: (1) demanding technical and interpersonal selection criteria for positions;[89] (2) continual training and continuous improvement efforts; (3) the attitude of "mindfulness" of the importance and necessity of identifying potential errors before they occur; (4) development of latent networks of expertise that are activated at identification of an unanticipated event;[90] and (5) alignment in organization structure of expertise and authority. Rear Admiral Dave Oliver describes the operation of these properties in his description of Admiral Hyman G. Rickover's creation of the U.S. nuclear Navy.[91]

Some ongoing research on high reliability organizations, their properties, and mindful organizing focuses on how organizations become reliable and how mindful organizing emerges in organizations.[92] This research places human error in a context similar to that described by statistician Ward Edwards Deming, when he argued that management should distinguish system error from individual error in industrial processes, because the vast majority of errors are a function of system-level structures, processes, and procedures.[93] Other studies of high-reliability organizations compare learning and innovation in the U.S. Navy *Los Angeles* (SSN-688)-class nuclear attack submarine program to Russian/Soviet navy nuclear attack submarine programs.[94]

Distributed Human-Machine Teams

Research on the organization of distributed configurations of human-machine teams conducting different tasks is related to studies of high reliability organizations—and to Marine Corps experimentation on distributed operations. Yanni Alexander Loukissas and David A. Mindell, in a study of data visualization to examine technologically mediated human roles and relationships, note that "the study of distributed computer-human relationships requires new methods that are capable of picking up on multi-channel interactions."[95] They developed methods to combine "individual, social, quantitative, and qualitative data in rich, graphical, real-time representations."[96]

We should anticipate that new forms of automation would change the arrangement and coordination of activities in organizations, and historians should be alert to such changes. Loukissas and Mindell argue research on new organizational configurations of human-machine teams addresses issues beyond those considered in conventional human factors studies that "emphasize workload, interface, and situational awareness,"[97] and include examination of the "social organization of human-machine teams and the cultural production of operator roles" that affect acceptance of new technologies.[98]

Bureaucratic Conflict: Expert Authority vs. Political Authority

Sociologist Max Weber examined conflict in bureaucracies between elected officials and technical experts, especially when officials issue decrees "ignored" by bureaucrats charged to implement them. In Weber's words, "the political 'master' always finds himself, vis-à-vis the trained official, in the position of the dilettante facing the expert."[99] Admiral Hyman G. Rickover addressed this issue frequently in his interactions with his fellow officers, and in his 1974 speech, "The Role of Engineering in the Navy," to the National Society of Former Special Agents of the Federal Bureau of Investigation.[100] Admiral Rickover's argument involved three issues. First, the Navy's reliance on technologies of all kinds was increasing. Second, to take advantage of technology, the Navy must raise standards of knowledge and performance for all personnel. Third, the Navy was allowing receding standards of technical competence. In doing so, the Navy increased its dependence on industry, and relied on reorganizations and management fads to compensate for lower standards of technical competence.

Admiral Rickover explains shortfalls in Navy leadership by arguing that Navy's leaders have, at potential historical turning points, "misread history." They have misunderstood the necessity of applying empirical premises to all manner of problems that derive from the Navy's purpose—to defend our nation. Rickover develops his observation about the necessity of applying an empirical attitude and demonstrable knowledge to many problems by presenting a conceptual history of Navy Department decision-making. He begins with the period following the Civil War when Navy leaders retained "faith in [*Monitor*-type vessels] as major combatant ships long after other nations had recognized that they were only a brilliant improvisation addressing a specific problem. The main line of naval progress remained in Europe. We had misread the naval results of the Civil War." During the 1880s, when the Navy was rebuilding, "the worst errors were caused by the imposition of the opinions of line officers on technical matters."

"The rising tide of technological complexity has engulfed the design engineer ashore as well as the line officer engineer at sea. In both areas, these men now face demands far beyond those which confronted their predecessors." In Rickover's view, young officers must be able to understand the technical details of their equipment; they cannot do this without learning the basics of engineering and science.

Of course, once one learns the basics, one must devote the time and effort to remain current. When Nobel laureate Richard P. Feynman was a member of the *Challenger* shuttle investigation, he noted that managers, who earlier in their careers had been engineers, estimated the likelihood of a shuttle failure at 1 in 100,000, and working engineers estimated likelihood of failure at 1 in 100.[101] The three-order magnitude difference in estimates made by working engineers and managers reflects the type of issue Admiral Rickover highlighted in his history of conflict—between line and engineering and engineering duty officers—over what premises should guide decisions about development and use of technology in the Navy.[102]

A crucial problem faced by Navy and Marine Corps commanding officers is that knowledge requirements for command have grown. All services face this problem. General Raymond T. Odierno explained the issue to me when I interviewed him in Baghdad in 2009. The increasing complexity of wartime decision-making involves overseeing and managing staff structures and processes to propose lines of operation and calculate and compare impacts, interactions, and tradeoffs of many policies and programs. The complexity of aligning the commander's staff structures, processes, procedures, and lines of operation with the task environment requires developing approaches to operational assessments and analyses that help commanders understand their mission(s); organizational structures, processes, and people; the operational environment; the ways and means to achieve desired ends; and the feasibility and wisdom of mission goals.[103] And commanders still have to defeat the enemy.

Rickover's political battles with much of the Navy and its military leadership are one instance of the conflict between authority of knowledge and of rank. As military organizations increasingly employ technologies, organization, and tactics that must be operated "under the rule of expert knowledge," it is inevitable that disagreements and conflicts will erupt between technical and non-technical officials. Practical implications of this conflict are revealed in the operation of the military personnel system, selection and promotion criteria, and the search for and accumulation of evidence by human capital professionals to justify criteria and premises for decisions.

What Should Be Written?

Some historians of technology argue that historiography of military technology should consider factors beyond those examined in traditional studies of weapons, battle tactics, and strategy.[104] Renowned historian Barton Hacker argues "understanding technological change requires paying attention to interactions between technology and social institutions, because social change impacts technology no less than technological change impacts society."[105] He cites Walter Millis's *Arms and Men* as an exemplar of historical analysis that integrates military policy, institutional history of the armed forces, and consequences of social and technological change. Millis, writing in 1956, notes that there is little literature that considers the "economic, social and political factors which affect all issues of military preparedness and war." In reviewing the field, Millis cites Harold and Margaret Sprout's 1939 *The Rise of American Naval Power* as the first study examining impact of institutions—"continuous factors within the fabric of our society"—on the development and employment of naval military power.[106]

Future studies of naval and Marine Corps military technology should engage the concepts of path dependence, institutions, and organizations developed by economic historians, consider interactions of science and technology explicitly (under different conditions of synthesized, catalogued, and accessible knowledge); examine development, diffusion, and experimentation of technologies in military high-reliability organizations and distributed human-machine teams; and social, economic, and political factors cited by Walter Millis. Katherine Epstein's *Torpedo*, published in 2014, is a recent example of a military history that examines development of a set of technologies with interpretation of events informed by six academic sub-fields of history: military, diplomacy, science and technology, business, legal, and policy.[107]

To conclude, I would like to consider three topics relevant to the question of what should be studied: the DOD's Third Offset Strategy, the development of acquisition processes appropriate to the Third Offset, and the organization of interdisciplinary and team-oriented historical research.

The Third Offset as a Topic in Naval History of Technology

In 2014, then–Secretary of Defense Chuck Hagel proposed the "Third Offset Strategy," a set of efforts to maintain American military superiority over current and potential foes by developing new operational concepts and technologies. Secretary Hagel saw the strategy as following two previous initiatives. During the 1950s, President Dwight D. Eisenhower proposed the First Offset, a program to build U.S. nuclear forces to deter and counter the USSR's conventional forces' numerical superiority. In the mid- to late-1970s, Secretary of Defense Harold Brown guided the Second Offset: stealth, precision-guided munitions, and intelligence, surveillance, and reconnaissance systems to counter the USSR and Warsaw Pact's improving military capabilities and numerical superiority of forces in central Europe. The proposed FY 2017 defense budget contains about $3.6 billion in Third Offset research and development funding to demonstrate various capabilities.

The technologies proposed for the Third Offset are exciting and ambitious, and have captured the attention of most observers. I've randomly surveyed more than 20 articles and essays about the strategy.[108] Of these articles, almost all assume the technical goals are achievable and that higher technical performance is equivalent to higher operational capability; one article raises the possibility of glitches in the human-machine collaboration initiative.[109]

Regardless of whether Third Offset human-machine collaboration capabilities involve learning machines that will "operate at the speed of light,"[110] as Deputy Secretary of Defense Bob Work put it, individuals' information processing and computational abilities are limited and may not match the size and complexity of their tasks in combat. The following summarizes relatively recent research:[111]

1. People have difficulty making decisions in unique and complex situations involving risk;
2. People have difficulty diagnosing the decision problem they face;
3. People perceive causality where none exists;
4. People have even more difficulty generating an adequate set of alternative actions from which to choose;
5. People's preferences may be inconsistent, and small changes in the way the problem is posed may produce complete reversals of

preferences;
6. Complex cognitive tasks involving conscious and focused thinking entail steps performed serially;
7. Little is known about decision-making under the stress of emergency conditions;
8. Little is known about judgment and decision-making under time stress;
9. Decreasing time available for making a decision leads people to reduce the number of factors they consider;
10. Understanding group-level decision-making is not a simple matter of scaling up from individual-level decision-making—group size and interactions among personnel introduce new properties; and
11. People may plan to use certain kinds of information in some future situations (e.g., directing forces in combat), but will actually ignore that information when it is received—that is, information seen as relevant during planning becomes less salient in the heat of battle, when there are new and unexpected cues, actions, or information.

Appreciating the complexity of combat tasks is fundamental to a proper assessment of any organizational design for highly automated, rapid-response battle (and of selection criteria for high office and training to accomplish very complex and ill-structured tasks). Real-time interactions between human operators and complex computerized systems have an inherently higher probability of error in any unanticipated and unrehearsed crisis situation.[112]

Knowledge of how people integrate information and make decisions in rapidly changing situations is necessary for historians and analysts. Otherwise, they cannot understand and report on how human-machine collaboration capabilities perform and align with organizational tasks, roles, command relationships, and communications channels, or minimize errors in operations.

Historians would make a great contribution to knowledge about human decision-making in military organizations if they carefully described the Third Offset acquisition programs to design, experiment with, and test human-machine collaboration and automation. To automate a task, programmers must be able to state explicit rules and their sequence to accomplish it. Yet, for many tasks throughout a combat organization, such as those involving interpersonal interaction, or adaptability, or flexibility, and problem solving, the tasks are not amenable to mathematical treatment, and may never be so.[113]

Navy leaders have known for a very long time about what chemist and philosopher Michael Polanyi called "tacit knowledge," or knowledge that is difficult to transfer via written or spoken instructions. For example, no one in the Navy, or outside it, can specify the sequence of every task that must be performed to get an aircraft off the carrier flight desk. A portion of the knowledge in the minds of Navy personnel enabling aircraft to launch and land is tacit. Similarly, retired Vice Admiral Lloyd M. Mustin reflected that use of weapons systems technologies involves more than application of theoretical physical principles:

> Unfortunately, the basic knowledge of radar is really very simple, and what becomes critical in keeping this radar going at close to designed efficiency at sea has nothing to do with basic knowledge. It has to do with a whole host of minutiae, detailed technical specifics, and these are what the technician has to learn about. It takes time, and until he has learned them, it's a much slower job for him to troubleshoot and to tune up and so forth. This has nothing to do at all with the basic theory of the thing, what you need in order for it to work. The problem lies in the detailed specifics of how do you go about achieving what you really need.[114]

Knowledge of how people integrate information and make decisions in rapidly changing situations is necessary for historians and analysts. Otherwise, they cannot understand and report on how human-machine collaboration capabilities perform and align with organizational tasks, roles, command relationships, and communications channels; or how to minimize errors in operations.

Acquisition Policies Appropriate to the Third Offset

The acquisition process and procedures used and created for the Third Offset Strategy also should be studied. This topic is rich in possible themes involving the social context of military technology. For example, a core element of the acquisition process problem is how to employ, exploit, and coordinate the information, knowledge, and products created by public and private sources of discovery, innovation, and analysis. Information and knowledge about military capabilities are limited and imperfect. To deal with this situation, a process is needed through which knowledge is communicated, acquired, and applied. The solution to the problem of organizing the acquisition processes is to harness and guide the interactions of people and companies—each of which possess, more or less, only partial knowledge about the task at hand.[115]

Commissions and blue ribbon study teams that developed recommendations to overhaul and modify the acquisition process conceived and justified their work as an effort to make the acquisition process rational—a process in which goals are set, ways and means are identified to achieve the goal, the courses of action compared, and the best solution chosen.[116] The recommendations to improve acquisition developed in the "Weapons Systems Acquisition Reform Act of 2009" recapitulate the assumptions and logic used by previous commissions about the design of a rational process.

Yet, post–World War II American planning and management processes have not operated as their designers assumed and expected; many programs have suffered budget overruns, schedule delays, and performance shortfalls. In 2008, then-Secretary of Defense Robert Gates observed,

> When it comes to procurement, for the better part of five decades, the trend has gone towards lower numbers as technology gains made each system more capable. In recent years these platforms have grown ever

> more baroque, ever more costly, are taking longer to build, and are being fielded in ever dwindling quantities.[117]

Budget overruns, schedule delays, and performance shortfalls occur because acquisition programs have been designed under the incorrect—but widely held—assumption that the future growth of scientific knowledge and technical know-how can be planned and scheduled. The assumption ensures that during the decades-long periods to develop new major classes of ships, aircraft, and ground vehicles, the platforms would be eclipsed by the tempo of technological development of command, control, communication, computer, and intelligence capabilities. By the time the platforms have been delivered, the technological capabilities originally associated with them have become obsolete. The logical impossibility of predicting the growth of scientific knowledge makes it equally impossible to accurately estimate program costs and to predict the schedule and tempo of work to create new capabilities.[118]

Describing and explaining the social context of the acquisition process provides senior leaders with the type of information they need to change the "demand signal" about the performance of the acquisition system,[119] and to request alternative sources of data or to experiment on organizational processes and procedures.[120]

The Ghost of Vannevar Bush in a "Traffic Jam"

Vannevar Bush, Robert Merton, Ted Gold, and many others cited above may have been correct that theoretical research guides and supports practical technological applications, and a growing body of knowledge necessarily underpins commercial and military technological innovation. One element of a predictable naval and Marine Corps technology traffic jam is continuing conflict over the justification for basic research in apportionment of R&D monies—until evidence is developed for some aspects of the science-technology relationship under specified situations, such as using high technology–readiness level components. Some arguments supporting the pivotal role of basic research in technology development primarily rely on assertions made by officials managing science and technology programs.[121]

In 2003, members of the congressional armed services committees and the authorization conference committee expressed concern about stagnant investment in basic research for DOD. The *FY04 National Defense Authorization Act* mandated an NAS assessment of the basic research portfolio of the Office of the Secretary of Defense, the three military departments, and the Defense Advanced Research Projects Agency to determine whether the portfolio includes adequate fundamental research. The conference committee report declared that DOD's "investment in basic research provides the foundation upon which our modern military is built. It is critical the basic research investment remain strong, stable, and focused on the fundamental search for new knowledge."[122] In 2005, *Assessment of Department of Defense Basic Research* was published.[123] Among the findings relevant to this essay were:

- Ongoing discovery from basic research is often required through the applied research, system development, and system operation phases.

- A DOD trend in basic research emphasis is less effort in unfettered exploration, which historically has been a critical enabler of the most important breakthroughs in military capabilities.
- DOD basic research has been focused more narrowly in support of specified needs.

The Missile Defense Agency's shrinking R&D account is an example of an outcome whereby procurement and sustainment take "precedence over internal research and development because of contractual obligations and immediate needs."[124]

Evidence from other domains regarding the science and technology interaction is anecdotal and may be subject to selection bias of choosing examples for review that support a thesis. For example, in 2012, the "Golden Goose Award" was established to

> recognize the tremendous human and economic benefits of federally funded research by highlighting examples of seemingly obscure studies that have led to major breakthroughs in biomedical research, medical treatments, and computing and communications technologies. [Since 2012 G]roups of researchers have been recognized each year for breakthroughs in the development of life-saving medicines and treatments; game-changing social and behavioral insights; and major technological advances related to national security, energy, the environment, communications, and public health.[125]

Evidence from academic studies of innovation over the last decade support the precedence of basic research for invention.[126]

Previous studies of the interaction between basic science and technology development, such as the 1967 Project Hindsight and the 1968 NSF-sponsored TRACES, do not provide reasonable guidance to policy-makers or historians; these studies have been characterized as "cooked up"—that is, studies designed to prove a previously determined answer.[127] One crucial contribution the historical community can make to current and future top-level policy is to develop evidence appropriate to informing policy discussions and debates. Such evidence would entail a program to investigate, describe, document, and assess the theory-technology relationship in current and planned research on modern weapons systems. Methodologies to assess and trace science-technology interactions have improved since *Project Hindsight* was written,[128] and further methodological improvements are feasible by melding historical research and qualitative research methods into a study's methodology.

Organization of Interdisciplinary and Team-Oriented Historical Research

The Third Offset Strategy's impact on Naval History and Heritage Command involves challenges and opportunities. The opportunities entail a program of analysis in the history program to contribute to the Fleet and combatant commanders in ways no other history program has. Ultimately, this line of historical analysis may result in a transformation of government history programs. A model for this type of organizational transformation might be the RAND Corporation in the late 1940s and early 1950s when small groups of interdisciplinary thinkers influenced the development of ideas, policies, and world views of the U.S. national security community. Andy Marshall, the former director of Net Assessment, was a co-author of a 2015 essay describing the early years of RAND and the “flaring of intellectual outliers.”[129] At RAND, three processes may have produced its early intellectual influence:

1. Independent, simultaneous generation of ideas through the imagination of individual scientists or historians or analysts;
2. Discoveries facilitated through processes that enable discussion and interaction; and
3. A group culture that expects and demands imagination, interaction, and consciousness of the group members’ distinctiveness.[130]

Barriers to Research

The opportunities are enticing to participate in a group intellectual effort. There are many obstacles and challenges to establishing such a group. Conducting research on ongoing technology projects requires knowledge and familiarity with technologies; organizational and sociological literature regarding the structure and performance of tasks, coordination, supervision, and feedback; and traditional historical research methods focusing on documents and tracing the development of ideas and actions over time. This research task imposes fundamental challenges to the researcher. First, the researcher must become well integrated into the organizations developing, deploying, or employing technologies. Even when the researcher has relevant knowledge of the technologies and technical issues and has been socialized and accepted in the organizations, the researcher is not a participant—in an operational sense—in the activity being studied.

The challenges are similar to those encountered by researchers seeking to conduct ethnographic and grounded sociological inquiry—e.g., familiarity with the culture of a particular organization may mask identification of important factors.[131]

My own limited experience in the Gulf War Air Power Survey and at the U.S. Joint Forces Command has reinforced the idea that analyzing a recent military campaign places a heavy diplomatic burden on the author. There are no easy ways to heft this burden. The differences between operator and policy-analysis subcultures generates strained relations between the two groups. Military officers are responsible for operations; policy analysts look at these operations as a source of data or means to an end—i.e., understanding how particular outcomes occurred. If not put tactfully, the policy analyst’s probing and questioning—which are necessary components of his task—can easily be construed by the operator as criticism of his decisions or performance. Documenting mistakes—even minor errors—for hindsight analysis contains the implicit criticism that, if the policy analyst were in charge instead of the generals, these mistakes could have been avoided.

Historians and analysts, by reviewing the minutia of operations, can cause information regarding activities at theater headquarters or other places to be known to national command authorities and others. This information can be troublesome on various matters, including disagreements about budget priorities before Congress, disputes over roles and missions, and so on. Thus, it is almost inevitable that on issues such as how reputations are made and how resources are divided up in Washington, D.C., even non-partisan and objective analysis can receive a political reception.[132] In a poignant story, Bart Hacker described how Department of Energy (DoE) leaders imposed bureaucratic delays on the publication of *Elements of Controversy* due to agency leaders' anxiety that Hacker had not read and incorporated comments from reviewers they trusted. DoE leaders could not refute Hacker's book with evidence; they imposed delays until Hacker arranged to have the book published by the University of California Press.[133]

Conclusion

The Department of the Navy deals with growing practical challenges in management and leadership. Successful and sustainable performance in setting conditions to defeat the many threats and challenges facing the United States depend on conceptual clarity and quality of evidence underlying policies to organize, train, and equip military forces.

Although historians of technology have participated in interdisciplinary research,[134] any recommendation to historians to consider social science literature to complement and inform historical research and analysis must acknowledge only small successes alongside general failure to achieve research-based prescriptions for organizational design and practice. The store of social science knowledge grows slowly.[135] To the extent that social science can inform historical research, it is in promoting thoughtful questions and clear specification of concepts for organizational analysis.[136]

Tasks of government military historians are not limited to collecting and organizing documents, and conducting oral history interviews. Historians embedded in operational units and at various headquarters echelons have the opportunity to observe and to collect participants' observations. The latter task requires historians to apply empirical social science research methodologies to collect and organize observations. The larger implications to the Navy of an expansion of military historians' professional skills involve building knowledge about the operation of human-technology-organizational systems to enable higher operational effectiveness of the Fleet.

Notes

[1] Barton C. Hacker, "Review of *Science, Technology, and the Military*. Edited by Everett Mendelsohn, Merritt Roe Smith, and Peter Weingart," *Technology and Culture*, Vol. 32, No. 3, July 1991, 645–46.
[2] David A. Hounshell and John Kenly Smith Jr., *Science and Corporate Strategy: DuPont R&D, 1902–1980* (New York: Cambridge University Press, 1988). See also Alfred D. Chandler Jr., *The Visible Hand: The Managerial Revolution in American Business* (Cambridge, MA: Harvard University Press, 1977); Leonard S. Reich, *Making of American Industrial Research: Science and Business at GE and Bell* (New York: Cambridge University Press, 1986).

[3] Margaret C. Jacob, *The First Knowledge Economy: Human Capital and the European Economy, 1750–1850* (Cambridge: Cambridge University Press, 2014). Jacob examined detailed data to support her argument. Milton Kerker (and others) arrived at the same conclusion on the basis of less detailed evidence. See Kerker, "Science and the Steam Engine," *Technology and Culture*, Vol. 2, No. 4, Autumn 1961.
[4] Barton C. Hacker, "Military Institutions, Weapons, and Social Change: Toward a New History of Military Technology," *Technology and Culture*, Vol. 35, No. 4, October 1994, 824–25; Barton C. Hacker, "Military Technology and World History: A Reconnaissance," *The History Teacher*, Vol. 30, No. 4, August 1997, 461–62.
[5] Alex Roland, "Science, Technology, and War," *Technology and Culture*, Vol. 36, No. 2, April 1995, 97.
[6] Cited in Steven Grundman, "Opinion: Fictional Work Gives View Of Future Wars," *Aviation Week & Space Technology*, 12 November 2015, http://aviationweek.com/defense/opinion-fictional-work-gives-view-future-wars?NL=AW-19&Issue=AW-19_20151112_AW-19_82&sfvc4enews=42&cl=article_5&utm_rid=CPEN1000000920854&utm_campaign=4257&utm_medium=email&elq2=d6785588eaff46d9a40c3e86f66f4ef8.
[7] Barton C. Hacker, "Military Institutions, Weapons, and Social Change," 773–74.
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[9] Rosalind Williams, a recipient of the Society for History of Technology da Vinci medal, asked whether if it makes sense to bracket technology as a special topic in history because technology is pervasive in people's activities. Rosalind Williams, "Our Technological Age, from the Inside Out," *Technology and Culture*, Vol. 55, No. 2, April 2014.
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[11] Sociologist Arthur L. Stinchcombe argued that for the existence of a "correlation between the time in history that a particular type of organization was invented and the social structure of organizations of that type which exist at the present time." "Social Structure and Organizations," in James G. March, ed., *Handbook of Organizations* (Chicago: Rand McNally & Co., 1965), 143.
[12] For example, Hone, Friedman, and Mandeles apply an organizational perspective to interpret the diffusion of technology from the United Kingdom to the United States. Thomas C. Hone, Norman Friedman, and Mark D. Mandeles, *Innovation in Carrier Aviation* (Newport, RI: Naval War College Press, 2011); Thomas C. Hone, Norman Friedman, and Mark D. Mandeles, "The Development of the Angled-Deck Aircraft Carrier," *Naval War College Review* Vol. 64, Spring 2011, 63–78. For another example of insight generated by attention to organizational processes, see Donald MacKenzie and Graham Spinardi, "Tacit Knowledge, Weapons Design, and the Uninvention of Nuclear Weapons," *American Journal of Sociology*, Vol. 101, No. 1, July 1995.
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[15] Vannevar Bush, *Science, the Endless Frontier. A Report to the President* (Washington, DC: U.S. Government Printing Office, 1945); Vannevar Bush, *Endless Horizons* (Washington, DC: Public Affairs Press, 1946); Vannevar Bush, *Modern Arms and Free Men: A Discussion of the Role of Science in Preserving Democracy* (New York: Simon and Schuster, 1949). See also the discussion of actions of the scientists in the politics of funding of science in the United States in Don K. Price, *The Scientific Estate* (New York: Oxford University Press, 1965).

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[118] Karl R. Popper, *The Poverty of Historicism* (New York: Harper Torch Books, 1964). Popper develops a logical proof that shows "*no scientific predictor*—whether a human scientist or a calculating machine—*can possibly predict, by scientific methods, its own future results*" [emphasis in the original], vii.
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