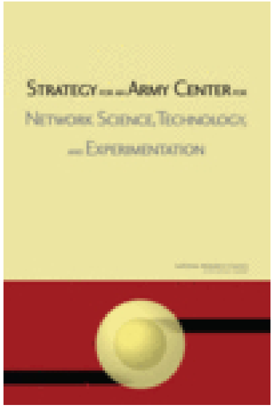

Strategy for an Army Center for Network Science, Technology, and Experimentation

Committee on Strategies for Network Science, Technology, and Experimentation, National Research Council

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STRATEGY FOR AN ARMY CENTER FOR NETWORK SCIENCE, TECHNOLOGY, AND EXPERIMENTATION

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Network Science, Technology, and Experimentation

Board on Army Science and Technology

Division on Engineering and Physical Sciences

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Preface

The 2005 NRC report *Network Science* developed a working definition for network science as "the study of network representations of physical, biological, and social phenomena leading to predictive models of these phenomena" (NRC, 2005, p. 2). In this light, network science can be seen as a cornerstone for future military operations and the conduct of network-centric warfare.

The present report, *Strategy for an Army Center for Network Science, Technology, and Experimentation*, builds on the *Network Science* report by evaluating a possible framework for the Army to conduct research, development, test, and evaluation (RDTE) in areas of network science important to the future. The study was conducted in an environment in which changes were well underway to relocate and alter significantly the network science, technology, and experimentation (NSTE) resources of the Army and in which there exist diverse views on effective ways to organize and conduct science and technology (S&T) within a military construct. The overall challenge for the Army is to organize its S&T resources so as to advance NSTE on a broad front while maintaining those relationships and activities that have proven productive.

The statement of task for the study was as follows:

> The Assistant Secretary of the Army (Acquisition, Logistics, and Technology) (ASAALT) has requested the NRC BAST to conduct a study to define advanced operating models and architectures for future Army laboratories and centers. The NRC will examine several representative centers, and address the following issues:
>
> 1. Consult with the ASAALT Base Realignment and Closure (BRAC) Technical Assessment Board to obtain data on organizational goals, functions that support

the goals, activities that support the functions, and the disciplines required to support the activities and the critical mass required for each discipline for the network science, technologies, and experimentation center (NSTEC).

2. Examine the various business models, managerial architectures and manpower needs both current and future for NSTEC, to include the assessment and potential utility of best practices in successful multi-disciplinary research consortiums.

3. Identify deficiencies in the Army infrastructure for conducting state-of-the-art S&T for network-centric warfare (NCW), and recommend how these should be improved.

4. Consider the establishment of a world-class user facility with state-of-the-art equipment within the NSTEC to engage the broad community (both civilian and military) doing R&D in networks, both human-engineered and biologically evolved, and situational awareness technologies and systems to further the Transformational goals of NCW. Include the delineation of the core competencies and a detailed manpower analysis (relevant disciplines, critical mass in each area, etc.) for such an organization.

5. Recommend relocations within existing legal authority to better manage the various assets and resources and to create an improved synergy among them to achieve the goals of NCW.

6. Explore existing legal authorities, which will enable the Army to best exploit partnerships, alternative funding and sharing of resources with industry through various relationships.

I would like to thank the committee for its hard work in interviewing numerous experts, assessing the pertinent issues, and developing recommendations to address these concerns. The committee in turn is grateful to the many Army personnel engaged in NSTE for the useful information they provided. We also greatly appreciate the support and assistance of the National Research Council staff, which ably assisted the committee in its fact-finding activities and in the production of this report.

Lastly, this study was conducted under the auspices of the NRC Board on Army Science and Technology (BAST). The BAST was established in 1982 as a unit of the National Research Council at the request of the United States Army and brings broad military, industrial, and academic scientific, engineering, and management expertise to bear on technical challenges of importance to senior Army leaders. The Board is not a study committee; rather, it discusses potential study topics, develops and frames study tasks, ensures project planning, suggests potential experts to serve as committee members or reviewers, and convenes meetings to examine strategic issues for the sponsor, the Assistant Secretary of the Army (Acquisition, Logistics, and Technology).

Although the Board members are listed on page vi of this report, they were not, with the exception of any Board members nominated and appointed to serve as formal members of the study committee, asked to endorse the committee's conclusions or recommendations, nor did they review final drafts of the report before its release.

Larry Lynn, *Chair*
Committee on Strategies for Network Science,
Technology, and Experimentation

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Frank Doyle, University of California, Santa Barbara,
Charles B. Duke, Xerox Innovation Group (retired),
Paul J. Kern, The Cohen Group,
Larry G. Lehowicz, Quantum Research International,
Richard M. Murray, California Institute of Technology,
Steven L. Schooner, George Washington University Law School,
George T. Singley, Science Applications International Corporation, and
Steven G. Wax, SRI International.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Gerald E. Galloway, Jr., University of Maryland, College Park. Appointed by the National Research Council, he was

responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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Acronyms and Abbreviations

AMSAA	Army Materiel Systems Analysis Activity
APG	Aberdeen Proving Ground
API	application program interface
ARCIC	Army Capabilities Integration Center
ARI	Army Research Institute for the Behavioral and Social Sciences
ARL	Army Research Laboratory
ARO	Army Research Office
ASA (ALT)	Assistant Secretary of the Army (Acquisition, Logistics and Technology)
BAST	Board on Army Science and Technology
BRAC	base realignment and closure
C2	command and control
C2D	Command and Control Directorate
C3	command, control, and communications
C3OTM	command, control, and communications on-the-move
C4ISR	command, control, communications, computers, intelligence, surveillance, and reconnaissance
CERDEC	Communications-Electronics Research, Development, and Engineering Center
CIO	Chief Information Officer
CISD	Computational and Information Sciences Directorate
COIN	counterinsurgency
COTS	commercial off-the-shelf

CRADA	cooperative research and development agreement
CTA	collaborative technology alliance
CTSF	central technical support facility
DARPA	Defense Advanced Research Projects Agency
DHS	Department of Homeland Security
DISN	Defense Information Systems Network
DOD	Department of Defense
ERDC	Engineer Research and Development Center
FAR	federal acquisition regulation
FCS	Future Combat Systems
FFRDC	federally funded research and development center
FGC	federal government corporation
GIG	Global Information Grid
GIG-BE	global information grid-bandwidth expansion
GOCO	government-owned, contractor operated
GWOT	global war on terrorism
HLD	high-level design
HRED	Human Research and Engineering Directorate
I2WD	Intelligence and Information Warfare Directorate
INFOSEC	information security
INSCOM	U.S. Army Intelligence and Security Command
IP	Internet Protocol
IPA	Intergovernmental Personnel Act
ISR	intelligence, surveillance, and reconnaissance
IT	information technology
ITA	international technology alliance
LAN	local area network
LCMC	life cycle management center
M&S	modeling and simulation
MANET	mobile ad hoc networks
MLS	multi-level security
NACA	National Advisory Commission on Aeronautics
NASA	National Aeronautics and Space Administration
NCO	network-centric operations

NCW	network-centric warfare
NDIA	National Defense Industrial Association
NISITA	International Technology Alliance in Network and Information Sciences
NRC	National Research Council
NRL	Naval Research Laboratory
NSA	National Security Agency
NSC	Natick Soldier Center
NSIF	network science integration facility
NSPS	national security personnel system
NSTE	network science, technology, and experimentation
NSTEC	network science, technology, and experimentation center
NVESD	Night Vision and Electronic Sensors Directorate
OMB	Office of Management and Budget
OSI	open system interconnection
PEO	program executive officer
PM	program manager
QoS	quality of service
R&D	research and development
RDEC	research, development, and engineering center
RDECOM	U.S. Army Research, Development, and Engineering Command
RDT&E	research, development, test, and evaluation
S&T	science and technology
S&TCD	Space and Terrestrial Communications Directorate
SCI	sensitive compartmented information
SCIF	sensitive compartmented information facility
SEDD	Sensors and Electron Devices Directorate
TRAC	TRADOC Analysis Center
TRADOC	Training and Doctrine Command
UARC	university-affiliated research center
UAV	unmanned aerial vehicle
UGS	unattended ground sensor
USAF	U.S. Air Force
USN	U.S. Navy

Summary

The U.S. military and its allies have committed to a strategy of network-centric warfare (NCW) with ever-increasing levels of investment in and dependence on networked systems. As a result, the Army has become increasingly aware of the critical role that network science will play in achieving national defense goals. This report discusses a strategy for an Army center for conducting network science, technology, and experimentation supportive of all of the military services and joint operations.

The report examines, evaluates, and recommends appropriate operating models and infrastructure for an Army network science, technology, and experimentation center (NSTEC). To a large extent, the study was initiated as a result of base realignment and closure (BRAC) decisions that are presenting the Army with many challenges and opportunities; a major study goal included minimizing the former and maximizing the latter. Although technologies for command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) technologies, and associated concepts such as situational awareness, are currently the main focus for developing the "network" in NCW, these areas are only part of the overall picture. The 2005 National Research Council (NRC) report *Network Science* (NRC, 2005) identified areas of research and challenges involving biological, social, and engineered networks that are key to advancing network science and technology. Future advances in NCW will be highly dependent on a combination of basic and applied research, multidisciplinary concepts, experimentation, and the timely transition of innovative developments to usable applications. The challenge for the Army is to expand the present emphasis on C4ISR networks to incorporate the full scope of emerging developments in network science by taking advantage of the impending BRAC relocations of

research, development, and engineering resources to Aberdeen Proving Ground (APG), Maryland.

At the onset of this study, the Army sponsor clarified the statement of task (see Preface) to include a consideration of networks in a broad sense, as well as an examination of the needs of the Army for network science and technology (S&T) investment that would support its longer-term goals. These goals relate to network layers commonly referred to as the transport, services, information, and human interaction layers. The Committee on Strategies for Network Science, Technology, and Experimentation was asked to compare these needs with the current Army organization capacity for undertaking S&T, to assess the spectrum of practical options available to pursue long-term goals, and to recommend an optimized collaborative approach for Army research, technology, and experimentation that would enable solutions for important real-world problems for the Army involving networks and network operations.

The study addresses the functions that a world-class center for network science, technology, and experimentation must perform. Clearly, basic and applied research and experimentation activities are essential,[1] but an NSTEC could also support acquisition program managers on a reimbursable basis to transition network technology, essentially spanning the gamut of funding for research, development, and acquisition.

Network science, technology, and experimentation (NSTE) is rapidly evolving with changing needs, emerging technology, and new capabilities. The committee acknowledged the importance of the role of the soldier in the successful application of network technology in warfare and recommends increased investments in behavioral and social sciences research that would consider human performance in networks and add to understanding of the adversary. The committee assumed that the purposes for establishing an NSTEC would be to promote creativity and innovation, to attract and retain intellectual talent, to establish partnerships that can capitalize on frontier research at universities and in industry, and to achieve affordable and timely network technology and system solutions through interactions with the warfighter/user.

The committee consulted directly with Army Materiel Command personnel and other personnel responsible for and familiar with BRAC planning and implementation. It reviewed models of existing organizations in government and industry that might possibly be used to form a basis for an Army NSTEC, including models envisioned in relevant past studies. The committee also reviewed the activities and resources of the Army and other military services that are currently engaged in NSTE. Deficiencies or shortcomings that a new organization for NSTE might be required to address were identified, and a mission statement to overcome these was formulated.

[1]These are activities supported through Army budgetary classifications 6.1, 6.2, and 6.3 for program funding.

The committee evaluated the pros and cons of centralized facilities versus purely distributed elements and determined that a hybrid of the two would be necessary based on practical limitations. It then considered the infrastructure resources necessary for an Army NSTEC and the physical realization of these in light of Army facilities planning for BRAC, and it examined legal and governance considerations necessary for an NSTEC to accomplish its mission and to exploit contemplated partnerships with industry and academia and relationships throughout the Department of Defense (DOD). It evaluated a variety of approaches over the course of the study and considered options for operating models, both new ones and those that have been explored in other studies.

The committee also considered where NSTE activities are situated within the Army, as well as elsewhere in the DOD or other government facilities, in academia, and in industry. The impending relocations of key Army organizations involved in NSTE from Ft. Monmouth, New Jersey, to Aberdeen Proving Ground, Maryland, were deemed a prime opportunity to facilitate establishment of a world-class organization for NSTE that the committee believes is urgently needed to confront the challenges of NCW.

In brief, the report provides answers to the following questions:

- What network science, technology, and experimentation is needed by the Army? (Chapter 2)
- What constitutes NSTE across the Army today? (Chapter 3)
- What infrastructure resources are needed? (Chapter 4)
- What operating and governance models are most likely to satisfy the creation of a world-class NSTE capability? (Chapter 5)

Network-centric operations have proven their worth in military operations and are a central premise for warfighting capabilities. NSTE must provide the developmental basis for network-centric operations in both conventional and irregular warfare. As the military increases its reliance on networks, the Army will be pressed to exploit NSTE to an unprecedented degree. The Army will need to consider a range of topics in a broad array of network science areas to translate its investment strategy into advances in network research and technology.

To facilitate the identification of NSTE activities, the committee developed the following definition:

> Network science, technology, and experimentation (NSTE) encompasses all information and information exchange, visualization, collaboration, manipulation, protection, restoration, transport, services, data storage, and application layers. Information sources (e.g., sensors) and the processing inherent in them are interfaced to the network, but the sensors and processing per se are not included in the definition, except for cases where the processing is necessarily integral to the network, such as for

distributed remote sensors. Human use of networks is a critical component of NSTE.

As a result of BRAC, many, if not most, of the personnel and facilities performing essential NSTE activities for the Army will move to APG. The two major organizations involved with NSTE include the Army Research Laboratory (ARL) at Adelphi, Maryland, and the Communications-Electronics Research, Development, and Engineering Center (CERDEC), now at Ft. Monmouth, New Jersey. Elements of other organizations are also involved with NSTE, including the Army Research Institute for the Behavioral and Social Sciences (ARI), the Army Research Institute of Environmental Medicine (ARIEM), the Engineer Research and Development Center (ERDC), and others. Without a plan to combine and unify NSTE activities, the Army will merely relocate and reconstruct CERDEC at APG in its present form and fail to capitalize on the synergies possible with network science research.

Options for physical realization of an Army NSTEC range from a centralized facility in a single location to an organization using networked connectivity that is fully distributed in multiple locations. There are important pros and cons for each, but regardless of the configuration selected, there will be a critical requirement for partnerships with academia and industry that will require interconnections to many locations.

The magnitude and diversity of the required infrastructure suggest a phased implementation approach to establishing an NSTEC. The BRAC timetable is relatively inflexible, and the requisite talents and skills of the leadership team that will be needed are likely to be different for different phases of implementation. The content of the NSTE R&D portfolio will also change as the new organization assumes its mission and matures.

Previous comparative analyses have narrowed the field of consideration of prospective models for Army research organizations to government-owned, contractor-operated (GOCO), federally funded research and development center (FFRDC), and government-owned, federal government corporation (FGC) operating models. The Army has a wealth of experience with a variation of the FFRDC known as the university-affiliated research center (UARC), and this is the path recommended by the committee.

A core NSTEC UARC/FFRDC could be established at any appropriate location or locations and then be relocated at or in proximity to Aberdeen Proving Ground as circumstances warrant. In its early days, the UARC/FFRDC could perform a “gap filler” role when (1) existing Army resources are inadequate to accomplish all aspects of NSTE or (2) particular Army organizations involved in BRAC relocation to APG are unable to retain key personnel. In the long-term evolution of the NSTEC, the core UARC/FFRDC could consolidate responsibility for S&T in network science research and applications.

Overall coordination and implementation of NSTE for the Army will require extraordinary leadership at a level commensurate with the importance of network-centric operations in the future. Besides incorporating the core UARC, the new NSTEC organization would alter existing boundaries of responsibility for the various NSTE functions that are now performed by multiple organizations. For this reason, a director for all NSTE activities should be assigned immediately to assist with planning and establishment of the recommended NSTEC organization with a UARC/FFRDC core.

Figure S-1 illustrates the committee's recommendation for how the new organization should be formed. All NSTE efforts would become the responsibility of

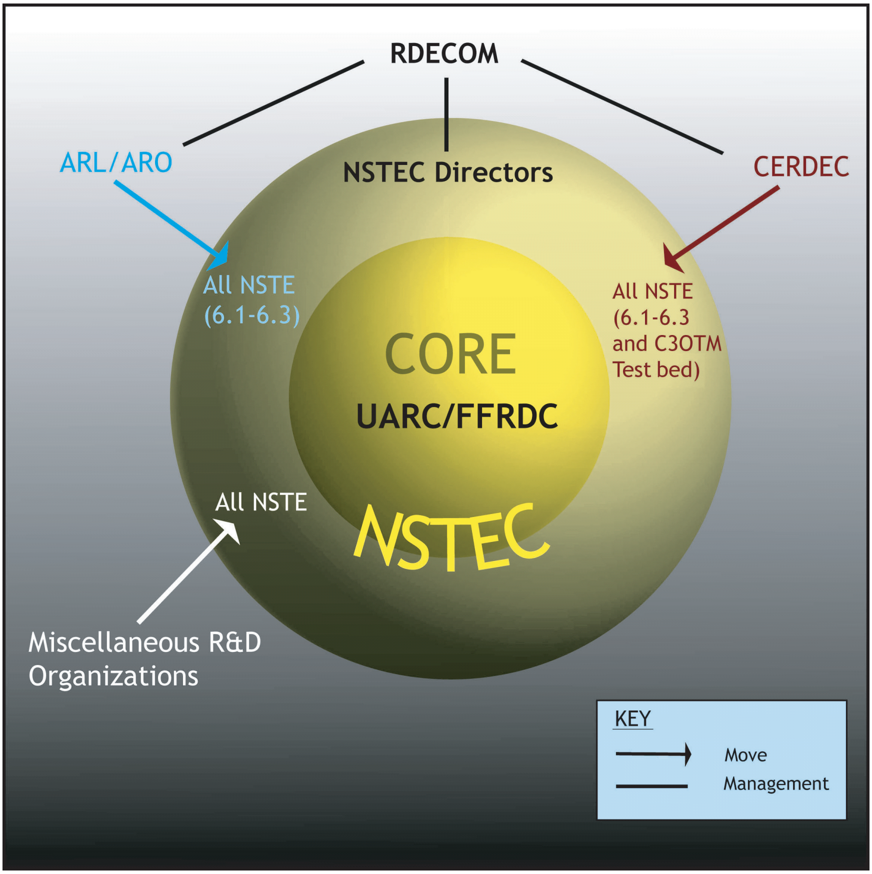

FIGURE S-1 Recommended NSTEC organization. (Acronyms are defined on pages xvi-xviii in the front matter.)

the proposed NSTEC. Within the NSTEC, the core UARC/FFRDC would begin by filling current gaps in S&T and would take responsibility for efforts that cannot be performed due to qualified technical staff deciding not to move to APG.

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations address the complex set of requirements outlined in the committee's statement of task, which is given in the Preface.

Conclusion 1: Table S-1 provides a priority list of the network science areas and applications that the committee believes will be most important to the Army in the future. These include communications and information; human performance in networks; adversary understanding; and other non-physical areas of network science, such as systems biology, neural networks, and economic networks.

Recommendation 1a: The Army should base its investment strategy for network science, technology, and experimentation (NSTE) on the priorities shown in Table S-1 and develop and fund a plan that:

- Continues the current Army focus on information networks, expanding these activities to address basic understanding and predictability of those networks;
- Provides the theoretical and scientific foundations for all network science research and applications;
- Significantly increases funding and efforts in human performance in networks and adversary understanding; and
- Invests in other disciplines, such as sociology, behavioral biology, and neural science, to ensure that the Army continually advances its understanding of network science.

Recommendation 1b: The Army should immediately increase funding in the critical areas of:

- Predictability of network performance,
- Human performance in networks, and
- Adversary understanding.

Moreover, the Army NSTE community should continuously consult with the Training and Doctrine Command (TRADOC), the Army Capabilities Integration Center (ARCIC), and the program executive officer/program manager (PEO/PM) of programs of record to identify additional gaps for immediate emphasis.

TABLE S-1 Network Areas and Priorities

Priority	Network Areas	Important Applications
1	Communications and information	Predictable performance: fundamental to command and control (C2) systems, logistics, training, etc., for both high and low levels of conflict, including operations at higher echelons down to the individual units and soldiers
2	Human performance in networks	Improved command decision processes, soldier and team interaction, training, social interactions, etc.
2	Adversary understanding	Social, cultural, organizational, religious, and economic command and control networks; critical counterinsurgency (COIN) interactions; intelligence analysis
3	Non-physical areas of network science (see Table 2-2)	Systems biology, neural networks, and economic networks

Recommendation 1c: In order to implement its investment strategy in NSTE, the Army should organize a center for NSTE (NSTEC) with a mission to:

- Strengthen the theoretical underpinnings of network science;
- Conduct basic research on how and why biological and social (non-physical) networks function and determine their applications to military networks;
- Manage activities in network science research, technology development, and experimentation for the Army;
- Focus science and technology (S&T) investments to enable network-centric operations and warfare;
- Focus applied S&T to enable social networks important to Army operations; and
- Enable development of network science applications and facilitate their transition to Army and joint operations.

Conclusion 2: Current responsibility for NSTE is fragmented across several organizations. As the BRAC relocations to APG occur with concomitant losses in personnel and facilities, the existing NSTE capabilities will be further divided and eroded, hindering essential progress toward improvements in the Army's ability to conduct network-centric operations and warfare.

Recommendation 2: The Army should change its organization and coordination of NSTE efforts to ensure essential support for future warfighting operations.

Conclusion 3a: The extensive infrastructure needed to support Army NSTE requirements will be developed initially from the facilities of existing organizations and will require a special planning effort to synchronize with BRAC relocations already in progress.

Conclusion 3b: The magnitude and diversity of the required infrastructure suggest a phased implementation approach to establish an Army NSTEC. A plan to develop NSTE capabilities and infrastructure could be phased over multiple years, beginning with the reorganization of existing and relocated facilities and ending with the establishment of a world-class center for network science, technology, and experimentation. An adequate plan will involve leadership with the appropriate talent and vision for all phases, especially as the content of the NSTE R&D portfolio matures.

Conclusion 3c: Based on Army needs, the NSTEC should be a hybrid operation consisting of two or three centralized facilities having interconnectivity to a variety of distributed supporting elements.

Recommendation 3: The Army should plan and fund for NSTE infrastructure resources that provide for (1) flexible configurations of network experiments and integration, both internally and externally; (2) facility designs that enhance and encourage academic and industry partnerships; and (3) an environment with world-class experimental capabilities and a campus-like atmosphere to attract truly talented people.

Conclusion 4: The UARC/FFRDC operating model has emerged in recent years as a flexible and productive model capable of integrating commercial and military R&D development for the Army. The UARC/FFRDC is also superior to other operating models, because it allows ongoing access to a broad range of expertise, talent, and innovation while efficiently using government resources.

Recommendation 4: The Army should establish a new UARC/FFRDC (or expand an existing UARC/FFRDC) to serve as the core of an overall Army NSTEC organization.

Conclusion 5: An NSTEC organization must exhibit a high degree of flexibility in personnel policies that will enable it to become a world-class leader in network research and development. Establishment and evolution of the NSTEC will require exceptional leadership.

Recommendation 5a: The Army strategy for NSTE should be to establish an NSTEC organization with a UARC/FFRDC core as shown in Figure S-1.

Recommendation 5b: The Army should immediately designate a director to establish an Army NSTEC at Aberdeen Proving Ground (Maryland). The NSTEC director should report to the U.S. Army Research, Development, and Engineering Command (RDECOM) at a level equivalent to the ARL and RDEC directors. All NSTE funding and resources should be assigned to this individual.

Recommendation 5c: For the NSTEC to be able to accomplish the mission envisioned, the Army should designate at least two deputy directors: one for technology and another for human performance/adversary understanding. This action will ensure that the large number of CERDEC engineers does not overwhelm research and development efforts in human performance and adversary understanding.

1

Introduction

The U.S. military and its allies have committed to a strategy of developing network-centric warfare (NCW) capabilities through ever-increasing levels of investment in and dependence on networked systems. As a result, the Army is becoming increasingly aware of the critical role that network science research, technology, and experimentation will play in achieving national defense goals. This report discusses a strategy for an Army center for conducting network science, technology, and experimentation supportive of all of the military services and joint operations.

This chapter provides the context for the study covered in this report, including clarifications to the statement of task made by the report's sponsor. It also discusses likely goals that the establishment of an Army center for network science, technology, and experimentation (NSTE) could meet, basic assumptions of the study, and the environment in which the study was undertaken. It also explains the organization of the report.

BACKGROUND

The overall study requirement was to examine, evaluate, and recommend appropriate operating models and infrastructure for a network science, technology, and experimentation center (NSTEC) with special attention given to including assets currently existing within the Department of the Army. Determining appropriate potential relationships between such a center and existing government, industry, and academic organizations was also important, since such relationships are critical for promoting the effective transfer of scientific knowledge and technologies among the user community, and for furthering the development and demonstration of technological innovations that will enable continuous development of NCW capabilities.

NCW capabilities are highly dependent on information and communications network technologies and are most often associated with conventional warfighting operations. However, the nature of likely future U.S. adversaries has changed. In the next decade, it is unlikely that any other existing military force would take on the U.S. military in a force-on-force conventional war. Although the Army must be prepared for traditional conventional war, the greater likelihood is that potential enemies are going to resort to asymmetrical or irregular approaches so they do not have to directly counter U.S. military technology.

To be fully relevant in the future, NCW capabilities that traditionally have been viewed in terms of large force-on-force operations will need to apply to the activities of small Army units and to interface with small groups of friendly foreign military, paramilitary, non-governmental organizations (NGOs), and civilian government forces. Future networks must be described not only in terms of military operations, but also in terms of how they can integrate the social, cultural, economic, and political aspects of human performance, including understanding the adversary in irregular warfare. In recognition of this, while the traditional focus of Army NSTE on physical networks must continue, it must also support research activities that are on the cutting edge of applying network science to the challenges of asymmetric warfare. In this context, an Army NSTEC may well become the key organization setting the course for S&T in network-centric warfare.

Technologies for command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR), and associated concepts such as situational awareness, are currently the main focus for development of the "network" in NCW. However, these technologies and concepts are only part of the overall picture. The contribution of the human dimension must be properly integrated within the spectrum of C4ISR technologies for the potential of NCW to be fully realized. This necessitates an integrated, multi-disciplinary approach to ensure that an NSTEC addresses human-intensive issues associated with the function of social and other non-physical networks.

A challenge for the Army is to expand the present emphasis on C4ISR networks to incorporate the full scope of the emerging field of network science. The impending base realignment and closure (BRAC) relocations of research, development, and engineering resources to Aberdeen Proving Ground (APG), Maryland, provides a prime opportunity to do so.

The committee grappled with what functions should be included within the construct for an NSTEC. Clearly, basic and advanced Army research S&T activities are essential,[1] but an NSTEC could also support acquisition program

[1]These are activities supported through Army budgetary classifications 6.1, 6.2, and 6.3 for program funding.

managers on a reimbursable basis to transition technology, essentially spanning the gamut of funding for research, development, and acquisition. The committee evaluated a variety of existing and creative approaches that could help the Army overcome very difficult organizational and bureaucratic barriers and considered options for various organizational models, both new ones and those that have been previously explored in other studies.

STATEMENT OF TASK AND STUDY OBJECTIVES

The statement of task for the study is contained in the Preface. This task statement was further clarified by the sponsor to include the specific study objectives outlined below:

- Consider networks in the broader sense. Examine the Army needs for network science and technology (S&T) to support its longer-term goals, including network layers commonly referred to as the transport, services, information, and human interaction layers. Compare these needs with the current Army organization to undertake S&T and assess the spectrum of practical options available to pursue them. These options should include physical locations, organizational models, and required infrastructure.
- Recommend an optimized collaborative approach for Army research, technology, and experimentation to solve important real-world Army problems involving network science and technology and network operations. Collaboration in this sense means developing a multi-disciplinary approach within the Army and also collaborating or partnering with academia, industry, and other relevant organizations to bring their expertise and intellectual capital to bear on relevant problems of mutual interest. Existing Army organizations, current plans, and legal authorities need to be considered. If changes are recommended, they need to be practical and capable of being executed in a timely and resource-constrained manner.
- Recommend how to relocate organizations currently involved with network science and technology at Ft. Monmouth, New Jersey, and other facilities to Aberdeen Proving Ground, Maryland, to facilitate establishment of a world-class center of NSTE activity for the Army.

MAJOR ASSUMPTIONS AND CONSTRAINTS

NSTE is rapidly evolving with changing needs, emerging technologies, and new capabilities. Flexibility is an essential characteristic for any organizational structure that will engage in NSTE in the future. The committee assumed that the purpose of establishing an NSTEC would be to promote creativity and innovation, to attract and retain intellectual talent, to establish partnerships that can capitalize on frontier research at universities and in industry, and to develop affordable and timely solutions to issues concerning network technology and systems through interactions with the warfighter/user.

The committee made other key assumptions focused on the uncertainties of need and the practicalities of resource constraints in recognition that the Army cannot undertake everything that it deems important. These include:

- Base realignment and closure (BRAC) decisions are faits accomplis, but the individual personnel who will physically relocate to Aberdeen Proving Ground (APG) remain to be determined.
- The location of APG could limit the ability to recruit and retain personnel with the highest qualifications and desired levels of expertise.
- Army compromises between the ideal and the practical are going to be necessary and should be carefully balanced.
- Study recommendations should be based on practical and realistic approaches.
- Recommendations should not require new enabling legislation.
- The proposed NSTEC would be capable of serving the needs of both Army and joint operational requirements.

Of necessity, the committee took a high-level approach to its analyses of both personnel and infrastructure. Detailed data on current and projected levels of personnel resources and investments in all of the network-related activities were not available for all organizations, making a detailed manpower analysis impossible. S&T funding for an NSTEC was estimated by extrapolating amounts provided for Fiscal Year 2006 network-related activities.

NETWORK SCIENCE

As a starting point, the committee reviewed findings and recommendations of the 2005 National Research Council (NRC) report *Network Science*, which identified for the Army key research challenges, specific research areas, and the scope of facilities and equipment necessary to conduct world-class research in network science (NRC, 2005). Although that report was focused on basic research, it provided findings that had considerable relevance to the establishment of an NSTEC. These findings can be briefly summarized as follows:

- Networks are pervasive in all aspects of life (biological, physical, and social).
- Fundamental knowledge about the prediction of the properties of complex networks is primitive.

- Current funding policies and priorities are unlikely to provide adequate fundamental knowledge.
- Network science is an emerging field, and there is consensus on the topics appropriate to a network science curriculum among practitioners of network research in diverse disciplines.
- The high value attached to the efficient and failure-free operation of global, engineered networks makes their design, scaling, operation, and protection a national priority.

The 2005 report also identified seven major research challenges for network science (pp. 36-37):

- *Dynamics, spatial location, and information propagation in networks.* Better understanding of the relationship between architecture and function is needed.
- *Modeling and analysis of very large networks.* Tools, abstractions, and approximations are needed that allow reasoning about large-scale networks as well as techniques for modeling networks characterized by noisy, incomplete data.
- *Design and synthesis of networks.* Sufficient understanding and adequate techniques are needed to design or modify a network to obtain the desired properties.
- *Increasing level of rigor and mathematical structure in characterizing networks.*
- *Abstracting common concepts across fields.* Practitioners of network science in disparate disciplines need uniform definitions for common concepts.
- *Better experiments and measurements of network structure.* Current data sets on large-scale networks tend to be sparse, and tools for investigating their structure and functions are limited.
- *Robustness and security of networks.* A clear need exists to better understand and design networked systems that are both robust to component variations and secure against hostile intent.

REPORT ORGANIZATION

The logic of the study and the organization of this report are represented by the following sequence of questions:

- What network science, technology, and experimentation is needed by the Army?
- What constitutes NSTE across the Army today?
- What infrastructure resources are needed?
- What operating and governance models are most likely to satisfy the creation of a world-class NSTE capability?

Chapter 2 discusses the scope of what a center for NSTE should do. Chapter 3 describes what constitutes NSTE in the Army today. Chapter 4 considers infrastructure requirements and the physical realization of an NSTEC, pre- and post-BRAC. Chapter 5 describes basic organizational goals, compares operating models, and evaluates alternatives.

2

What Network Science, Technology, and Experimentation Is Needed by the Army?

This chapter discusses what constitutes network science, technology, and experimentation (NSTE) in the Army; proposes a mission statement for an Army center of NSTE activities, an Army NSTEC; and identifies science and technology research areas that such a center might undertake.

SCOPE OF NETWORK SCIENCE, TECHNOLOGY, AND EXPERIMENTATION

Discussions of network science, its elements, and its criticality to military applications vary widely depending on how network science is defined. The committee chose to adopt the definition from the 2005 National Research Council report *Network Science*, which defined basic network science as "the study of network representations of physical, biological and social phenomena leading to predictive models of these phenomena" (NRC, 2005, p. 2). This definition is intentionally very broad and includes interactions between complex, multi-disciplinary nodes. The *Network Science* report also summarized various areas of network research that are of interest to the Army (Table 2-1).

As currently used by the Army and within the greater military establishment, the word "network" is used in terms such as "network-centric operations," "network-centric warfare," or just "the network" to refer to information or communications networks and the humans that use them. Such networks play an increasingly important role in modern warfare in enabling command and control and providing information on force locations and activities. This is true for both conventional high-intensity warfare (e.g., Desert Storm and the more recent "run to Baghdad") and counterinsurgency (COIN) warfare. The former application is

TABLE 2-1 Areas of Network Research of Interest to the Army

Research Area	Key Objective
Modeling, simulating, testing, and prototyping very large networks	Practical deployment tool sets
Command and control of joint/combined networked forces	Networked properties of connected heterogeneous systems
Impact of network structure on organizational behavior	Dynamics of networked organizational behavior
Security and information assurance of networks	Properties of networks that enhance survival
Relationship of network structure to scalability and reliability	Characteristics of robust or dominant networks
Managing network complexity	Properties of networks that promote simplicity and connectivity
Improving shared situational awareness of networked elements	Self-synchronization of networks
Enhanced network-centric mission effectiveness	Individual and organizational training designs
Advanced network-based sensor fusion	Impact of control systems theory
Hunter-prey relationships	Algorithms and models for adversary behaviors
Swarming behavior	Self-organizing unmanned aerial and ground vehicles; self-healing
Metabolic and gene expression networks	Soldier performance enhancement

SOURCE: NRC, 2005.

obvious and widely accepted, but the importance of communications networks applies equally to the latter; consider, for example, the physically smaller network involving an unmanned aerial vehicle (UAV) supporting a squad of soldiers who need to know what is around the next corner.

It is clear that the use of communications and information networks will continue to be critically important to the Army, and major investments are currently being made in systems to support such networks. However, at this time the largest fraction of these investments is being devoted to developing and acquiring technology for operational systems, while support for research into the theoretical foundations for networks is lacking. Basic research in network science is needed to expand understanding of the fundamentals of network structure, performance, and predictability, along with the corresponding strengths and weaknesses of networks. This knowledge can ultimately be applied to the creation and management of functional networks of various types important to Army and joint operations.

In addition to physical networks, such as communications and information networks, a wide variety of biological and social (non-physical) networks can be identified. As listed in Table 2-2, these non-physical networks range in nature and scale from the molecular to the intercultural. The structure and functional characteristics of these networks are worthy of study in terms of their potential for application to Army operations. Nonetheless, essential basic and applied research in many of these areas has been neglected by the Army. Future advances in NCW are highly dependent on a combination of basic and applied research, multi-disciplinary concepts, experimentation, and timely transition of innovative developments to usable applications.

Coordinated efforts to expand awareness and understanding of diverse networks are among several appropriate goals for Army NSTE. All of the networks in Table 2-2 are relevant to Army and joint military operations; this fact provides a strong motivation for the Army to take the lead in NSTE collaboration across the military services.

COMMUNICATIONS AND INFORMATION NETWORKS

The Army's vision of a network-centric capable force is for one that is robustly networked by means of a communications and information infrastructure that is global, secure, real-time, reliable, Internet-based, and user-driven. For this reason, the Army's highest priority for NSTE should be ensuring the predictable performance of communications and information networks.

A typical communications and information network topology is shown in Figure 2-1. It consists of network nodes that are interconnected by network infrastructure. The nodes themselves may have their own sub-networks. As depicted in Figure 2-1, the Defense Information Systems Network (DISN) Global Information Grid (GIG) is the central focus for NCW operations, with various sub-networks (including homes, offices, and other military-affiliated networks with GIG interfaces). The technical scope for an Army NSTEC would include science and technology for both the network infrastructure and the nodes.

The principal areas of research that are most important to the requirements of communications and information infrastructure and networks for military operations are as follows:

- Network infrastructure, architecture, and topology to ensure
  — Sufficient bandwidth to allow acceptable levels of quality of service,

  - Capacity to be self-forming to be effective in highly dynamic situations, and
  - Flexibility to support all Army-projected missions.
- Network connectivity robustness to enable
  - Rapid recovery,
  - Scalable routing protocols, and
  - Support of multiple network structures.
- Network security to ensure
  - Network availability throughput under cyberattack,
  - Wired and wireless distribution of cryptographic keys, and
  - Multi-level security (MLS) to provide for secure transmission of different levels of classified information.
- Network management capabilities to
  - Minimize bandwidth overhead,
  - Minimize requirements for hands-on operation, and
  - Enable operations by all military personnel.

Other focus areas include:

- Cognitive capabilities to activate network management functions during set-up, operation, maintenance, and monitoring of networks.
- Leveraging commercial off-the-shelf technologies (COTS) for military networking requirements. COTS-based networking technologies could help lower the cost and power requirements of network components.
- Standardizing interfaces to the GIG and applications (such as Internet Protocol [IP]-based commercial applications) to help interoperability. Standards that apply across the Army, Navy, and Air Force will be key to fostering re-usability, global connectivity, and interoperability.
- Training researchers on methodologies for experimentation and validation of conceptual network designs in terms of a systems perspective. Training on specific military requirements (e.g., information assurance, mobile ad hoc networks, UAV networks) and to evolve solutions for networking is key to overall system performance and effectiveness.

HUMAN PERFORMANCE IN NETWORKS, ADVERSARY UNDERSTANDING, AND OTHER NETWORK AREAS

Behavioral and social science research in human factors, leader development, personnel, training, and social networks has much to contribute to improving human performance in networked systems. Soldiers and leaders alike will be critical nodes extracting and using information from networks to gain information and make decisions. Human performance research will be critical to designing the information and communications aspects of networks so that the needs of

TABLE 2-2 Examples of Biological and Social (Non-physical) Networks

Network Type	Functional Elements	Node Components	Challenges	Threats to Soldiers	Operational Implications
Neural	Sensory inputs: visual, aural, tactile	Communications systems, "soldier as a sensor"	Input capacity, mental awareness	Sensory overload, non-optimal cognition, differences in individual comprehension	Confusion, incapacitation, no common operating picture of the battlefield
	Autonomic/visceral	Brain, nerves, heart, glands	Involuntary/ uncontrollable	Physical illness, incapacitation, death	Physical performance degradation
	Motor function	Brain, nerves, muscles	Training conditioned responses	Inadequate training, injury	Physical performance degradation
Metabolic	Nutrition/hydration	Water and food supplies	Maintaining health and energy output	Interruption of supplies	Physical and psychological performance degradation
Personal and Personnel support	Health maintenance, medical care	Health maintenance/ medical treatment systems	Seamless from battlefield to hospitals	Lack of expertise, supplies, transportation, facilities	Loss of troops to injury or illness
	Physical protection	Personal protection equipment	Effective versus obstructive	Impediments to movement, exposure to elements or enemy	Physical performance degradation, injury or loss of troops
Mobility	Transportation	Transportation system	Availability and quality	Inadequate availability	Isolation, impaired troop movement, vulnerability to attack

Disease transmitting	Infectious agents	Viruses, bacteria, vectors of transmission	Contagious illnesses	Spread among troops, biological warfare	Incapacitation, injury or loss of troops
Human	Inter-personal, inter-unit, inter-service, and inter-cultural relationships	"Battlefield buddies," squads, platoons, rank hierarchy, and native peoples	Interdependence, efficacy of group performance, barriers due to differences in rank, language and cultural differences	Individual versus group goals and function; lack of cooperation; impediments to communication, verbal and otherwise	Conflict, confusion, functional degradation of performance of individuals or groups, offensive/threatening behavior by troops or enemy
Economic	Use of natural, human, and financial resources in financial infrastructure to produce products and services	Capital and operational budgets, human resource management systems, physical plants and equipment	Creation of value-added products and services, successfully competing with other business networks	Competition, waste, inefficiency, mismanagement, technical obsolescence, governmental regulation effects	Inadequacy of funding; personnel supply, support, management, and retention; research budget; facilities and maintenance

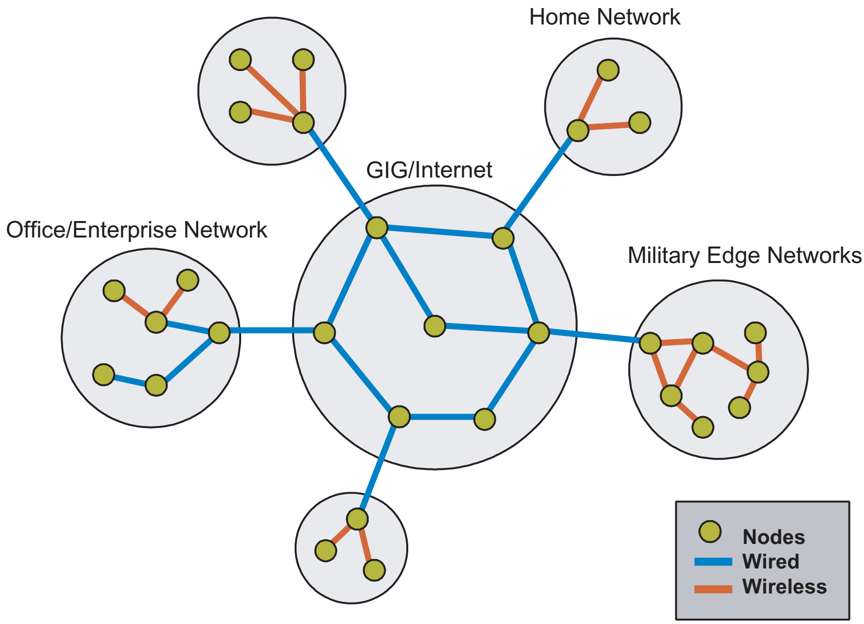

FIGURE 2-1 Typical communications and information network topology.

users for timely and useful information are met in a manner that is compatible with human cognition.

Cognitive psychology can contribute to understanding the processes of situational awareness and decision making in networked environments. Leaders will direct others via networks, communicating information and their decisions and providing support remotely. Therefore, research on social networks and leadership development for the purpose of understanding and optimizing team and leader behaviors in a networked environment (e.g., collaboration) will be critical to the operational success of a networked Army. Research in social networks can also help the Army to identify the skills in personnel that will be necessary for soldiers and leaders to operate in the networked environments of the future, as well as the types and structures of organizations needed. Such research will help improve not only the operation of networked systems, but also how to train soldiers to use the systems most effectively in future battlefield scenarios.

Knowledge of social networks is critical to understanding interactions between and among personnel who are integral to military operations—in units of U.S. and coalition forces, and in indigenous populations. It will also be important for understanding how adversary networks and cells work at the ethnic, religious, familial, tribal, and economic levels. Detailed understanding of the social structure and communications patterns of adversary forces is essential to intelligence acquisition and analysis, and to the ability to disrupt enemy assets and objectives. Analysis of financial and social as well as command and control (C2) linkages can provide powerful information and tools in counterinsurgency (COIN) operations. Social network and behavioral modeling research is particularly critical to understanding and predicting the behavior of adversaries under a variety of situations.

Specific applications of biological and other non-physicals networks, such as those identified in Table 2-2, are less predictable, but many are likely to have significance to the Army in the longer term. The Army should invest selectively in areas that will ensure awareness and understanding of emerging network developments and applications.

PRIORITIES

Communications and information network areas continue to represent the highest priority for the Army, as they are necessary for the linkage of multiple infrastructure nodes and cover a wide range of military applications. Less obvious, perhaps, are the many facets of human performance in networks, ranging from the physiological make-up and function of individual soldiers to the psychological and behavioral performance of multitudes of linked soldiers and other individuals. Much of what will be learned from research and study in these vital human areas will trickle down and be applicable to research in network areas involving understanding adversaries and in other network areas involving the biological and social sciences and their applications (see Table 2-2). The Army's support of research efforts in all of these disciplines will have far-reaching benefits.

Table 2-3 groups all network areas of particular importance to the Army into four categories. While the categories are broad and somewhat overlapping, it is evident that an integrated approach in all network areas will be essential to support successful development of applicable technologies and capabilities. This integrated approach will require close working relationships between engineers and scientists in computer, behavioral, social science, and other relevant disciplines.

The committee assigned Priorities 1, 2, or 3 in Table 2-3 based on the potential criticality of the network areas to Army missions now and in the foreseeable future. These priorities also indicate the relative value of NSTE expenditures. Thus, continuing efforts in the network areas of communications and information are Priority 1 both in terms of potential criticality and relative amount of expenditures. The two categories assigned Priority 2 (human performance in networks and adversary understanding) would require a major boost in investment emphasis—on the order of 20-25 percent of the Army's fiscal and personnel resources for NSTE.

TABLE 2-3 Network Areas and Priorities

Priority	Network Areas	Important Applications
1	Communications and information	Predictable performance: fundamental to command and control (C2) systems, logistics, training, etc., for both high and low levels of conflict, including operations at higher echelons down to the individual units and soldiers
2	Human performance in networks	Improved command decision processes, soldier and team interaction, training, social interactions, etc.
2	Adversary understanding	Social, cultural, organizational, religious, and economic command and control networks; critical counterinsurgency (COIN) interactions; intelligence analysis
3	Non-physical areas of network science (see Table 2-2)	Systems biology, neural networks, and economic networks

The assignment of Priority 3 in Table 2-3 to efforts in non-physical areas of network science should not be interpreted as meaning that efforts in such areas should be stopped, or that funding should be dramatically reduced during times of tight budgets. The Priority 3 areas are in fact what would differentiate an integrated center for network science, technology, and experimentation from typical networking research centers. For this reason, those charged with establishing and administering an Army NSTEC must actively advocate that the full scope of network science as laid out in the 2005 NRC report *Network Science* be pursued.

NSTE S&T Investment Strategy

Future science and technology investments for NSTE should correspond to the priority assignments shown in Table 2-3. These considerations, combined with the need to provide solid scientific foundations for all pertinent network applications, lead to a recommended investment strategy for NSTE as follows:

- Continue the current Army focus on information networks, expanding these activities to address basic understanding and predictability of those networks.
- Develop and fund a plan that will provide the theoretical and scientific foundations for all network science research and applications.

- Significantly increase funding and efforts for human performance in networks and adversary understanding.
- Make selected investments in other disciplines, such as sociology, behavioral biology, and neural science, to ensure that the Army continually advances its understanding of network science.

Proposed Mission Statement

Based on the considerations discussed above, the committee proposes that an appropriate mission statement for the Army NSTEC, whose activities would range from basic research to network applications, would include the following elements:

- Strengthen the theoretical underpinnings of network science.
- Conduct basic research on how and why biological and social (nonphysical) networks function, and determine their application to military networks.
- Manage activities in network science research, technology development, and experimentation for the Army.
- Focus science and technology (S&T) investments to enable network-centric operations and warfare.
- Focus applied S&T to enable social networks important to Army operations.
- Enable development of network science applications, and facilitate their transition to Army and joint operations.

CHAPTER SUMMARY

Without a plan to combine and unify NSTE activities, the Army will merely re-construct the Communications-Electronics Research, Development, and Engineering Center (CERDEC) at APG in its present form and fail to capitalize on the synergies possible with network science research. Ultimately, the technical content of Army programs in NSTE should be selected, coordinated, and managed by a center for NSTE activity, an Army NSTEC, influenced by a highly qualified staff who are specifically recruited for this purpose, and by discussions with the primary customers (e.g., program managers (PMs)/program executive officers (PEOs), warfighters, the Army Chief Information Officer, and others). There should be a conscious effort to avoid competition with commercial network research activities unless there is a case for efforts to meet special needs. Every effort should be made to collaborate with commercial network research organizations in areas of ongoing research.

As the military increases its reliance on network-centric operations and warfare, the Army will be pressed to exploit NSTE to an unprecedented degree. The

2005 NRC report *Network Science* identified several areas of network research of interest to the Army and assessed value propositions for pursuing network science to achieve Army objectives. The committee combined relevant findings from that report with its own understanding of Army requirements to determine an S&T investment strategy and a mission statement for a new center of Army NSTE activity.

Conclusion 1: Table 2-3 provides a priority list of the network science areas and applications that the committee believes will be most important to the Army in the future. These include communications and information; human performance in networks; adversary understanding; and other non-physical areas of network science, such as systems biology, neural networks, and economic networks.

Recommendation 1a: The Army should base its investment strategy for network science, technology, and experimentation (NSTE) on the priorities shown in Table 2-3 and develop and fund a plan that:

- Continues the current Army focus on information networks, expanding these activities to address basic understanding and predictability of those networks;
- Provides the theoretical and scientific foundations for all network science research and applications;
- Significantly increases funding and efforts in human performance in networks and adversary understanding; and
- Invests in other disciplines, such as sociology, behavioral biology, and neural science, to ensure that the Army continually advances its understanding of network science.

Recommendation 1b: The Army should immediately increase funding in the critical areas of:

- Predictability of network performance,
- Human performance in networks, and
- Adversary understanding.

Moreover, the Army NSTE community should continuously consult with the Training and Doctrine Command (TRADOC), the Army Capabilities Integration Center (ARCIC), and the program executive officer/program manager (PEO/PM) of programs of record to identify additional gaps for immediate emphasis.

Recommendation 1c: In order to implement its investment strategy in NSTE, the Army should organize a center for NSTE (NSTEC) with a mission to:

- Strengthen the theoretical underpinnings of network science;
- Conduct basic research on how and why biological and social (non-physical) networks function and determine their applications to military networks;
- Manage activities in network science research, technology development, and experimentation for the Army;
- Focus science and technology (S&T) investments to enable network-centric operations and warfare;
- Focus applied S&T to enable social networks important to Army operations; and
- Enable development of network science applications and facilitate their transition to Army and joint operations.

3

Network Science, Technology, and Experimentation Across the Army Today

This chapter reviews the different organizations across the Army that have a role in NSTE today. The committee developed and used the following definition for network science, technology, and experimentation (NSTE) to determine which organizational elements of the Army are currently engaged in NSTE efforts:

> Network science, technology, and experimentation (NSTE) encompasses all information and information exchange, visualization, collaboration, manipulation, protection, restoration, transport, services, data storage, and application layers. Information sources (e.g., sensors) and the processing inherent in them are interfaced to the network, but the sensors and processing per se are not included in the definition, except for cases where the processing is necessarily integral to the network, such as for distributed remote sensors. Human use of networks is a critical component of NSTE.

NSTE ORGANIZATIONS

Using the above definition, the committee identified current Army organizations having significant S&T investments in NSTE efforts in the areas listed in Table 2-3. Detailed information on NSTE funding and personnel resources was requested from these organizations, but the data provided were incomplete and unusable. The committee therefore relied on briefings provided during its information-gathering sessions and on the personal knowledge of its members in preparing the analysis presented in this chapter.

Currently, NSTE efforts conducted by the Army are primarily in the area of information and communications. Much less work is ongoing in human performance in networks and other priority network areas described in Chapter 2. Figure 3-1 depicts the principal Army organizations currently engaged in NSTE, and Table 3-1 summarizes the present physical locations for ongoing work in each of the priority network areas. Specific organizations and their work are discussed below.

Information and Communications

NSTE efforts in information and communications are performed at the Army Research Laboratory (ARL), which includes the Army Research Office (ARO), and at the Communications-Electronics Research, Development, and Engineering Center (CERDEC). Most of this work takes place at three major sites: ARL, Adelphi, Maryland; Aberdeen Proving Ground (APG), Maryland; and Ft. Monmouth, New Jersey. Although the committee was provided with only minimal financial data, it estimated that in Fiscal Year 2006, total NSTE investments in information and communications networks were ~$145 million, with ARL responsible for basic and applied research (~$70 million) and CERDEC responsible for applied research, advanced technology development, and experimentation (~$75 million).[1]

Army Research Laboratory

ARL is the Army's corporate, or central, laboratory for basic and applied research. Its mission is to provide innovative science, technology, and analysis to enable the full spectrum of operations. In general, the Army relies on ARL for scientific discoveries, technologic advances, and analyses to provide warfighters with capabilities to succeed on the battlefield.

ARL consists of ARO and seven directorates. Those directly involved in NSTE are ARO, the Computational and Information Sciences Directorate (CISD), and the Human Research and Engineering Directorate (HRED). The HRED efforts are discussed in the section below titled "Human Performance in Networks."

The directorate primarily engaged in NSTE at ARL is CISD, which conducts a broad spectrum of research focused on high-bandwidth communication, advanced command and control (C2) techniques, battlefield visualization, weather decision aids, and defensive information operations. CISD also addresses scientific developments that would enable modeling, design, analysis, prediction, and control in the performance of a complex network of networks—in particular, tactical sensor and communications networks and the overlying decision-making networks.

[1] J. Miller, Director, U.S. Army Research Laboratory, "ARL Research in Network Science," briefing to the committee, September 21, 2006.

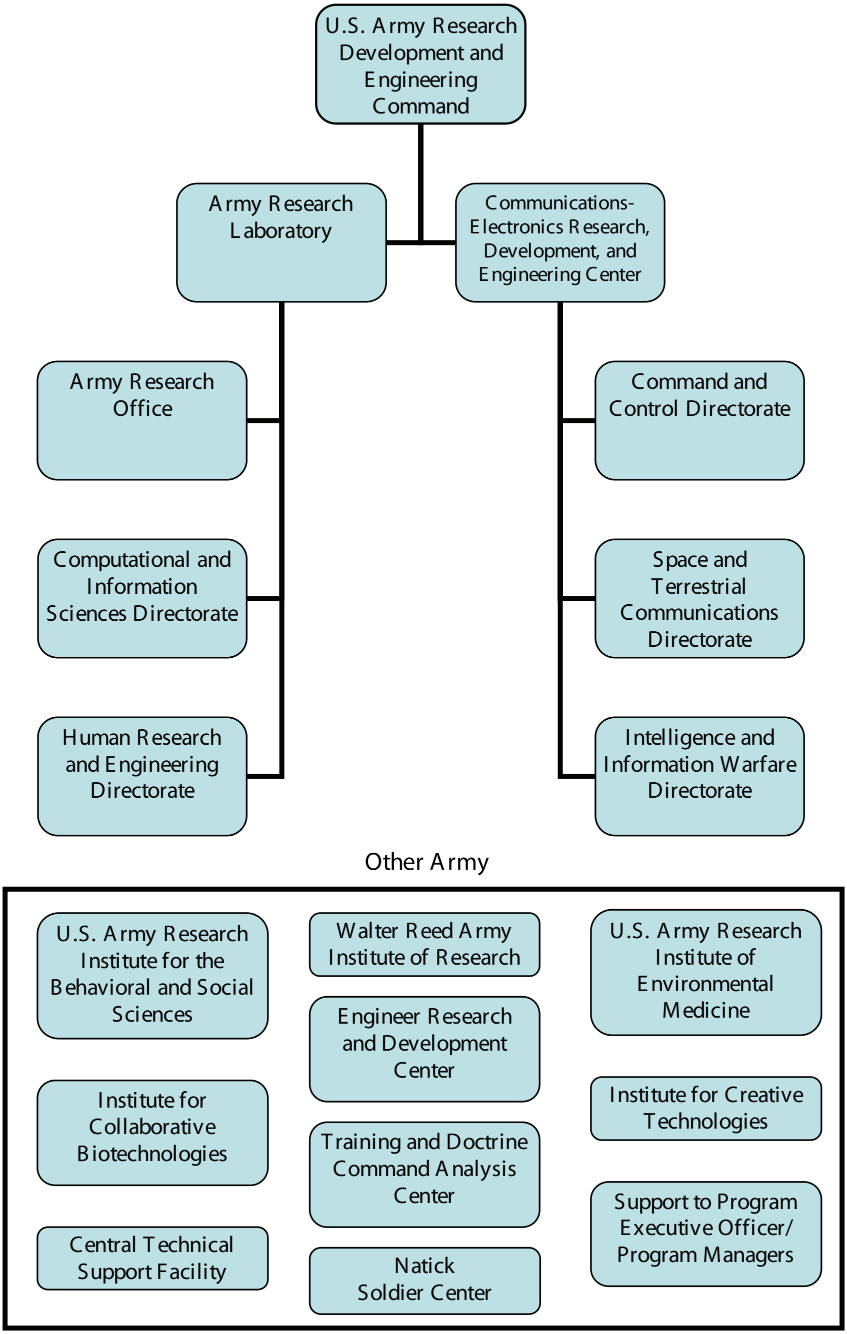

FIGURE 3-1 Current Army organizations engaged in NSTE.

TABLE 3-1 Current Locations of Army NSTE

Network Areas	Organization	Current Location
Information and communications	Army Research Laboratory Army Research Office	Research Triangle Park, NC
	Army Research Laboratory Computational and Information Sciences Directorate	Adelphi, MD, and Aberdeen Proving Ground, MD
	Communications-Electronics Research, Development, and Engineering Center	Ft. Monmouth, NJ
Human performance in networks	Army Research Laboratory Human Research and Engineering Directorate	Aberdeen Proving Ground, MD
	U.S. Army Research Institute for the Behavioral and Social Sciences	Arlington, VA
	U.S. Army Research Institute for the Behavioral and Social Sciences Field Unit	Ft. Knox, KY
	Natick Soldier Center	Natick, MA
	U.S. Army Research Institute of Environmental Medicine	Natick, MA
	Army Engineer Research and Development Center	Vicksburg, MS
Adversary understanding	Army Research Laboratory Human Research and Engineering Directorate	Aberdeen Proving Ground, MD
Other network areas	Institute for Collaborative Biotechnologies (University-Affiliated Research Center)	Santa Barbara, CA
	Institute for Creative Technologies (University-Affiliated Research Center)	Marina del Rey, CA
	Communications and Networks Collaborative Technology Alliance	Distributed
	The International Technology Alliance in Network and Information Sciences	Distributed

ARO represents the Army's most long-range view for pursuing S&T advancements in network technology. ARO's mission is to serve as the Army sponsor of extramural basic research in the engineering, physical, information, and life sciences. It competitively selects and funds basic research proposals from educational institutions, non-profit organizations, and private industry. The ARO research program consists principally of extramural academic research conducted through single investigator efforts, university-affiliated research centers, and specially tailored outreach programs. Each approach has its own objectives and set of advantages. The priorities set by ARO serve as a means to integrate Army-wide, long-range planning for research, development, and acquisition.

To address network science research, ARL has created five network science grand challenges. These are:

1. Develop a fundamental understanding of the performance, scalability, and behavior modeling of secure networks;
2. Enable autonomy and self-configuration;
3. Develop networks that seamlessly support coalition/joint operations;
4. Secure information sharing among different security domains; and
5. Understand underlying phenomena of decision-making networks, while jointly addressing the physical (e.g., mobile ad hoc wireless networks), the social (e.g., people, organizations, cultures), and the cognitive (e.g., perceptions, beliefs, decisions) aspects of networks.

In addition to the work of the directorates and ARO, ARL also has a strong outreach effort with other government activities involved with network science. Organizations with which ARL interacts include:

- CERDEC in the areas of mobile ad hoc wireless networks (MANET), network design tools, security, performance analysis, and experimentation;
- The Defense Advanced Research Projects Agency (DARPA) in the areas of MANET networking, sensor networking, and optical and other communications;
- The Army Research Institute (ARI) in the development of collaboration mechanisms;
- The Naval Research Laboratory (NRL) in MANET networking and performance analysis;
- The U.S. Military Academy at West Point for research in secure networks and social networking;
- The Army Engineer Research and Development Center (ERDC) in social networking; and
- The U.S. Army Intelligence and Security Command (INSCOM) in social networking.

Communications-Electronics Research, Development, and Engineering Center

The CERDEC mission is to develop and integrate command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) technologies that enable information dominance and decisive lethality for the networked warfighter. CERDEC's areas of focus are (1) develop and transition C4ISR technologies in support of the global war on terrorism and the Department of Defense transformation; (2) proactively support the Army Materiel Command (AMC) Life Cycle Management Commands (LCMCs) and key customers with highly qualified and responsive C4ISR engineers; (3) expand system engineering capability (integrated modeling and simulation, architecture, and experimentation) to support current and future force requirements; and (4) leverage Army C4ISR capabilities for homeland defense.

CERDEC has about 1,600 scientists and engineers engaged in these missions. An important role of CERDEC is the engineering and management support provided to program executive officers (PEOs) and their program managers (PMs) in the development, production, and fielding of systems. The three CERDEC directorates that are the primary S&T leaders for NSTE are the Command and Control Directorate (C2D), the Space and Terrestrial Communications Directorate (S&TCD) and the Intelligence and Information Warfare Directorate (I2WD).

The C2D mission areas are in battle command, portable and mobile power, platform integration and prototyping, environmental control systems, and navigation. The battle command area has two components concerned with NSTE: (1) the command and control component, which develops enabling technologies to support and advance the exercise of authority and direction by a properly designated commander over assigned and attached forces in the accomplishment of a mission; and (2) the integrated ground and air command and control platform systems component, which develops tactical command and control platform systems by designing, fabricating, and integrating the C4ISR systems into vehicular, watercraft, and dismounted soldier platforms.

The S&TCD mission is the focal point for the Army's tactical communications systems and for integrated, secure seamless tactical communications for the digitized battlefield. S&TCD performs research, development, and engineering functions in all aspects of terrestrial, avionic, and space-dependent communications technology. This technology includes adaptive, reliable seamless battlefield communications with full electronic counter-countermeasures capability and information security (INFOSEC). S&TCD has the primary responsibility for DOD communications, networking, and network security. Key areas of investment include information assurance, antennas, mobile networking, and systems engineering.

The mission of the I2WD is to ensure information dominance by providing enemy situation awareness, targeting, and electronic combat technology to the warfighter. The I2WD provides effective intelligence, surveillance, and reconnaissance (ISR) sensors, ISR processing, and capabilities for electronic warfare; air/ground survivability (force protection); information operations; and

ISR modeling and simulation materiel to the U.S. Army. It does this through research, development, prototype demonstrations, and rapid transitions of state-of-the-art technologies into systems, as well as through development, production, and fielding of specified equipment in support of Army and national intelligence requirements.

NSTE development efforts at CERDEC are focused in the following areas:

- Network-aware adaptive applications,
- Mobile ad hoc networking systems,
- Affordable on-the-move satellite solutions,
- Broadband, multi-port, omni-directional antennas,
- Broadband, power-efficient amplifiers,
- Sensor management/tasking, including
  - — Data compression (especially for sensor data),
  - — Onboard processing at the sensor,
  - — Automated sensor queuing, and
- Automated decision aids.

Importantly, CERDEC also addresses the "experimentation" element of NSTE. This is accomplished primarily through the command, control, and communications on-the-move (C3OTM) test bed located at Ft. Dix, New Jersey. This major (~$15 million per year) experimentation effort provides a relevant operational field experimentation venue to assess and quantify the effectiveness of an individual system or a system of systems. It also enables assessment and quantification of the enhanced combat effectiveness provided by technology insertions to the current force, to the Future Combat Systems (FCS) program, and to other programs of record.[2] The C3OTM test bed assesses technical performance using objective, surrogate, and simulated systems. It uses operational mission threads in both scripted and unscripted play, and it develops its own test methodologies, assessment metrics, and automated data collection, reduction, and analysis techniques. The facilities available at Ft. Dix, New Jersey, include 42,000 contiguous land acres under a joint basing concept. The test bed features commercially restricted airspace to support unmanned aerial vehicle (UAV) operations; nearby naval and supersonic air operations; Warren Grove Bombing Range 20 miles south; access to USAF/USN runways, hangars, test facilities and firing ranges; and access to materiel, military vehicles, personnel, and National Guard and Army Reserve units.

Although the committee did not include research on sensors in its NSTE definition, the interfaces of sensors to physical networks are fundamental to Army NSTE efforts. Sensor research is performed primarily at three sites: Ft. Belvoir,

[2]G. Martin, technical director, Communications-Electronics Research, Development, and Engineering Center, "Briefing to the BAST Network Science," briefing to the committee, November 16, 2006.

Virginia, in the Night Vision and Electronic Sensors Directorate (NVESD) of CERDEC; Adelphi, Maryland, by the ARL CISD and Sensors and Electron Devices Directorate (SEDD); and, at Ft. Monmouth, New Jersey, by CERDEC.

Human Performance in Networks

The Army has two primary organizations that perform human, behavioral, and social science research and development. These are the Human Research and Engineering Directorate of the ARL, currently located at APG, and the U.S. Army Research Institute for the Behavioral and Social Sciences, headquartered in Arlington, Virginia.

Human Research and Engineering Directorate

The Human Research and Engineering Directorate (HRED) of ARL is the Army's human engineering laboratory and is the principal Army organization involved in research on human performance in networks. It conducts broad-based programs of scientific research and technology directed toward optimizing soldier performance and soldier-machine interactions to maximize battlefield effectiveness. One of its major functions is enabling the individual soldier, crew, and battle staff to comprehend and manage the vast quantities of data expected to flow across the digitized battlefield in both automated and degraded support modes. HRED has ongoing research in network science and technology in such areas as social networks, control of robotic elements in network environments, human behavior representation in models and simulations, and technology development to improve human-computer interactions. It is establishing a capability to simulate network-centric, distributed environments that are cognitively demanding in order to assess situational awareness behaviors.[3]

Army Research Institute

The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI), part of the Department of the Army Office of the Deputy Chief of Staff for Personnel, G-1, also conducts research to improve human performance. Its mission is to improve soldier, leader, and unit performance through advances in the behavioral and social sciences with a focus on personnel, training, and leader development. ARI was funded in Fiscal Year 2007 to perform research in social networks, and in human collaboration in networks and in social networks. ARI's Armored Forces Field Unit, located at Fort Knox, Kentucky, is scheduled to move under the BRAC in 2011 to partner with network science organizations already

[3]R.J. de Pontbriand, associate director for research, U.S. Army Research Laboratory, "Human Dimension in Network Science," briefing to the committee, August 23, 2006.

in place or moving to APG. In the past, this small unit (fewer than 8 scientists) has conducted advanced development in approaches to training units in digital and networked environments.

Both HRED and ARI conduct research in cognitive processes such as decision making and situational awareness that is applicable to the study of human performance in networks. However, the total resources that they have to conduct broad areas of research to support the soldier make up less than 2 percent of the Army's S&T budget. The number of scientific personnel in these organizations is less than 12 percent of the number in CERDEC. Therefore, without significant additional resources, it will be extremely difficult for HRED and ARI to conduct all of the NSTE necessary to improve human performance in networks.

Other Efforts

Additional research on human performance relevant to NTSE is ongoing at the Natick Soldier Center and the U.S. Army Research Institute of Environmental Medicine, both located at Natick, Massachusetts. The Medical Research and Materiel Command laboratories at the Walter Reed Army Institute of Research facilities in Bethesda, Maryland, also conduct neuroscience research that is applicable to human performance.

Adversary Understanding

Recognition of the importance of adversary understanding to successful military operations is rapidly increasing, but there is relatively little work ongoing other than efforts associated with the immediate training and sensitization of forces deploying to the Middle East. Research in dynamic network analysis, which involves developing mathematical and behavioral technologies to better understand social networks in organizations, including terrorist networks, is funded through ARL cooperative technology agreements (CTAs) monitored by HRED, the Office of Naval Research, and ARI. Current research in adversary understanding includes improvements in tools to enable more efficient user behavior in locating, understanding, and coding data and in updating analyses as new political, economic, military, social, and infrastructure data are acquired. An example of this research can be found in "Destabilization of Covert Networks" (Carley, 2006).

Efforts in Other Network Areas

There are multiple NSTE efforts in network science research ongoing through various CTAs, international technology alliances (ITAs), and university-affiliated research centers (UARCs). These include:

- ARL Communications and Networks CTA: Self-configuring wireless network technologies that enable secure, scalable, energy-efficient, and survivable mobile and sensor networks, currently being funded at $7 million per year.

- The International Technology Alliance in Network and Information Sciences (NISITA): Established by IBM in collaboration with ARL and the UK Ministry of Defense, the NISITA furthers research in network-centric systems to advance the technological capabilities of armed forces engaged in urban warfare and to enhance distributed, secure, and flexible decision making to improve coalition operations. It is currently being funded at $7 million to $8 million per year in both the United States and the United Kingdom.[4]
- Institute for Collaborative Biotechnologies UARC: Biologically derived sensors, electronics, and information processing, currently being funded at $6 million per year.
- Institute for Creative Technologies UARC: Immersive environments through full sensory immersion having three-dimensional mobility with compelling interactive stories, currently being funded at $10 million per year.

Modeling and simulation capabilities, which are relevant to NSTE, are located at APG through the U.S. Army Materiel Systems Analysis Activity (AMSAA), the Army Research Laboratory (ARL), and also the TRADOC Analysis Center (TRAC) in Ft. Leavenworth, Kansas. NSTE is also being conducted through existing acquisition programs, the most comprehensive being the FCS.

CHAPTER SUMMARY

Network-enabled operations have proven critical for today's military and are a central premise for the development of future warfighting capabilities. The developmental basis for these operations is ongoing work in network science, technology, and experimentation at ARL, CERDEC, ARI, and multiple other Army organizations.

Conclusion 2: Current responsibility for NSTE is fragmented across several organizations. As the BRAC relocations to APG occur with concomitant losses in personnel and facilities, the existing NSTE capabilities will be further divided and eroded, hindering essential progress toward improvements in the Army's ability to conduct network-centric operations and warfare.

Recommendation 2: The Army should change its organization and coordination of NSTE efforts to ensure essential support for future warfighting operations.

[4] J. Gowens II and A. Swami, U.S. Army Research Laboratory, "ARL Research in Network Science," briefing to the committee, August 23, 2006.

4

Infrastructure Resources Necessary for Army Network Science, Technology, and Experimentation

This chapter discusses the infrastructure needed for the Army to develop a world-class network science, technology, and experimentation (NSTE) capability. Many of the organizations currently engaged in NSTE will move to Aberdeen Proving Ground, but the committee recognized that much of the NSTE infrastructure would continue to be distributed. Consequently, the chapter also discusses the advantages and disadvantages of distributed and centralized approaches to organization.

All of the network areas shown in Table 2-3 (i.e., communications and information, human performance in networks, adversary understanding, and non-physical network science research areas) have infrastructure requirements that are necessary to support NSTE activities. The first two areas tend to be focused on the development of new capabilities associated with enabling information networks to support network-centric operations and on the social and human networks involved in decision making. Network-centric operations involve people, processes, and information technologies working together to enable timely and trusted access to and sharing of information, as well as collaboration among those who need it. The Global Information Grid (GIG) is the foundation for enabling essential social and human networks that lead to effective and timely decisions. Army NSTE must be capable of supporting development of these emerging complex social/human models.

In addition, there is a need to conduct experiments that can improve the understanding of the usability of these new decision-making networks in a manner that will translate into new capabilities. This improved understanding of information technologies and the decision-making process will also help the Army to develop new capabilities that will deny adversaries similar advantages.

Hence, the NSTE infrastructure being sought by the Army must also be capable of supporting experiments for the development of new technologies to disrupt the information and human networks of adversaries.

INFRASTRUCTURE FRAMEWORK

The infrastructure framework for an Army network science, technology, and experimentation center (NSTEC) must be capable of supporting:

- Development of fundamental network theory and network technologies,
- Assessment of impacts on human performance,
- Integration of new technologies and social networks into capabilities, and
- Experimentation as a means to test and confirm fundamental theories and models and/or to characterize new technologies and operational concepts while also being capable of promoting training of personnel when applicable.

Network science theory currently is focused on fundamentals of information theory, decision making, and understanding of network vulnerabilities. These theoretical foundations are based on those elements of networks that technologies can provide and support, as well as on improving the understanding of how social/human networks evolve with respect to new network technologies (e.g., getting humans connected in different ways—as an example, consider how teenagers stay continuously connected ("24/7") via wireless cell phones, both synchronous and asynchronous). The 24/7 wireless cell phone is more than just voice, including an ever-expanding richness of collaboration and social networking never seen before, as evidenced by new applications of multi-point video, gaming, music, etc.

Theories of networks and decision-making models need experimentation to test or confirm, discard, or modify the principles on which a fundamental understanding of the subject is based. These "network models" are essential to characterize how new network technologies will scale with size or degrade due to "black-outs" and malicious attacks. However, experiments on network models are very sensitive (in a very non-linear way) to the environment, and innovative approaches will be needed to design an infrastructure that enables live and virtual simulations to be performed at geographically separated laboratories.

For some time, there has been recognition that conducting complex network experiments, including social/human behavior, is very difficult in a controlled environment. That is, successfully achieving the integration of interdependent and very mobile/dynamic network technologies and social/human networks is the "Achilles' heel" of successful network experiments. Special consideration must be given to the infrastructure testing environment (complex wireless propagation, mobility, chaotic behavior, etc.) to allow various levels of integration (one-to-one systems, multiple-systems, and system-of-systems), and to allow testing of various technical issues, theories, and models. The importance of integration has been highlighted in earlier "digitization" efforts by the Army, and the essential role of integrating human performance in battle command exercises has been studied in multiple C2 experiments for the Future Combat Systems (FCS) (Lickteig et al., 2003). Other complexities of the system-of-systems integration environment are discussed in Krygiel (1999).

Development of Theory and Associated Technologies

The development of new theories, models, and technologies requires a world-class environment that will foster innovation and "network thinking." A world-class environment should have a university or campus-like feel with interconnected buildings, libraries, open areas (inside and outside) for discussions, public spaces with wireless Internet access, multi-media information displays, conference facilities, and lodging for visitors. State-of-the-art collaboration facilities are needed that incorporate best practices from industry and academia—such as the "smart" rooms (intelligent agent technology, voice/gesture activated, etc.) present at the MIT Media Lab. There will also be a need for some dedicated facilities for secret, top-secret, and sensitive compartmented information.

Theoretical research will require extensive network modeling facilities, including a computing infrastructure with supercomputing capabilities. An improved understanding of the complex, large-scale, and dynamic nature of human and social network interactions will be advanced through the use of high-fidelity models that include physical wireless networks, i.e., complex models that will involve very intensive computations. New approaches in areas such as parallel computing, biological computers, and large-scale network computing (grid computing) will be required. In addition to the computing infrastructure, the investigation of new networking technologies (e.g., large-scale ad hoc networks) places new demands on reconfigurable network labs (with emphasis on wireless functionality) that can quickly adopt new technologies and easily be adapted to human/social networking.

The computing requirements for such research will require an infrastructure that includes a set of dedicated labs (i.e., facilities for sensitive compartmented information, command and control, advancing networking, etc.) that are designed around a controlled environment with human subjects as participants. An NSTEC would also have to establish laboratories in field locations with access to soldiers and leaders who can serve as subjects in experiments. These field-location laboratories must be dedicated sites that are highly instrumented and allow for the collection of data that can be analyzed and used in developing new models and refining a theoretical understanding of network characteristics and applications.

In addition, these dedicated labs would host new information technologies (e.g., physical networks, command and control, networked sensors, etc.). Some labs, for example, might host a set of technologies dedicated to research on adversary networks. Due to the necessary levels of security and nature of this work, these special dedicated labs would require that isolated and secure networks be in place that could quickly improve awareness of vulnerabilities and promote the development of new technologies to deny network-centric operational capabilities to adversaries.

High-capacity (i.e., gigabyte) optical fiber and wireless (Wi-Fi and next-generation 802.xxx systems) networks are key enablers for mobile multi-point and multi-media (data, voice, video, etc.) information transmission. These networks would ensure GIG connectivity to the other Army and governmental organizations concerned with network advances, such as the Army Materiel Command, Department of the Army staff, the Army Training and Doctrine Command, the Army Intelligence and Security Command, the Defense Information Systems Agency, and the Department of Homeland Security. An optical fiber backbone would enable access to a rich set of network services (including security authentication, data management, collaboration, discovery, etc.) as well as to other NSTEC facilities and test ranges. All facilities and the computing infrastructure would need to operate through this high-capacity backbone and be interconnected with all associated sites. Given the classified nature of some work, these networks would have to be secure and approved for use at different levels of security classification (e.g., secret level, top-secret level, sensitive compartmented information, etc.).

Human Performance in Networks

Critical nodes in the Army networks of today and in the future are the soldiers and leaders who (1) seek and use complex information from networks; (2) must quickly make decisions based on that information and communicate and collaborate with subordinates, peers, and superiors over the network; and (3) control actions and equipment on other network nodes. In the areas of human performance, the focus of the NSTE infrastructure framework is on "intellectual capital" and research that is complementary to network science theory, integration, and experimentation. Indeed, the dynamic configuration of the networks per se should be driven by the human need for information and connection necessary to make decisions. Four actions are required to ensure that human performance in networks is optimized:

1. A substantial increase in ARI and HRED efforts is needed if research on human performance in networks and adversary understanding is to have any impact. This does not mean a change in emphasis solely to add network-related research: both ARI and HRED have important research missions without the addition of network research, and that other research

is funded at levels that are barely adequate. The committee believes that the Army definitely needs to have more personnel than the roughly 15-20 scientists who are currently conducting or scheduled to perform research in behavioral and social science areas related to networks at ARI and HRED. Substantial growth in both personnel and resources is called for, with something on the order of 20-25 percent of the Army's fiscal and personnel resources for NSTE dedicated to human performance in networks and adversary understanding.

2. Hire or retrain in-house scientists in such relevant areas as social networks, decision making and other cognitive processes, behavioral representation and modeling, performance measurement, and neural sciences.
3. Require teaming between information, human factors, and behavioral scientists so that network interfaces are compatible with human capabilities and information requirements to promote flexible and reconfigurable networking.
4. Ensure that the impact of research in information and communication science is measured in terms of how it benefits human performance in the network, both in the laboratory and in field environments. This will require new experimental paradigms and measurement techniques and tools (as described in the section titled "Experimentation" below in this chapter).

Integration of New Technologies

As mentioned earlier, an integration capability that can handle the increasing complexity of interdependent technologies and a scale of experimentation that includes human/social networks is essential. This will call for a network science integration facility (NSIF) that should include several key components as follows:

- A large-open-space laboratory area to allow the integration of network technologies onto platforms (vehicles, robots, humans, etc.),
- The ability to accommodate a scale-up of as many as several hundred nodes (i.e., a number representative of the types of networks the Army plans to field; known also as the "sub-net topology") in a virtual network with the capability to have a large fraction of the nodes in motion, and
- Full instrumentation (including for social/human networks) to allow detailed diagnostics of integration and performance issues.

The NSIF should be connected with other network test beds, such as those of the Army Future Combat Systems (FCS) program, and it should be able to exercise control over other network test beds as necessary to expand overall experimentation capabilities. The NSIF networks will require significant networking capacity with external networks; indeed, extending the Department of Defense Information Systems Network (DISN) GIG into the NSIF environment should be a high Army priority, regardless of expense.

Integration with network systems outside the NSIF will enable the connection of various elements of research in a manner that allows interoperability and performance issues to be characterized and resolved. In addition to the DISN GIG, this integration should include the networks of other DOD services, federal agencies (intelligence, Department of Homeland Security (DHS), health, local, etc.), and selected coalition/multi-national partners.

Experimentation

The DOD has long embraced experimentation as a fundamental tool for building capabilities. As in the physical sciences, experimentation is essential in this case for improving fundamental understanding and expanding knowledge in the areas of information and communications, adversary understanding, and human performance in networks. In addition to the necessary infrastructure and tools, successful experimentation requires a culture for "new system thinking," committed leaders (because experimentation is naturally disruptive of the status quo), and skilled personnel.

The basic infrastructure and tools needed for the experimentation environment are discussed in Boutelle and Grasso (1998) and NRC (2004). These include:

1. Information and physical infrastructure
    a. Networks
    b. Information repositories
    c. Architecture frameworks
    d. Test facilities and integration capability
    e. Training facilities
    f. Places and platforms

2. Tools
    a. Modeling and simulation
    b. Prototypes, surrogates, etc.
    c. Artificial environments
    d. Data capture and dissemination

Most experiments will require networking connectivity and capacity as well as computing power and data storage. In addition, experiments will be dependent on the existence of accepted operational, technical, and system architectures for the integration of assets and their application to scenarios and missions. Having data repositories with such information readily available and accessible to other locations can ease experiment planning and support the extension of results to other cases or scenarios (NRC, 2004).

An instrumented test range requires a physical infrastructure. As discussed earlier, core facilities for such things as simulations, war games, integration and testing, and training must all be provided as part of a distributed test range. The associated facilities must be equipped with the basics of uninterrupted power, good lighting and ventilation, suitable climate control, and adequate space as well as any specialized equipment needed for specific activities. Equally critical is the timely availability of networked vehicles across distributed experimental ranges, aircraft, and the various platforms that are integral to the experiments. Major elements of an instrumented-distributed test range for Army NSTE should include:

- A facility of ~100 nodes, most or all of which can be in motion (representing vehicles, in a typical future Army sub-net);
- The CERDEC Fort Dix command, control, and communications on-the-move (C3OTM) test bed that is fully connected back to an NSTEC and other Army test ranges (e.g., central technical support facility (CTSF) at Ft. Hood, Texas, Army FCS at Ft. Bliss, Texas, etc.); and
- The ability to conduct "adversary network attacks" and appropriate diagnostics.

As the Army learned from its earlier experiments in digitization, the integration of the above test ranges will be critical to supporting future experimentation objectives (Boutelle and Grasso, 1998; Krygiel, 1999). The ranges will combine with other components to allow collaboration experiments and a wide exchange of new innovative concepts.[1]

External network facilities need to include:

- Capability to connect into all elements of NSTE infrastructure, including ranges and network C2 lab facilities;
- A network C2 facility for ~50-seat fixed nodes completely under the control of an NSTEC;
- Configurable laboratory space (similar to the CTSF at Fort Hood) to allow for participation by representative command elements (i.e., C2, battle management, squad/company/battalion/brigade, joint/multi-national); and
- Ability to connect/interact with other external C2 facilities (e.g., Fort Dix, Fort Hood, universities, joint experimentation facilities, etc.).

Ultimately, experiments must support embedded and distance training and learning capabilities via a system that links platforms into a virtual environment

[1]A high-capacity and flexible external network is necessary to conduct related research and other S&T together.

that will be necessary to provide an appropriate level of realism in live experimentation conducted across a large network. Connecting remotely into training systems that are integrated into platforms will help operators and experimental investigators to shift seamlessly between training and experimentation. Note that the operators of the units participating in experiments must be aware of such goals and be well trained in their usual roles as well as agile enough to handle new, and networked, surrogate systems and new concepts. The spectrum of experiments to be conducted would include human-in-the-loop experimentation, prototypes, surrogates, and stimulators. Artificial environments sometimes would be required.

As previously noted, network science experimentation requires new "tools" with emphasis on an integrated family of models ranging from customized spreadsheets and war games to high-resolution simulations. These tools should include a sophisticated system for data collection and information capture, and they should provide a capability for interpretive analysis so that learning derived through experiments can be put to use in informing decisions about future forces (NRC, 2004). Simulation and stimulation facilities, such as those currently at the CTSF at Ft. Hood and at the National Training Center (NTC) at Ft. Irwin, California, are necessary to provide capabilities regarding:

- Force-on-force and counterinsurgency;
- Intelligence via remote sensors (e.g., unattended ground sensors); and
- Modeling of complex environments (e.g., urban/town), as well as adversary social networks (e.g., tribal, financial, political, etc.).

Table 4-1 summarizes key NSTEC infrastructure elements and the features of each element. The table highlights characteristics of the infrastructure necessary to support NSTE in priority network science areas and to accomplish the mission recommended (see Recommendations 1a and 1c in Chapter 2).

Development of the NSTEC capabilities and infrastructure could be phased over multiple years, and there are several reasons why a phased implementation approach might be the most favorable for the Army. Foremost is the erratic nature of government funding for the BRAC, which has already affected the BRAC timetable. The requisite talents and skills of the leadership team that is needed are likely to be significantly different for different phases. Moreover, the content of the NSTE R&D portfolio will change as the infrastructure for the center is established and the new organization matures. Phase 1 might include infrastructure inherited from the existing BRAC planning that could later be integrated into the NSTEC. Phase 2 might include the infrastructure needed to "stand up" distinct NSTEC facilities at a target date, and Phase 3 might encompass the infrastructure needed for future growth and modernization due to expected advances in network science knowledge and technology.

TABLE 4-1 Elements of NSTEC Infrastructure

Elements	Features
NSTEC campus facilities	• Interconnected buildings, libraries, open areas, Wi-Fi (wireless Internet) access, conference facilities • Smart rooms (intelligent software agent technology, voice/gesture, etc.) • Secret/top-secret/sensitive compartmented information facilities • Dedicated network innovation labs Fully instrumented Human performance Mobile and C2 networks, networked sensors, etc. Adversary networks
Networks and services	• High-capacity (Gb) optical fiber (multiple colors) • Wireless LAN, Wi-Fi, and next-generation 802.xxx • Labs interconnected with conference and demonstration facilities • High-capacity backbone inter-connections to all labs • DISN (GIG-BE) DOD network to APG • Firewalls, gateways, and security guards (support multi-level security) • Virtual private network (VPN) services • Security services (authentication, access, etc.)
Computing	• Supercomputing capabilities • Parallel computing, biological computing • Information technology (IT) computing (researchers computers, software, mobile wireless devices, etc.)
Data storage	• Robust and secure repositories • Search engines and accessibility • Data capture and dissemination
Application services and tools	• Architecture framework tools • DOD NCES (Net-Centric Enterprise Services) to include collaboration, security, management, etc. • IT applications (e-mail, business, human services, etc.)
Simulation and stimulation	• Force-on-force • Sensors • Complex environments • Adversary networks • Artificial environments
Instrumented and distributed test ranges	• Ft. Dix C3 on-the-move test range modernization • Army FCS test ranges • Army's Ft. Hood central technical support facility • APG test range modernization

TABLE 4-1 Continued

Elements	Features
Integration, testing, training, and experimentation facilities	• Network science integration facility (NSIF) • Training facilities (10,000 sq. ft.) • Platforms (20, increasing to 50) • Prototype fabrication labs • Surrogates • Large-open-space lab (30,000 sq. ft. growing to 100,000 sq. ft.) • Network instrumentation: three phases—scale from 20 nodes to 100 nodes
Human performance (intellectual capital)	• Communication and collaboration tools (multi-point computer, video, and audio conferencing) • Intelligent computer software "agents" to enable enhanced collaboration and improved understanding of human performance

ORGANIZATIONAL ELEMENTS OF AN NSTEC

In addition to the infrastructure needed to support a center for NSTE, a full NSTE capability will also involve government, industry, and academia, and all three must be considered in determining an organizational approach for an Army NSTEC. The unique contributions of each of these groups are described below.

Army Contributions

Chapter 3 discusses the NSTE activities that are meeting current Army needs. The primary Army organizations engaged in NSTE are ARL (ARO, HRED, and CISD) for basic research; CERDEC (C2D, S&TCD, and C3OTM test bed) for applied and advanced research and technology development; and ARI for basic, applied, and advanced research. The estimates of annual NSTE investments in these three organizations are ARL, ~$70 million; CERDEC, ~$75 million; and ARI, ~$2 million, with corresponding staffing. The committee sought more detailed information on the actual funding levels and staff related to NSTE, but the Army was unable to supply usable data.

Academic (University) Contributions

Universities provide access to state-of-the-art research at all levels, including the global level. A steady and continuing relationship with academia can ensure responsiveness to evolving Army sponsorship requirements as well as comprehensive understanding of the sponsor's requirements and problems. It will be important for an Army NSTEC to engage multiple universities in providing broad and diverse thinking on relevant advances in network science.

Other contributions made by academia may include:

- Broad access to information, including proprietary data;
- Independence and objectivity;
- Quick response capability; and
- Freedom from real and/or perceived conflicts of interest.

Industry Contributions

Industry provides the path most frequently used by the government for transitioning technology to the operating forces. Relationships with industry can also provide an NSTEC with knowledge concerning best commercial practices and cost-effective approaches. In addition, industry can provide commercial surrogates and prototypes (e.g., state-of-the-art wireless systems and networks), access to large-scale system architecture, engineering and integration expertise, models for commercial networks and information systems, general logistics support in experimentation preparation and execution, and commercial tools to aid analysts in interpreting data.

Other contributions made by industry include:

- Broad access to industry information, including proprietary data;
- Broad access to specialized facilities (e.g., software integration); and
- Support for technology transfer agreements between government and industry.

Scope and Structure

An NSTEC would be established to perform S&T in network science, network technology, and network experimentation. As discussed in Chapter 3, a considerable amount of NSTE work, on the order of $150 million annually, is funded by the Army today. However, current efforts in network science research are not adequate for Army needs, and there are important network areas that are not being addressed by the Army S&T program (NRC, 2005). In order to form an NSTEC, the Army would need to consolidate its efforts in network technology and experimentation and combine them with an augmented program of network science research. The importance of networks to military performance is increasing rapidly, and NSTE deserves substantially increased attention by the S&T community.

In the long term, the NSTEC should become a joint entity serving the needs of all of the U.S. military services in a coherent, collaborative fashion. While addressing the Army's current needs seems to be a practical first step, a longer-term vision should be maintained by NSTEC management. This is an important issue that will impact the scale and scope of the research and basic technology efforts in NSTE.

Centralized Versus Distributed Facilities

Just what should an NSTEC look like? Should the emphasis be on an attractive central campus featuring buildings and infrastructure, or is a virtual "co-laboratory" of distributed activities more appropriate? Do the imperatives of existing resources suggest an immediate change or an incremental approach to implementation? One thing is clear—an NSTEC, to be a world-class organization and a key contributor to the Army's future success, must attract first-class talent, and that means providing cutting-edge challenges for top-flight scientists and engineers, providing them an environment in which to strive and achieve.

An obvious but far from optimal version of an NSTEC would involve merely relocating elements of various existing Army organizations to a centralized government-operated location such as Aberdeen Proving Ground. To be effective, any such relocation should involve an attractive physical plant with state-of-the-art technical facilities. This alternative could be considerably enhanced by delegating existing special authorities available to the Army for utilization by an NSTEC in areas such as personnel management, acquisition, and other financial and business practices.

The advantages of a distributed (versus centralized) NSTEC include:

- Access to highly talented and specialized knowledge and expertise in the large field of network science that can be leveraged globally;
- Cost-effective and efficient global access to specialized facilities, such as the MIT Media Lab, Microsoft labs, National Security Agency labs, and operating force experiments (e.g., regional joint forces experiments);
- Access to specialized platforms (e.g., aircraft, ground vehicles, ships, etc.);
- Access to industry and university laboratories and expertise; and
- Distributed operations that mirror how the Army fights in the field.

The disadvantages of a distributed (versus centralized) NSTEC include:

- Increased management overhead due to many distributed moving parts;
- Increased operating expenses (external networks, management, etc.);
- Information sharing across a large distributed environment involving data repositories and content staging cost and complexity; and
- Increased security risks.

CHAPTER SUMMARY

There are key elements of infrastructure that will be essential to the creation of a center for NSTE. Current and ongoing NSTE activities in the Army provide a firm basis for the infrastructure requirements that would be needed to establish an NSTEC. The key elements of the required infrastructure are listed in Table 4-1.

Options for physical realization of an NSTEC range from the extremes of a centralized facility in a single location to fully distributed facilities using networked connectivity. There are advantages to both; but regardless of which is selected, there will be important needs for contributions from academia and industry, which will require interconnections to many locations.

Conclusion 3a: The extensive infrastructure needed to support Army NSTE requirements will be developed initially from the facilities of existing organizations and will require a special planning effort to synchronize with BRAC relocations already in progress.

Conclusion 3b: The magnitude and diversity of the required infrastructure suggest a phased implementation approach to establish an Army NSTEC. A plan to develop NSTE capabilities and infrastructure could be phased over multiple years, beginning with the reorganization of existing and relocated facilities and ending with the establishment of a world-class center for network science, technology, and experimentation. An adequate plan will involve leadership with the appropriate talent and vision for all phases, especially as the content of the NSTE R&D portfolio matures.

Conclusion 3c: Based on Army needs, the NSTEC should be a hybrid operation consisting of two or three centralized facilities having interconnectivity to a variety of distributed supporting elements.

Recommendation 3: The Army should plan and fund for NSTE infrastructure resources that provide for (1) flexible configurations of network experiments and integration, both internally and externally; (2) facility designs that enhance and encourage academic and industry partnerships; and (3) an environment with world-class experimental capabilities and a campus-like atmosphere to attract truly talented people.

5

Goals, Models, and Alternatives for an NSTEC

This chapter discusses organizational goals, operating models, and other issues considered by the committee that bear on the development of alternatives for establishing an Army center for NSTE. The committee recognized that the potential creation of an NSTEC would realistically occur in an environment of existing organizations and resources, legal constraints, and plans in progress. However, the committee believed that merely yielding to what seemed a likely or inevitable course of development strictly based on these circumstances was not the most useful perspective from which to conduct its study. Whatever model is used, basic organizational goals for an Army NSTEC should be kept in focus.

ORGANIZATIONAL GOALS

Decisions involved in setting the best organizational structure should be grounded in a clear set of goals that take into account and balance historical experience and current conditions, while allowing some flexibility in dealing with changing conditions in the future as fundamental understanding of networks increases and innovations in network applications emerge. At its core, the organization must be able to attract (i.e., compete for) and wisely use the intelligence and talents of scientists and researchers; adequately partner with the creativity and innovation of the private sector (including industry and academia) concerning the application of network structures; and deliver results that meet the special needs of military operations. The organization must be able to achieve each of the above well into the future under uncertain economic, political, and social conditions, and unrelenting technological change. This section explains in greater detail the core goals and their implications.

Attracting and Retaining Human Talent

When assessing the needs of highly qualified people, several issues require attention. Studies suggest that the most important factor in attracting and retaining talented technical professionals is challenging work in the field of their chosen endeavor. In the long term, several unknowns directly related to the emerging field of network science impact the kinds of work incentives that can be offered. These unknowns include:

1. Whether network science as a field of study will connect sufficiently with industry objectives so that increasing job opportunities and work challenges arise that attract the best young minds;
2. Whether network sciences will evolve so that new skills and abilities emerge that support more learning opportunities and thus career longevity;
3. Whether network science as a field of work will evolve in a stable pattern (as opposed to fits and starts that lead to career instability); and
4. Whether new professions, occupations, credentials, and job specialties will emerge in the field of network science that fit well within the federal governmental system.

The answers to these unknowns will determine whether the Army is in a position to support long-term careers in network science and thus get the technical and military-related results needed from an NSTEC. If network science develops in a manner that successfully addresses the unknowns listed above, then the Army will be well positioned to deal with more traditional key issues such as developing management so that good management is the norm and is supportive of a positive work atmosphere; offering continuously available attractive job benefits; using innovative organizational structures; and managing to encourage a team orientation to research work so that strong career relationships emerge.

In the near term, the incentives needed to compete for qualified people may be within the Army's reach. They include competitive salaries and benefits; policies supportive of rewards and recognition; attractive work/life balance in jobs; family-friendly policies; opportunities for educational advancement; attractive on-site amenities; and flexibility in work culture (flexible dress and environment). For exceptionally qualified people, other incentives come into play and may be more difficult for the Army (or any federal lab) to offer due to legal constraints. These incentives include competitive salaries and housing assistance in high-cost areas of the country; first-class relocation assistance; and support for child education. Finally, incentives that promote diversity in terms of race, ethnicity, national origin, and culture, including assistance with immigration issues, may be important to members of the workforce now and likely even more so in the future.

Partnering with Industry and Academia

There is a long history of federal laboratories and research connecting with and partnering with private industry and academia. This experience can suggest ways by which the organizational goals of an NSTEC could be fulfilled, e.g., by enabling new network science applications for the military. As with the computer and biological sciences, the creative and innovative lead in exploiting network science clearly exists in private industry and academia. The private sector has been responsible for bringing most of the practical network science applications, especially computer and communications network technologies, into the service of both consumers and the military. Without access to the talents and resources of private industry, it would be impossible to stay on the leading edge of network science applications, much less continually and economically create special versions of such applications suited for military applications.

While history provides examples of successful collaborations between government and the private sector, the NSTEC approach to partnership should be multi-dimensional and not limited to standard models. The participating parties and forms of collaboration will depend on the types of research undertaken. For example, a project involving engineering improvements to field wireless capabilities of current communications networks would benefit from industry involvement.

Other types of projects require other strengths. An experimental exploration of how to make timely decisions utilizing massive data sets from large-scale data fusion test facilities would have to involve leading-edge academic efforts in data fusion, social networking, and modeling. This would allow well-framed questions to be examined such that predictive (and therefore practically useful) results could be obtained. Other types of projects, e.g., defining how both large and small military units could utilize advanced network communications capabilities to improve command and control, might involve partnering with industry or academia or both in combination.

An Army NSTEC must be prepared to exploit the most relevant research capabilities wherever they might be found. This requirement will involve structuring a wide variety of partnership arrangements, from simple to complex, based on determining the directions of research with high potential payoff. Collaborations need to be nurtured that combine the knowledge and competencies of both the academic and the industrial world, encouraging partnerships in the development of future military capabilities.

Meeting Special Military Needs

The growth of network science and applications will fuel the global availability of network technologies in the consumer market, in turn leading to competition-driven technological innovation. These products and services will sometimes have direct military applications for network-centric warfare; however, in many cases they will have to be modified for military use. A core organizational goal for an NSTEC would be to develop these special applications quickly and economically. Similarly, advances tailored to military needs will require vision and focus, as well as unprecedented agility in coordinating diverse efforts. In this regard, it will be particularly important for an NSTEC to leverage industry efforts and to avoid duplicative investments in technology development.

One highly successful model of government and industry collaboration dates back to the pioneering days of aviation. Specialized facilities (primarily wind tunnels) of the National Advisory Commission on Aeronautics (NACA) were made available to industry to test and evaluate industry developments. This arrangement created a natural forum for government and industry experts to interact to their mutual benefit. The world-class facilities and infrastructure of an NSTEC may prove attractive to industry for its own experimentation and demonstration purposes. This in turn could create a forum for productive interchanges between NSTEC researchers and the broader community of network scientists.

The primary aims of collaboration and partnering between the military and private industry are access to technology and intelligent people, as well as the sharing of research and development costs. Secondary but also important reasons concern local economic development (including jobs) and support of education (especially higher education). Such collaboration helps in sustaining long-term U.S. global economic and technological competitiveness. All of these aspects are relevant for the general advancement of network science. Thus, making collaboration between people on both sides (private and government) easy, and making technology transfer between industry and the government as smooth as possible, should be viewed as primary goals for an NSTEC organization.

Private industry most likely will not be in a position to readily leverage benefits from government-sponsored research in network science, especially that which may be critical or essential to invention or innovation for military purposes. The pace of development of commercial products for the marketplace is much too fast to depend on government-funded research. Therefore, it might be necessary to provide incentives for business to collaborate with government in such instances.

Effective incentives for collaboration might include easier technology transfer; programs that simultaneously foster local economic development; technical and financial support to private enterprise (especially for smaller businesses); access to laboratory facilities for industry research and testing; and programs that support local education and thus contribute to increasing the talent pool. Collaboration with industry can also be assured through strong mandates and reward systems for collaboration within the labs, clear congressional and administration support for government-industry collaboration, and funding support within the labs.

OPERATING MODELS FOR NSTEC GOVERNANCE

The operating model chosen for NSTEC governance should be capable of addressing the following key elements:

- Bringing the best and brightest minds to bear on the networking problems confronting the military;
- Ensuring incentives for motivating the workforce;
- Minimizing the effects of technological obsolescence on personnel and research equipment and infrastructure;
- Establishing effective collaboration throughout the Department of Defense (DOD) and with other agencies of government, the private sector, and internationally;
- Enhancing joint service/combined operations networking; and
- Adopting technology, management approaches, and business practices that optimize or smooth the path for the flow of technology into fielded military capabilities.

Box 5-1 shows that these goals are consistent with criteria developed by the RAND Corporation to assess optimal operating models for military R&D laboratories (Owen et al., 2001).

Structure

An Army NSTEC should have strong and effective management, be supported by state-of-the-art infrastructure, and be attractive to top-flight scientists and technologists. The leadership of an NSTEC should be supportive of the technical interests of an excellent workforce, foster a spirit of innovation, and be proactive in advancing the leading edge of network technology. Policies should be adopted that support:

- Long-term career development and stability to make work at the NSTEC an attractive career step for up to 5 years;
- Management development for proven managerial talent;
- An expeditious hiring process;
- Opportunities for creativity on the job;
- Use of innovative organizational approaches;
- Competitive salaries/benefits; praise/reward/recognition policies; family-friendly policies; educational advancement; and a flexible work culture; and
- Attractive state-of-the-art facilities and on-site amenities.

BOX 5-1
Key Attributes of an Army
Network Science, Technology, and Experimentation Center

- Understand and influence the Army's long-term vision in order to maintain military technological superiority.
- Plan and direct a research program to implement the Army vision.
- Influence and leverage commercial technology/system developments.
- Conduct high-quality, revolutionary government-funded research, development, engineering, and analysis in key advanced technologies/systems.
- Conduct high-quality, comprehensive, evolutionary government-funded research, development, engineering, and analysis.
- Perform the "smart-buyer" function for current and future materiel acquisitions.
- Plan and direct the integration of technologies into current and future weapon systems.
- Evolve as necessary to effectively and efficiently achieve mission goals.

SOURCE: Adapted from Owen et al., 2001.

To compete at the highest levels, the Army should additionally consider incentives such as the following:

- Housing and relocation assistance;
- Support for child education;
- Programs to address workforce diversity in terms of race, ethnicity, national origin, and culture; and
- Provision for a budget commitment to the top 10-20 percent of recruits for capital equipment as part of the hiring process, thereby allowing recruits to select equipment in an arrangement analogous to a university "start-up package" model.

Special Authorities

If all or part of the NSTEC will be a government-owned, government-operated laboratory or network of laboratories staffed primarily by a civil service workforce, full advantage must be taken of existing management flexibilities afforded by special authorities, particularly those in the areas of personnel and procurement.[1] As a prerequisite to taking advantage of these flexibilities, NSTEC leadership must encourage line managers and affected staff officers (including contracting and personnel officials) at all levels to use such nontraditional methods when appropriate, and make available specific training for doing so.

The value of flexible personnel management and procurement techniques is not necessarily immediately obvious, at least to federal insiders. As some may observe, most of the federal government usually operates by using standard legal authorities to conduct its business, which may lead one to ask: Why do anything different? The simple answer is that many organizations get by on sub-standard management systems and practices; unless challenged to be top-flight or world-class organizations, they will not necessarily recognize the need to do things differently.

Personnel

If an Army NSTEC is to perform world-class research and technology development, it will have to be a world-class organization with world-class talent. These "best and brightest" have many career opportunities available to them and are much less likely than less-talented candidates to wait through the months-long hiring process that is often standard in the federal government. The traditional federal personnel hiring sequence—(1) classify a position, (2) recruit candidates, (3) evaluate candidates, and (4) make an offer—is simply not the optimal system for an organization such as that being envisioned for an NSTEC. Instead, a system whereby the best and brightest talent among network science technologists are being constantly sought is preferred, e.g., via an ongoing competitive procedure for appointments. Rather than filling an already classified position, an alternative sequence on a much shorter time scale will often be appropriate, such as, for example, (1) identifying a highly qualified candidate in a key area of network science, (2) creating a position attractive to the candidate and the NSTEC, and (3) making an offer. Such a sequence can be completed in weeks or even days rather than months and is an approach that has been used successfully by the Defense Advanced Research Projects Agency (DARPA).

The full extent of authority available to create alternative personnel systems within the DOD has often been underutilized either by inaction at DOD top levels, or by the inability of responsible human resources professionals to fully embrace nontraditional concepts (Coffey et al., 2003; DeYoung, 2003).[2] In 2008,

[1]Maximizing available existing special authorities is an alternative for Army laboratory governance referred to as "baseline plus" (Owen et al., 2001).

[2]Letter from J. Lieberman, J.M. Inhofe, M.L. Landrieu, J. Bingaman, E.M. Kennedy, B. Nelson, and J. McCain, to Donald Rumsfeld, Secretary, United States Department of Defense, highlighting "our concerns with the Department of Defense's efforts to recruit and retain top-flight scientific and engineering talent for its laboratories," in a press release dated August 5, 2002. Additionally, the head of the DARPA Human Resources Directorate told a member of the committee of the apparent inability of some other DOD human resources specialists to comprehend the DARPA approach.

the national security personnel system (NSPS) might become applicable to DOD organizations performing NSTE. There is no reason to believe, however, that the NSPS will afford an NSTEC, or any other laboratory organizations, more flexibility than is already available to them. Arguably, the NSPS may be viewed as a step backward from alternative approaches.[3] Meanwhile, the DOD plan to implement the NSPS has been partially thwarted because key elements of the NSPS have been permanently enjoined by court action (USDC, 2006).

For the most part, statutes authorizing laboratory demonstration projects and similar projects allow flexibility within existing federal pay levels (most commonly used are "pay bands"), but do not necessarily authorize federal employees to be paid at competitive rates in circumstances where job market rates exceed federal limits. However, authority to exceed normal federal pay limits does exist under at least two available authorities, but only for limited terms. One authority is the Intergovernmental Personnel Act (IPA), which allows personnel from eligible organizations (typically universities) to come to the federal government and act as federal employees for 2 to 4 years while being paid by their sending institution. The federal government reimburses the sending institution in whole or part for the expense of the employee's salary and benefits. The second authority (known as the "experimental personnel authority") was pioneered by DARPA but is available to any designated DOD laboratory. Terms are up to 4 or 6 years. Salary and bonuses for specially qualified scientists and engineers may considerably exceed normal federal pay limits.[4] Such term-limited employment arrangements can generate a continued flow of "new blood" (and more pertinently, new ideas) into the organization.

Procurement

As with the federal personnel system, the federal procurement system seems to function adequately, and its weaknesses may not be immediately apparent. The federal procurement system is very extensive and involves a variety of players ranging from Congress and the President to a myriad of contracting officers, contract administrators, inspectors, auditors, and others. Moreover, it is complex, involving laws; formal and informal regulations, guidance, and standards; court and administrative decisions; and its own lore. This complexity has led

[3]For example, since 1980, a number of the laboratory demonstration projects under various authorities have often achieved a noteworthy degree of success using alternative approaches to staffing requirements.

[4]The IPA is found at Title 5 USC 3371-3376; the "experimental personnel authority" was originally authorized by Sec. 1101 of P.L. 105-261 and extended by Sec. 1116, P.L. 108-136 (see Title 5 USC 3104 note). If the Army NSTEC were to become a world-class organization and present challenging technical problems to the scientists and engineers employed there, it might not be necessary to match the private sector job market dollar-for-dollar in order to attract outstanding talent. However, financial compensation so low as to require a significant sacrifice on the part of potential employees will undoubtedly have an adverse effect.

observers to make such comments as, "If someone were asked to come up with a contracting system for the federal government, it is inconceivable that a reasonable person or committee of reasonable people could come up with our current system" (Nagle, 1992, p. 519).

Additionally, the effects of the regulatory nature of the federal procurement system have been aptly described by one expert in the following terms:

> A body of laws, regulations, and practices has developed that control the many daily procurement actions between DOD and its suppliers. Although each of these may have a valid historic rationale, the result is that there are only a few firms skilled in conducting defense business, and they may be totally isolated from, and uncompetitive with, their commercial counterparts. Even firms that operate in both military and commercial worlds are forced to separate the two parts of their operations. . . . Other commercial firms simply refuse to accept R&D contracts from DOD because of their specialized rules. (Gansler, 1996, pp. 23-24)[5]

Having separate procedural business practices for defense industry projects and the broader commercial sector presents real-world problems. In areas such as network science, where cutting-edge research is being conducted by non-defense firms, means must be found by which these separate ways of conducting business can be bridged. Means for overcoming other barriers that exist between commercial firms seeking entry to the federal procurement system and defense contractors likewise must be found. A key role for an organization such as an NSTEC will be to form relationships or partnerships with both the non-defense sector (commercial industry and academia) and the defense industry to help bridge the gap. How an NSTEC could conduct its business would be critical to that effort.

Standard contracting vehicles used in government laboratory R&D contracting include the procurement contract (typically a cost-reimbursement type contract), assistance instruments (grants and cooperative agreements), and the cooperative research and development agreement (CRADA). These are used respectively to (1) acquire goods and services for the direct benefit and use of the government, (2) stimulate and support private sector activities that have a governmental purpose, and (3) transfer government technology to the private sector and involve the private sector in government R&D. However, the statutory purpose and approved uses of these contracting vehicles were not necessarily intended to be applicable to multiple objectives on the part of the government, nor were they necessarily designed for complex transactions involving multiple parties.

The standard procurement contracting authorities can be used intelligently

[5]The situation described by Gansler more than 10 years ago has worsened. There are barely half a dozen large contractors capable of performing the role of system integrator (prime contractor) on major defense procurement programs. The isolation of the defense industry from the broader commercial sector continues at other levels as well.

and flexibly, but layers of bureaucracy, excessive oversight, and certain inflexible rules often deter their innovative and optimal use. Government intellectual property rules, government cost and accounting standards, and the complexity of government regulations can limit the willingness of private sector parties to participate in government R&D programs. There are, however, a number of statutes that permit government research, prototype development, and acquisition for experimental purposes to be done outside the purview of the basic laws and regulations that traditionally are used for government procurement.[6]

To perform contract research or carry out prototype projects, an Army NSTEC should make routine use of these "other transactions" authorities in preference to using standard authorities.[7] These authorities allow, or in certain circumstances require, cost sharing. Cost sharing and recovery of funds should be considered in projects that have potential commercial implications as well as military payoffs.[8] Costs that are recovered under these authorities can be used to fund additional research. Cost recovery should not be a primary goal of any project, but it should not be overlooked. Note also that signal equipment (a key element of communications networks) can be acquired in experimental quantities outside the normal procurement statutes.[9]

In order for an NSTEC to make full use of the special acquisition techniques inherent in these statutes, it is essential that DOD and the Army delegate adequate authority. Other than reporting requirements, any existing DOD and Army limitations on the use of these authorities should be lifted, and the NSTEC should be allowed to experiment and innovate to the full extent consistent with the statutes themselves. Any funds recovered under these statutes should become available to the NSTEC.

A number of DOD organizations have already made effective use of the special acquisition authorities referred to above. For example, these authorities have been used to support research projects, especially those involving consortia of diverse firms, government agencies, and organizations. Useful examples are available from DARPA and the Army Research Laboratory consortia. This form of contracting has the potential to be particularly attractive to commercial firms due to its simplicity, flexibility in crafting intellectual property provisions, and the avoidance of cost-reimbursement contracting.

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[6]Primary statutes in this regard include "Research Projects: Transactions Other Than Contracts and Grants" (Title 10 USC 2371); "Section 845" prototyping (Title 10 USC 2371 note); and "Procurement for Experimental Purposes" (Title 10 USC 2373).

[7]Despite the statutory requirements related to these authorities, their "routine" use is indeed possible to support R&D projects given an understanding of what is actually involved in research or prototype development.

[8]Cost-sharing contracts (FAR 16.303) and cost sharing or recoupments (FAR 35.003) are both possible using standard procurement contracts. Cost recovery under Title 10 USC 2371 is more flexible than recoupment and not limited to the total amount of the government investment.

[9]The authority under Title 10 USC 2373 to purchase ordnance, chemical, and aeronautical supplies may also prove useful.

Major prototype projects conducted by a number of DOD agencies under Section 845 of Title 10 USC 2371 provide additional examples of the potential of alternative acquisition approaches. Prototyping is an important "try before you buy" approach to acquisition. Such an approach is probably more important in the area of network science than in many other areas. The Army should advocate that Congress remove legislative restrictions added to the prototyping authority in recent years.[10]

The use of special acquisition authorities is not an end in itself. An NSTEC would have to develop complementary policies and utilize flexible acquisition approaches to help implement such policies. It would also need to develop policies that implement flexible approaches to produce real effects. These include:

- Developing working relationships using the infrastructure networks to establish continual teaming with key players including universities, industry, networks of program executive officers, program managers, and joint networks;
- Developing capital equipment policy and planning that renews equipment on a timescale consistent with the fast pace of technological advances;
- Incentivizing participation by all contributors through shared results and recognition of the value of their connection with and enhancement of the NSTEC;
- Focusing attention on a "try before you buy" approach to prototyping;
- Establishing close relationships with the central technical support facility (CTSF), the Army Capabilities Integration Center (ARCIC), and other technology transition organizations and crafting these relationships to the advantage of the Army at large;
- Conducting deliberate and well-planned funding of target activities; and
- Seeking Army and DOD agreement to modify the acquisition cycle to fit the needs of networks (as distinguished from platforms).

Governance and Business Attributes

The potential for improvements in the governance and business practices of federal laboratories has been repeatedly studied over the decades (Coffey et al., 2003; Bement, 1980; Deutch, 1987). The pressure for federal laboratories to operate more efficiently and effectively has led to calls for laboratory reform or reinvention and more recently has been driven by consolidation, closure, realignment, and personnel downsizing dating from the end of the Cold War. A fairly clear lesson from previous studies is that for an NSTEC to operate effectively

[10]Prototype projects (Section 845, Title 10 USC 2371 note) conducted outside the federal acquisition regulations are useful both to bring commercial firms into defense acquisition programs and to allow traditional defense contractors to become more "commercial-like" and innovate outside the current system.

and efficiently, its governance and business practices cannot follow the model of a government-owned, government-operated laboratory subject to personnel, procurement, and other government bureaucratic systems, nor will minor adjustments to a "business as usual" approach be sufficient.

Two highly credible reports on the subject of laboratory governance, one general and one specific to the Army, contain similar findings (Coffey et al., 2003; Owen et al., 2001). Both studies conclude that the most effective models, given all considerations, are either government-owned, contractor-operated (GOCO); a federal government corporation (FGC); or a federally funded research and development center (FFRDC). Examples of each are the Livermore National Laboratory (GOCO), the Tennessee Valley Authority (FGC), and the MIT Lincoln Laboratory (FFRDC).[11] A comparative analysis of these three forms is provided in Table 5-1.

The GOCO and FFRDC operating models have long histories of successfully conducting research and development (R&D). Over the years, however, there has been a gradual increase in regulation that has constrained their independence and innovation in adopting best practices in business and management.

Within the Department of Defense, FFRDCs are subject to increasing constraints, and few new FFRDCs have been formed in recent years. A number of new UARCs have been created. UARCs are similar to FFRDCs in many ways but are subject to less regulation. An example of a UARC with a long history of success is the Johns Hopkins University Applied Physics Laboratory in Laurel, Maryland. This laboratory actually started as an FFRDC but later lost that status and was subsequently chartered as a UARC.

A FGC that is legislatively established by Congress with its own charter may be the best approach to creating a world-class NSTEC. However, since there is no existing example of an FGC chartered specifically to perform R&D, such an approach would be experimental in nature and involve risks that may be inappropriate for an undertaking so closely aligned with DOD transformation and successful Army operations.

As useful as the FFRDC model has been in the past, the increasing constraints placed on FFRDCs, and the reluctance of DOD to push for the creation of new FFRDCs, limits its attractiveness as a model for an NSTEC. The UARC may, however, be considered a more viable model.

The GOCO also provides a possible model for an NSTEC. Within the Department of Energy, the GOCO national laboratories are administered and receive government oversight through management and operations contracts (FAR Sub-

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[11]The terminology used in the cited reports and adopted here is not necessarily universally used or mutually exclusive. The committee finds the terminology used, combined with the examples, useful for this report. It should be noted that many GOCO (and some FFRDC) facilities are not laboratories. As far as the committee is aware, no FGC has research and development as its primary mission. Other models not cited in Coffey et al. (2003) or Owen et al. (2001), such as the university-affiliated research centers (UARCs), have many similarities to the models cited.

TABLE 5-1 Comparative Analysis Adapted from RAND E-Delphi Exercise

Assessment Criteria	Government-owned/ Contractor-operated (GOCO)	Federally Funded Research and Development Center (FFRDC)	Federal Government Corporation (FGC)
Understand and influence the Army's long-term vision	Good	Excellent	Good
Plan and direct a research program	Excellent	Excellent	Excellent
Influence and leverage commercial technology	Good	Good	Excellent
Conduct revolutionary research, development, test, and evaluation in key areas	Good	Excellent	Good
Conduct comprehensive evolutionary research, development, test, and evaluation	Good	Excellent	Excellent
Perform the "smart buyer" function	Good	Excellent	Excellent
Plan and direct the integration of technologies	Excellent	Excellent	Excellent
Evolve the organization	Good	Excellent	Good

NOTE: "Good" and "Excellent" ratings adapted from original 1-5 rating scale.
SOURCE: Adapted from Owen et al., 2001.

part 17.6), as does the NASA Jet Propulsion Laboratory. This is not necessarily the only way to provide oversight, but it constitutes a convenient model for consideration of the government-contractor relationship. If it is pre-determined to select a university or nonprofit organization as the operating contractor, the contract could be awarded non-competitively (FAR 6.302-3); otherwise, competitive procedures could be used.

Absent legislative relief, any conversion from functions now performed by government civilian employees to functions performed by contract would require compliance with laws and regulations governing such conversions, primarily by Office of Management and Budget (OMB) Circular A-76 (OMB, 1999). The financial cost and difficulty of complying with all the rules governing conversion from a government to contractor performance model resulted in the Naval

Research Laboratory rejecting a plan to convert to non-government performance in the 1990s (Coffey et al., 2003). Creation of an NSTEC by conversion of existing civil-service functions (as opposed to creating a new organizational entity from scratch) might make the contract approach (GOCO, FFRDC, or UARC) far less attractive in practice than in theory.

Whether existing models (FGC, GOCO, FFRDC, or UARC) are practical or not, they do provide insight into the attributes that an NSTEC should have as a world-class science and technology organization. These include flexibility in personnel policies, in particular, hiring practices, competitive compensation, and personnel incentives. Flexible business practices and funding approaches are required to avoid technological obsolescence and ensure that needed research and experimental equipment can be acquired in a timely fashion. Flexible contracting approaches are required to ensure that key business relationships and effective collaboration can occur.

Command Relationships and Leadership

In addition to the form of governance, an NSTEC must have adequate visibility and independence provided by respected leadership and key relationships. An NSTEC director should be respected for technical expertise as well as management ability, and the NSTEC should report directly to the Army's Research, Development, and Engineering Command (RDECOM) and have an organizational status equivalent to that of CERDEC and ARL. This will facilitate the transition of personnel and functions to the new organization and ensure adequate status for coordinating all Army NSTE activities with other R&D agencies and joint activities.

Given that organizations likely to be incorporated in an NSTEC are affected by BRAC, and many decisions regarding disposition and relocation have already been made, it is essential that an NSTEC director be appointed as soon as possible. The appointed director should play a primary role in the BRAC planning and execution process and in organizing initial elements of the NSTEC. The urgency is such that it may be appropriate to appoint the NSTEC director immediately pending the establishment of the NSTEC in consonance with overall BRAC planning.

Ideally, the NSTEC director would combine varied strengths including (1) those needed to shepherd the NSTEC through the complex management challenges of BRAC implementation while creating an essentially new organizational entity and capability incorporating many pre-existing parts and (2) the technical insights and judgment to establish an NSTEC research portfolio and attract top-flight researchers to join the NSTEC. As the NSTEC becomes established and evolves, the relative importance of these strengths will shift from the first to the second. It may be that the necessary strengths cannot be found in a single executive and that consideration should be given to forming a management team that incorporates the necessary strengths.[12]

Alternatives

An obvious but far from optimal version of an NSTEC would involve merely relocating elements of various existing Army organizations to a centralized government-operated location such as Aberdeen Proving Ground. Another alternative would involve chartering a completely new non-government organization, such as an FGC, GOCO, UARC, or FFRDC, with government funding and under Army supervision. Maximum flexibility might be obtained by legislative authorization of a specially chartered FGC, but the time involved and experimental nature of this approach might make one of the other types of organizations attractive as an initial step. The physical attributes of this organization could be varied from centralized to distributed; it could recruit its workforce from current Army organizations affected by BRAC as well as from a broader workforce market. A variation on this alternative might be to charter an existing or new UARC or FFRDC to serve as the core of an NSTEC.

Another alternative could combine the best features of the two alternatives mentioned above. That is, a new or existing non-governmental organization would be chartered. It might be located on leased land at Aberdeen Proving Ground or at a different location. It could recruit from current experienced government employees as well as the private sector. In addition, existing government organizations could be combined either physically or as a virtual organization to make a government cadre for the NSTEC. An element of the government organization could manage the non-government wing of the NSTEC as well as be an operating agency for part of the NSTEC's work.

The final selection from the alternatives should focus on pursuing the goals discussed in this chapter and on utilizing flexible business and operating methods consistent with achieving the NSTEC mission recommended in Chapter 2.

Recommended Strategy

Given the foregoing discussion, the committee believes that chartering a new or existing UARC or FFRDC (hereafter referred to as UARC/FFRDC) to serve as the core of an NSTEC would be the most effective course of action. It should be feasible to establish the core UARC/FFRDC so as to allow flexibility

[12]Historic examples include teams such as Leslie Groves and Robert Oppenheimer of the Manhattan Project. Also, in NASA at the inception of Project Apollo, NASA Administrator James Webb had a background as an aggressive manager in both government and industry and was known to be politically savvy while his deputy, Hugh Dryden, had a technical background and a long history with NASA's predecessor organization. In the NASA case, the supporting team of Werner Von Braun, Samuel Phillips, George Mueller, and Robert Gilruth was outstanding.

in the early days of the overall NSTEC establishment and also allow the core to continue as the NSTEC evolves in future years. In order to play such a role in an evolutionary environment, the core UARC/FFRDC needs to have a broad charter in NSTE from the outset.

The NSTEC UARC/FFRDC could be established at any appropriate location or locations and then be relocated at or in proximity to Aberdeen Proving Ground as circumstances warrant. In its early days, the UARC/FFRDC could perform a “gap filler” role when (1) existing Army resources fail to match key elements of the NSTEC mission or (2) Army organizational elements involved in BRAC relocations lose the expertise of key personnel who choose not to relocate.

The target date for Ft. Monmouth to close is September 2011, and actions regarding budget shifts in accord with the government’s planning, programming, and budget execution system will need to occur with the submission of the Fiscal Year 2009 budget. To meet the timelines for implementation will require making budgetary shifts of existing funds to phase in the UARC/FFRDC capability.

In the long-term evolution of an NSTEC, it may make sense for the core UARC/FFRDC to take over performance of much of the NSTEC mission. Whatever the ultimate mix of government and non-governmental performance responsibilities, the core UARC/FFRDC must be closely integrated with the Army’s mission needs in network science. Personnel interchanges and co-location of Army and UARC/FFRDC personnel should occur routinely.

The core UARC/FFRDC must retain flexibility in acquiring facilities and research equipment as a key means of avoiding technological obsolescence over time. The use of an independent advisory board could also be considered to provide feedback on NSTEC currency and performance. The NSTEC as a whole should be some mix of distributed and centralized facilities, starting with 1 to 3 physical centers connected to a variety of remote facilities. The degree of distribution or centralization should be driven by mission needs and effectiveness in achieving research results rather than be pre-determined.

The committee believes that the alternative of creating a UARC/FFRDC that addresses some but not all NSTEC mission areas at the core of an NSTEC organization makes more sense than creating a new UARC/FFRDC to immediately displace all existing Army efforts in NSTE.

The committee also believes that establishing a UARC/FFRDC as a core element in an NSTEC is better than retaining only the civil service laboratory model of governance and operations. Initially at least, it seems highly likely that much of what becomes the NSTEC will be constituted as a civil service laboratory. Those parts of the NSTEC that retain that form must be chartered to take full advantage of the special authorities discussed in this chapter. The least attractive alternative for an NSTEC is a business-as-usual civil service laboratory.

Figure 5-1 illustrates the NSTEC organization with a UARC/FFRDC core that the committee recommends. At the outset, all relevant existing work would become the responsibility of the proposed NSTEC. Within the NSTEC, the core

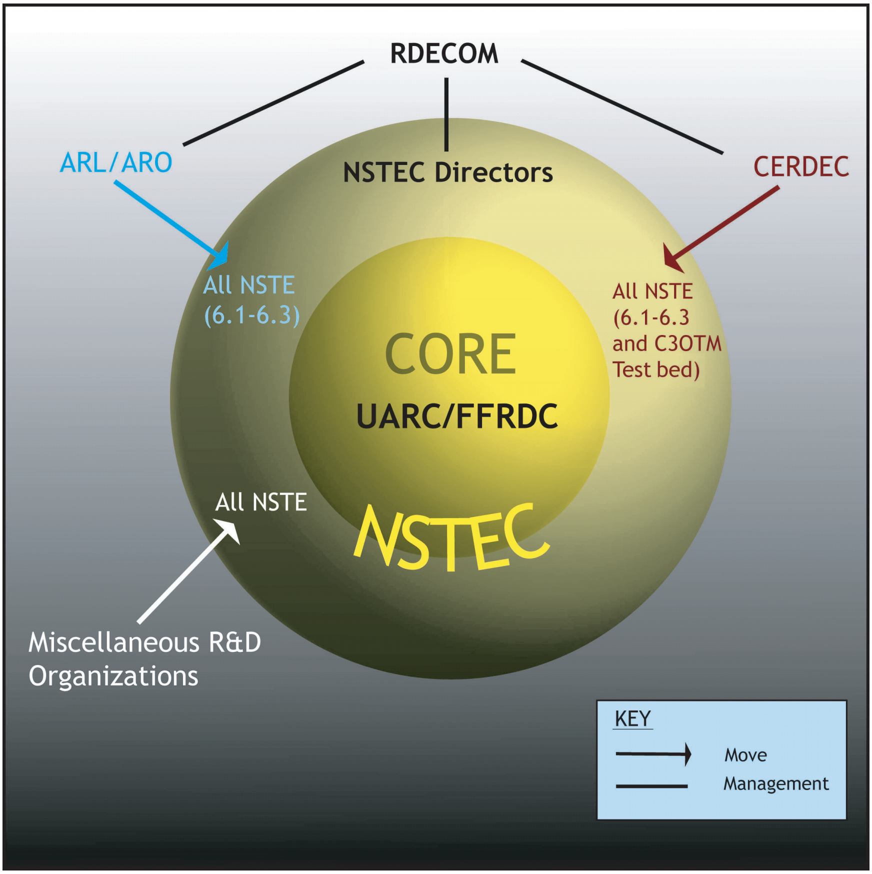

FIGURE 5-1 Recommended NSTEC organization. (Acronyms are defined on pages xvi-xviii of the front matter.)

UARC/FFRDC would begin by filling current gaps in S&T and would take responsibility for efforts that cannot be performed due to qualified technical staff deciding not to move to APG.

CHAPTER SUMMARY

Previous comparative analyses of prospective models for Army research organizations have narrowed the field of consideration for an NSTEC to government-owned, contractor-operated (GOCO), federally funded research and development center (FFRDC), and federal government corporation (FGC) operating models. The Army has a wealth of experience with a variation of the FFRDC known as the university-affiliated research center (UARC).

Conclusion 4: The UARC/FFRDC operating model has emerged in recent years as a flexible and productive model capable of integrating commercial and military R&D development for the Army. The UARC/FFRDC is also superior to other operating models, because it allows ongoing access to a broad range of expertise, talent, and innovation while efficiently using government resources.

Recommendation 4: The Army should establish a new UARC/FFRDC (or expand an existing UARC/FFRDC) to serve as the core of an overall Army NSTEC organization.

The coordination and implementation of NSTE for the Army will require extraordinary leadership at a level commensurate with the importance of network-centric operations in the future. The new organization would alter existing boundaries of responsibility for the various NSTE functions, and the scope of responsibilities is equivalent to that of the present research, development, and engineering centers (RDECs). For this reason, a director for all NSTE activities should be assigned immediately to assist with planning and establishment of the recommended NSTEC organization and core shown in Figure 5-1. The NSTEC director should be provided with a supporting management team to assure the availability of expertise in all the management and technical disciplines necessary to carry out the complex process of transitioning existing organizations to an NSTEC and incisively establishing and managing the NSTE research portfolio.

Conclusion 5: An NSTEC organization must exhibit a high degree of flexibility in personnel policies that will enable it to become a world-class leader in network research and development. Establishment and evolution of the NSTEC will require exceptional leadership.

Recommendation 5a: The Army strategy for NSTE should be to establish an NSTEC organization with a UARC/FFRDC core as shown in Figure 5-1.

Recommendation 5b: The Army should immediately designate a director to establish an Army NSTEC at Aberdeen Proving Ground (Maryland). The NSTEC director should report to the U.S. Army Research, Development, and Engineering Command (RDECOM) at a level equivalent to the ARL and RDEC directors. All NSTE funding and resources should be assigned to this individual.

Recommendation 5c: For the NSTEC to be able to accomplish the mission envisioned, the Army should designate at least two deputy directors: one for technology and another for human performance/adversary understanding. This action will ensure that the large number of CERDEC engineers does not overwhelm research and development efforts in human performance and adversary understanding.

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Appendixes

Appendix A

Committee Meetings

AUGUST 23-24, 2006, WASHINGTON, D.C.

Using Networks to Advance the Army Network Science, Technology and Experimentation Center.
John Parmentola, Director, Research and Laboratory Management, Office of the Deputy Assistant Secretary of the Army (Research and Technology).

Dealing with the Unexpected: A Critical Challenge for DOD.
David Alberts, Director, Research and Strategic Planning, Office of Assistant Secretary of Defense (C3I).

ARL Research in Network Science.
Anathram Swami, Army Research Laboratory (ARL), U.S. Army.

Whither a Science of Networks?
J. Christopher Ramming, Program Manager, Defense Advanced Research Projects Agency (DARPA).

Toward New and Better Protocols for Wireless Networking.
J. Christopher Ramming, Program Manager, Defense Advanced Research Projects Agency (DARPA).

BRAC Update (Unofficial Observations).
Pete Cahill, Senior Principal Analyst and Program Manager, BRTRC, Office of Research and Laboratory Management, Assistant Secretary of the Army (Acquisition, Logistics and Technology) [ASA(ALT)].

Human Dimension in Network Science.
Rene de Pontbriand, Human Research and Engineering Directorate (HRED), Army Research Laboratory (ARL), U.S. Army.

SEPTEMBER 21-22, 2006, WASHINGTON, D.C.

Strategies for a Network Science, Technology, and Experimentation Center.
Gary P. Martin, Director, Communications-Electronics Research, Development and Engineering Center (CERDEC).

Army Capabilities Integration Center.
John Kincaid, Deputy Chief, Science and Technology Division, U.S. Army Training and Doctrine Command, Capabilities Developments Directorate, Army Capabilities Integration Center (ARCIC).

ARCIC Gaps Process.
John Kincaid, Deputy Chief, Science and Technology Division, U.S. Army Training and Doctrine Command, Capabilities Developments Directorate, Army Capabilities Integration Center (ARCIC).

FCS (BCT) Program Overview to Network Science, Technology, and Experimentation (NSTE).
MG Charles A. Cartwright, Program Manager, Future Combat Systems (Brigade Combat Team), Program Executive Office (PEO), U.S. Army.

Strategies for a Network Science, Technology, and Experimentation Center.
Gary P. Martin, Director, Communications-Electronics Research, Development and Engineering Center (CERDEC).

Battle Command Requirements and Technical Challenges.
Gary P. Martin, Director, Communications-Electronics Research, Development and Engineering Center (CERDEC).

Transforming Through BRAC 2005: RDAT&E at APG.
Craig College, Deputy Assistant Chief of Staff for Installation Management Headquarters, U.S. Army.

ARL Research in Network Science.
John M. Miller, Director, Army Research Laboratory (ARL), U.S. Army.

ARL BRAC 91 Relocation Lessons Learned.
John Pellegrino, Director, Sensors and Electron Devices Directorate (SEDD), Army Research Laboratory (ARL), U.S. Army.

DA G-6/CIO Views on Network Science, Technology, and Experimentation (NTSE).
Vern Bettencourt, Deputy, Chief Information Officer/G-6, Office of the Secretary of the Army, U.S. Army.

Communications-Electronics Life Cycle Management Command (C-E LCMC).
MG Michael Mazzucchi, Commanding General, Communications-Electronics Command (CECOM); Program Executive Officer for Command, Control, Communications-Tactical (PEO C3T), U.S. Army.

RAND's Organizational Design Research for Army R&D.
Bruce Held, Director, Force Development and Technology Program, RAND Arroyo Center.

NOVEMBER 15-16, 2006, WASHINGTON, D.C.

Presentation of NSTE Data.
Pete Cahill, Senior Principal Analyst and Program Manager, BRTRC, Office of Research and Laboratory Management, Assistant Secretary of the Army (Acquisition, Logistics and Technology) [ASA(ALT)].

Army Materiel Command/Army Corps of Engineers Planning for BRAC at Aberdeen Proving Ground.
Judy Wettig, Director, APG BRAC Transition Team, and *John Koss*, Contractor, MCFA Planning.

Discuss Parallel ASB Study. (Via audio teleconference.)
Joe Braddock, former chair, Army Science Board; currently trustee of the Potomac and Aztec Foundations.

Defense Information Systems Agency Perspective on NSTE.
Ed Siomacco, Deputy Program Director, Net-Centric Enterprise Services Program Office, Defense Information Systems Agency (DISA).

Briefing to the BAST Network Sciences.
Gary Martin, Director, Communications-Electronics Research, Development and Engineering Center (CERDEC).

JANUARY 16-17, 2007, IRVINE, CALIFORNIA

No briefings.

FEBRUARY 14-15, 2007, WASHINGTON, D.C.

No briefings.

Appendix B

Biographical Sketches of Committee Members

Verne L. (Larry) Lynn (NAE), *Chair,* is an independent consultant to industry and the Department of Defense (DOD). Mr. Lynn is retired director of the Defense Advanced Research Projects Agency (DARPA), the principal agency within DOD for research, development, and demonstration of concepts, devices, and systems for advanced military capabilities. He also served in DOD as the deputy undersecretary of defense for Advanced Technology and was vice president and chief operating officer for the Atlantic Aerospace Electronics Corporation. Mr. Lynn has authored over 40 technical publications in the areas of military surveillance and weapons systems, and he has extensive knowledge of military organization and operations for research, development, and acquisition. He is a fellow of the Institute of Electrical and Electronics Engineers and serves on the Defense Science Board.

Raj K. Aggarwal is vice president of Global Technology at the Rockwell Collins Corporation. He is a former director of research and technology for Alliant Techsystems, Inc., and a director of advanced programs for Honeywell, Inc. Dr. Aggarwal received a B.S. degree in physics (with honors) and B.S. and M.S. degrees in electrical and communications engineering from Delhi University in Delhi, India. He received his Ph.D. in electrical engineering from Purdue University. He is a member of the Board on Army Science and Technology (BAST) and served previously on the NRC Committee on Unmanned Ground Vehicle Technology. Dr. Aggarwal has knowledge of research and development organizational models in industry as well as experience with DOD research, development, and acquisition.

A. Michael Andrews II is vice president and chief technology officer of L-3 Communications, where he guides the company's long-term R&D initiatives. Prior to joining L-3 in June 2003, he served as deputy assistant secretary of research and technology/chief scientist for the United States Army, a position he held since 1998. Andrews was instrumental in the development of the Future Combat Systems and realigning Army S&T toward Future Force capabilities. Prior to coming to the Army in 1997, Dr. Andrews held a variety of leadership positions at Rockwell International. He has produced over 50 technical articles and has several patents in infrared sensors, materials, and signal processors. He is a member of the Naval Research Advisory Committee, was a member of the National Research Council's Committee on Review of the National Nanotechnology Initiative, was an advisor to the Defense Science Board Task Force on Roles and Authorities for the DDR&E, and is an advisor to the DSB Summer Study on 21st Century Strategic Technology Vectors. Dr. Andrews is a recipient of various honors, including the U.S. Army's Meritorious Civilian Service Award, the Presidential Rank Award, Rockwell's Engineer of the Year Award, selection as a fellow of the Institute of Electrical and Electronics Engineers, the University of Illinois Distinguished Alumnus Award, the SPIE's Defense & Security 2005 honoree of the year, and a career profile in the April 2002 IEEE Spectrum Magazine. Dr. Andrews received his B.S. and M.S. in electrical engineering from the University of Oklahoma and his Ph.D. in electrical engineering from the University of Illinois.

Richard L. Dunn is an independent consultant and senior fellow at the University of Maryland. He conducts research in national security operations and is an expert in the analysis of laws, policies, and practices that impact the effective implementation of technology. He served as the first general counsel for the Defense Advanced Research Projects Agency (DARPA), where he pioneered efforts in conducting prototype projects outside normal DOD contracting statutes. He also served as counsel to the NASA Space Commercialization Task Force and as a staff judge advocate (legal officer) in the U.S. Air Force. Mr. Dunn's degrees include a B.A. cum laude from the University of New Hampshire, a J.D. from the University of Maryland, and an LL.M. with highest honors from George Washington University.

Gerald Harris, a senior consultant with the Global Business Network, develops global scenarios for long-term development of the electric power industry. He is a former director of business planning for the Pacific Gas and Electric Company and a published expert in the field of scenario planning to support potential investment strategies. Mr. Harris has led scenario projects linking planning goals to R&D objectives for companies in diverse fields, including oil and natural gas, engineering and construction, and information technology. He received his B.A. degree in economics from Morehouse College, where he graduated Phi Beta Kappa, and an M.B.A. in finance and business economics from the University of Chicago.

Jason F. Providakes is executive director at the MITRE Corporation, managing programs for theater and strategic systems with enterprise-wide implications across the DOD, including the Global Information Grid. Dr. Providakes was chief engineer for the MITRE-Washington C3 Center, where he managed technology development and integration, and he is former executive director of the MITRE Army Program. He has published extensively in the field of over-the-horizon radar and serves as a member of the Army DARPA Senior Advisory Group and the Army Science Board. Dr. Providakes received his B.S. degree from Worcester Polytechnical Institute and his M.S. and Ph.D. degrees from Cornell University, all in electrical engineering.

Zita M. Simutis is retired director of the Army Research Institute (ARI) for the Behavioral and Social Sciences, where she served in positions ranging from research psychologist to technical director to chief psychologist of the Army over a 30-year career. At ARI, she was responsible for directing and managing long-term research as well as short-term studies involving applied personnel performance and training. She has authored numerous articles on training, leader development, and soldier-computer interfaces. Dr. Simutis received her B.S. degree in psychology from the University of Illinois and M.A. and Ph.D. degrees in experimental psychology from the University of Connecticut.

W. David Sincoskie (NAE) is vice president of the Network Systems Research Laboratory at Telcordia. He is former executive director of the Computer Networking Research Department at Bellcore, where he managed projects on the AURORA gigabit test bed, IPv6, IP over ATM, NSFNET, and broadband service control. Dr. Sincoskie co-authored the first specifications for local ATM, and he pioneered the use of packet switching technology in broadband networking. He is a member of the National Academy of Engineering and received the IEEE Fred W. Ellersick prize paper award in 2003. Dr. Sincoskie serves on the NRC Board on Army Science and Technology. He received B.E.E., M.E.E., and Ph.D. degrees in electrical engineering from the University of Delaware.

Ronald L. Smith is in private practice and is a clinical associate professor in the University of Nevada School of Medicine. He is a former neurobiologist at the NASA Ames Research Center and was a postdoctoral fellow at the UCLA Brain Research Institute. He currently serves on the Joint Independent Science Panel on Chemical and Biological Defense and has reviewed research involving modeling and simulation and operations research for the Department of the Army. Dr. Smith received his M.A. and Ph.D. degrees in anatomy (neuroscience) from the University of California at San Francisco and his M.D. degree from the Autonomous University of Ciudad Juárez, Mexico.