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The Strategic Direction For Army Science and Technology

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27 February 2013

MEMORANDUM FOR THE SECRETARY OF THE ARMY

SUBJECT: Final Report of the 2012 Army Science Board (ASB) Study on The Strategic Direction for Army Science and Technology (S&T)

I am pleased to forward the final report of the ASB Study on the Strategic Direction for Army Science and Technology (S&T) consistent with the terms of reference you approved. The ASB sincerely appreciates your sponsorship of this important effort.

The study team conducted an extensive literature survey, received briefings and analyzed the resulting data as well as written responses to the study team's lines of inquiry. The study team interviewed Army, Navy, Air Force and Office of the Secretary of Defense research, development and acquisition leaders. Army Research, Development and Engineering Command (RDECOM) organizations were visited, as well as the Naval Research Laboratory and Air Force Research Laboratory. The customers of RDECOM S&T were also visited and interviewed, including Army Program Executive Officers and Life Cycle Management Commands.

In summary, the study found that the Army lacks a S&T strategy and investment plan to meet likely future challenges, improve the transition of technology and advanced capabilities to acquisition, seize valuable technological opportunities, and foster invention and innovation and recommends the Army: (1) better focus Army Materiel Command S&T organizations' in-house efforts as well as improve sponsorship and leveraging of best-in-class sources; (2) provide laboratory directors 'direct hire' authority for 'the best' personnel with graduate degrees in science and engineering and greatly increase uniformed military personnel with science and engineering degrees; and (3) better position the Army Research Office and Army Research Laboratory for support of their critical long term research missions.

I endorse the study findings and recommendations. The ASB believes they support your efforts to bring the generating force in balance with the operating force while preserving the Army's technological advantage over our potential adversaries, improving both the value added and efficiency of the S&T enterprise.

George T. Singley, III
Chair, Army Science Board

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Contents

Figures

Tables

EXECUTIVE SUMMARY

> "The time has come for all leaders in the generating force to ask themselves, 'Is my organization as flexible, adaptable and versatile as the forces we support? Are we truly designed for an era of strategic uncertainty?" As the Secretary of the Army, this will be my focus for the remainder of my tenure."[1]
>
> Honorable John M. McHugh, Secretary of the Army

This report summarizes an assessment of the Strategic Direction for Army Science and Technology (S&T), conducted by the Army Science Board (ASB) between October 2011 and July 2012. The study was sponsored by the Secretary of the Army, the Honorable John M. McHugh. The Terms of Reference (TOR) (Appendix B) for the study directed the ASB to "analyze the current [Army Materiel Command (AMC)] Research, Development and Engineering Command (RDECOM) portfolio of S&T projects and objectives" and to provide findings and recommendations on a number of strategic issues.

The TOR focuses on two principal motivating factors: (1) S&T mission effectiveness; and (2) anticipated Department of Defense (DOD) budget reductions. With respect to S&T mission effectiveness, the TOR states: "Research, Development, Test and Engineering (RDT&E) is vital to the Army's success. Our strategic vision is based upon a decisive technological superiority to any potential adversary. Recent studies show that we are not achieving the goals that we have set for ourselves." Furthermore, "there have been a number of recent studies that have formed the basis for the missions of RDECOM and have been critical of their accomplishments." With respect to anticipated DOD budget reductions, the TOR states: "The Secretary of Defense has suggested that the Services take at least a 10% cut to their science and technology spending as part of his efficiency initiatives."

To conduct the study directed by the TOR, the study team interviewed personnel at a large number of relevant Army organizations, including the Assistant Secretary of the Army for Acquisition, Logistics and Technology (ASA(ALT)), the Deputy Assistant Secretary of the Army for Research and Technology (DASA(R&T)), U.S. Army Training and Doctrine Command (TRADOC), RDECOM Headquarters, all of the subordinate organizations within RDECOM, the Program Executive Officers (PEOs)/ Program Managers (PMs) and Life Cycle Management Commands (LCMCs). The purpose of these visits was to gather information on the Army S&T strategy, on Army S&T portfolio and funding allocations, on the Army approach for portfolio management and technology transition, and on Army organization, personnel and facilities for conducting S&T. The study team also visited many equivalent organizations within the Navy and Air Force, as well as relevant Office of the Secretary of Defense (OSD) offices. The purpose of these visits was to understand how the Army's approach to S&T aligns with OSD, and how it may differ from the other Services. These visits, along with reviews of prior studies and other pertinent sources of information, provided baseline data for the study assessment.

STRATEGY

To assess the "strategic direction" of Army S&T, the study team first searched for the Army S&T strategy. While the team found many elements of what might constitute a strategy, it did not find a single, authoritative, and documented strategy. ASA(ALT) and DASA(R&T) are well aware of this shortcoming

[1] McHugh, John M., "Today's Army: Flexible, Adaptable, and Versatile," *Army Magazine*, October 2010, p. 16.

and are in the process of defining and aligning an S&T strategy with the recent changes to the national military strategy, from which OSD S&T and individual Service S&T strategies must proceed. Many of the issues assigned by the TOR for assessment by the study team are dependent on the strategy. In the absence of a current S&T strategy, the study team evaluated S&T strategic issues within the context of significant environmental forces and insights gained from the interviews.

Strategy is a means to an end. The end is defined by strategic objectives. The strategic objective for Army S&T is well established. As stated by DASA(R&T), the Army S&T *raison d'être* is to "foster invention, innovation, maturation and demonstration of technologies to enable future force capabilities while exploiting opportunities to transition technology enabled capabilities to the current force."[2] Implicit in this and other stated leadership positions is the understanding that S&T must serve the needs of the warfighter and provide our soldiers with new and improved capabilities to perform their missions against any current and/or future threat. Thus, the core objective of Army S&T is getting technology out of the laboratory and into the hands of the warfighter. While this objective is simple, clear, and enduring, the current global socio-economic and security environments present a set of challenges that the Army S&T strategy must address:

1. Commercialization and Globalization of Technology. During the early cold war years, U.S. government (USG) Research and Development (R&D) investment was roughly equivalent to U.S. commercial spending, and most of the USG spending was on defense. While USG R&D spending has increased about 20% from 1965 to today, commercial R&D spending has increased by over 200%, far outstripping USG spending. Similarly, global R&D spending has accelerated over the same period, to the point that spending by the rest of the world is now more than USG and commercial spending combined. The challenge is clear: DOD and the Army have lost the ability to ensure technological dominance through internal R&D, because adversaries are able to exploit commercially available technologies on a global scale. The Army must do the same. It can no longer afford to be internally focused and must be able to leverage externally-developed technologies just as aggressively as our adversaries.

2. Declining DOD budgets. As stated in the TOR, the Army should expect cuts of at least 10% to its S&T budget. The magnitude of anticipated DOD budget reductions may not allow a status-quo approach to S&T spending, with "vanilla," across-the-board trimming of all portfolio elements. The study team addressed this new fiscal reality by considering a new approach to S&T portfolio management which categorizes S&T efforts by: (1) those that must be done in-house, (2) those that must be sponsored by the Army but conducted via outside agencies/contractors, and (3) those external efforts that should be monitored and leveraged. The expectation is that the global environment will drive the Army S&T portfolio to be reshaped, with less work in category (1), more work in category (2), and significantly more work in category (3).

3. International Competition for Science, Technology, Engineering and Mathematics (STEM) Personnel. During the early post-Cold War period, the United States led the world in educating scientists and engineers. Today, it is generally acknowledged that U.S. universities continue to turn out the best scientists and engineers in the world, but data indicate the number of U.S. citizens graduating with advanced technical degrees from U.S. universities has slowed, relative to the rate at which U.S. universities award degrees to citizens of other countries (particularly

[2] Freeman,. Marilyn, *Army Science and Technology Strategic Direction*, briefing to the Association of the United States Army, October 2011.

emerging nations). Compounding this issue, U.S. visa policy makes it increasingly difficult for graduates from foreign countries to apply their skills in the U.S. workforce. Together, these factors make it increasingly difficult for the Army to attract and retain the best and brightest students. The Army has done quite well in recruiting talent over the past decade in the "down" economy, but an improving economy will make it more difficult to compete against well-compensated, commercial industry alternatives.

4. Changing Security Environment. As the conflicts in Iraq and Afghanistan wind down, the Army must adapt to a new national security strategy. The past decade of warfare has impacted Army S&T by shifting much of the portfolio into a near-term focus geared towards responding to urgent operational needs in the theaters of conflict. Consequently, resources in S&T have been realigned away from longer term pursuits which spawn much of the discovery and innovation required to ensure future technological superiority. During the visits and interviews with Army S&T organizations, the study team noticed a lack of innovation and effort related to potentially disruptive capabilities caused by this imbalanced focus on the near term.

The study recommends development of an Army S&T strategy that responds to these environmental factors. An essential element should include portfolio balance in at least two dimensions: time horizon balance, and balance of in-house vs. sponsored vs. leveraged external efforts. As noted above, the impending end to current conflicts should provide an opportunity to adjust the portfolio to a better balance of longer term (higher-risk, higher-payoff) projects and shorter term technology transition opportunities. At the same time, adjusting the balance of internal/external work in line with the changing R&D environment will leverage increased commercial and global R&D spending to effectively augment USG spending. To provide some parameters on what a proper balance might look like, the study team established a set of criteria for determining which S&T efforts should be done in each of the three categories (in-house, sponsored, leveraged) and applied these criteria to sample technology areas currently conducted primarily in-house by the RDECOM Research, Development and Engineering Centers (RDECs). The results, while neither exhaustive nor all-inclusive, indicate that this methodology can be useful to the Army in developing its S&T strategy.

TECHNOLOGY TRANSITION

Another important element of the Army S&T strategy should be a technology transition strategy. Since the ultimate objective of Army S&T investment is to enhance warfighting capabilities, the ability to transition technology from the laboratory to fielded capability is essential to obtaining return on this investment. In terms of time horizon, there are four paths to field a technology: (1) near-term insertion of mature technologies or non-developmental items (NDI) direct to the field in response to urgent operational needs, (2) mid-term technology insertion into a Post-Milestone B (MS B) Program of Record (POR) via Engineering Change Proposals (ECPs), (3) mid-to-far-term technology insertion into a new (Pre-MS B) POR, and (4) long-term technology developments associated with Pre-MS A advanced concepts. The two mid-term transition paths require transition from S&T to acquisition programs. The two paths on the short-term and long-term ends of the spectrum reside outside of the formal acquisition processes, but must also ultimately be turned into PORs and therefore also traverse the S&T-to-acquisition "chasm."

The chasm between S&T and acquisition is widely recognized as the key impediment to transition. This chasm is often referred to as the "valley of death."[3] Understanding the causes of this chasm is fundamental to the development of an effective strategy for bridging the chasm and improving the Army's ability to field technology-enabled capabilities. During the interview process with both the S&T and acquisition communities, the study team endeavored to understand the root causes, so that it could recommend effective remedies. The interviews revealed a very different perspective regarding technology transition between the S&T and acquisition communities and identified several causes of the chasm.

The most basic of these causes is the fundamental difference in risk paradigms between the S&T and acquisition communities. The job of an acquisition PM is to execute contracts on cost and schedule, while meeting all key performance parameters. The PM is reluctant to take any unnecessary risk that could prevent him or her from meeting contractual obligations. Taking risk, on the other hand, is inherent in the job of an S&T project manager.

Adding to this fundamental difference in risk paradigms is the limitation in technology maturity that can be achieved through the budget authorities available to the two communities. Budget Activity (BA) 1 to BA 3 is available to fund S&T, while acquisition programs are funded via BA 4 to BA 7. BA 3 funded efforts cannot deliver the level of technology maturity required by acquisition programs to meet the risk aversion thresholds. Within the limits of BA 3 funding, the S&T community can generally demonstrate only the basic functionality of a technology by means of representative prototype hardware/software in a representative environment in the laboratory. To insert this technology into his program, however, the program manager generally requires that the technology has been demonstrated to meet critical performance thresholds with actual prototype hardware/software in a realistic environment for his product, with all critical system interfaces systematically exercised. Obtaining this level of maturity generally requires BA 4 or BA 7 budgetary authority.

Prototyping is widely recognized as an essential means for bridging this chasm. Indeed, competitive prototyping prior to MS B is required by statute (Weapon Systems Acquisition Reform Act of 2009 (WRASA)), unless a waiver can be justified. Prototyping directly addresses the first two causes of the chasm: the different risk paradigms and the inability of S&T to satisfy POR required technology maturity. Defining a prototyping environment that effectively addresses all of the causes of the chasm should be considered an important element of the Army S&T technology transition strategy. In defining this environment, it is also important to recognize that prototyping is a means for not only bridging the S&T to acquisition chasm, but also for facilitating transition for all four of the transition paths.

The type of prototyping is not the same for each path, but must be tailored to the unique needs of each. For near-term insertion of technologies directly to theater operations, rapid prototyping is required. At the other end of the time spectrum, advanced concept prototyping should focus on demonstration of the feasibility and utility of technology-enabled systems that satisfy the operational capability needs of the concepts. In the mid-term portion of the time spectrum, the prototyping opportunities should focus on maturing technologies and reducing system integration risk on the PORs. For new PORs, during the Technology Demonstration (TD) phase prior to MS B, such prototyping should be conducted competitively to the maximum extent possible within time and resource constraints to allow for alternative approaches to be tested and matured.

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[3] Moore, Geoffrey A. , *Crossing the Chasm: Marketing and Selling Disruptive Products to Main Stream Customers,* Harper Business Essentials Publications, New York, 1999.

While the type of prototyping varies across the time spectrum, the study team believes there are advantages to the Army having an integrated prototyping environment managed through a centralized, Defense Advanced Research Project Agency (DARPA)-like office (with decentralized execution via the RDECs and PEOs/PMs): the Technology Transition, Innovation, and Prototyping Office (TTIPO). To operate effectively across the entire time spectrum, this office should be capable of working with Combatant Commands (COCOMs) to rapidly field mature or NDI technologies, working with PEOs/PMs to prototype technologies for insertion into PORs, and working with TRADOC to formulate technology-enabled solutions to game-changing advanced concepts. The study team noted that the advanced concepts capabilities within S&T have diminished over the past decade due to near-term pressures. This office could provide the opportunity to re-invigorate this capability and ensure that innovative capabilities are well represented in the prototyping portfolio.

ORGANIZATION

Organizational structure must be aligned with and supportive of any organization's strategy. This is particularly important for large organizations, such as Army S&T, in which there are multiple transactions crossing multiple organizational boundaries. RDECOM was established in 2004, in large part to remedy known organizational coordination and efficiency issues. The TOR directs that the ASB evaluate organizational options since "recent studies … have been critical of their [RDECOM's] accomplishments". The TOR specifically directs assessment of two courses of action regarding organizational structure: “Fix RD&TE under the current strategy,” and “form a small corporate research center.” The latter approach would "embed product development, developmental and operational test and engineering into product-focused groups and increase reliance and leverage from other government … and commercial activities." Greater reliance on external developments is consistent with the proposed portfolio management strategy (in-house, sponsored, leverage) discussed previously.

To conduct this assessment, the study team examined several R&D organizational models, including the U.S. Air Force and U.S. Navy models and Apple and General Electric Company (GE) industry models. Criteria specified in the TOR were used as points of comparison for evaluating the strengths and weaknesses of these models with respect to accomplishing Army S&T strategic objectives. These criteria included: (1) a long-term research horizon addressing game-changing technologies, (2) effectiveness of technology transition strategies, (3) leverage of investments through competition of ideas, and (4) ability to maintain technical superiority, with access to required technologies and in-house competent buyer expertise.

The industry models highlighted some important differences in organizational design between near-term (Apple) and longer-term (GE) product development time horizons. However, they were not considered particularly relevant to an Army S&T organizational evaluation because they (like all industry) are driven primarily by profit and growth motives. Customer satisfaction is, of course, another important consideration for industry. However, for Army S&T, delivering capabilities to the customer (the warfighter) is by far the principal motivation. The evaluation therefore focused on understanding whether the Army could benefit from some of the organizational features of the Air Force and Navy.

In considering the strengths enabled by the different S&T organizational alignments of the Air Force and Navy, the study team determined that the Army should take measures to foster technology transition and minimize research redundancies through consolidated and integrated management of the BA 1 to BA 3 S&T program. The current institutional funding approach should be transitioned to a competitive approach over a period of several years, with an objective of awarding at least a majority of the BA 2 to BA 3 program on a competitive basis. An integrated BA 1 to BA 3 management approach should establish policies to enable a focus on critical technologies in the corporate laboratory, and to maintain an enterprise-wide balance between near-term objectives and a longer-term research horizon. The corporate laboratory should be positioned to maintain a core focus on basic and applied research in the critical technologies, enabled with sufficient discretionary funding. To lengthen research horizon, customer-funded work not supporting critical core technologies should be offloaded to other laboratories. To ensure responsiveness to Army leadership goals and objectives, the corporate laboratory should report at a four-star level, with access to and direction from Headquarters, Department of the Army (HQDA) through the ASA(ALT). Furthermore, a realigned S&T organization should include enablers to improve technology transition, especially at the 6.3–6.4 gap.

The ASB believes the potential for increases in performance and efficiency justifies three organizational adjustments:

1. The Army Research Office (ARO) should be realigned as a Direct Reporting Unit to ASA(ALT), with an expanded role under the direction of DASA(R&T) to develop and maintain a strategic S&T plan, and to manage the policy, programming and prioritization of the BA 1 to BA 3 program. ARO should continue to sponsor competitive execution of the AMC-wide BA 1 program, both extramural and intramural, and with additional staffing, assume responsibility for integration of the BA 2 to BA 3 program over a period of time to increase competition and decrease research duplication.

2. The Army Research Laboratory (ARL), the corporate research laboratory, should report directly to the Commanding General, AMC, with a dotted line relationship to ASA(ALT). ARL should divest much of its current customer-funded workload, and thereby become smaller and more research-focused, with a longer-term horizon, and focus on basic and applied research on the critical technologies. ARL should also organize and staff internally to increase leverage of other government and industrial activities and global R&D.

3. Also, in accordance with the previous discussion on technology transition, the Army should establish a TTIPO, reporting to ASA(ALT). The TTIPO should manage an integrated prototyping environment that operates across a broad time horizon, facilitates technology insertion into PORs through prototyping, and fosters innovation through the definition, analysis and prototyping of technology-enabled solutions to game-changing advanced concepts.

FACILITIES

Facilities are critical to any research organization. A funded facilities plan is an important component of an organization's strategic plan. In its visits to Army S&T facilities, the study team noted several important issues that need to be addressed in an S&T facility plan. Foremost among these is that the Army spending on S&T facilities appears to be inadequate to maintain technical superiority and a competitive edge in attracting top talent. All Laboratory Directors commented on challenges with maintenance and repair, and noted they are forced to rely on use of mission or customer funds for some critical maintenance and repair requirements. On the other hand, the team also noted some duplication of specialized facilities, e.g., multiple dry-rooms for battery research, and multiple software engineering facilities. Further the team believed that there was investment in facilities and equipment not essential to the performance of the critical in-house effort.

A comprehensive strategic modernization and recapitalization plan for Army S&T is needed to address these issues. Such a plan should include a rigorous inventory assessment to identify unnecessary duplication and excess facilities, and enable divestiture or redirection of use over time of unneeded facilities to free-up additional investment for critical infrastructure supporting “must-do” technologies. Where MILCON funding is unavailable, the Army should pursue innovative funding options for building and maintaining facilities. For example, the Army could pursue third-party financing in the same manner that various national laboratories use these funding sources to maintain state-of-the-art laboratory facilities.

PEOPLE

People are critical to organizational success. Good people can make almost any organizational structure "work," while even the best organizational designs can fail without the right people. In particular, world-class R&D organizations need world-class leaders, managers, chief engineers and STEM personnel. As noted previously, there is a fierce global competition for STEM graduates. The Army has done quite well in recruiting and retaining top STEM people over the past few years, but will face a more difficult environment when the economy improves. In this competitive market for the best and brightest, recruiting and hiring should be as streamlined as possible. However, even with current “Lab Demo” authorities, most of the laboratory directors report frustrating delays in hiring. They also report excessive bureaucratic delays in management of Senior Executive Service (SES) and Senior Technologist (ST) positions, which are controlled by the Civilian Senior Leader Management Office.

Also, within the Army (as with the other military services), effective S&T is highly dependent on an understanding of the operational environment in which the technologies will be used. The best way of marrying operations and technology in S&T efforts is to have uniformed personnel with backgrounds and experience in both areas. The Army has fewer uniformed scientists and engineers than the other services and lacks career development paths for military STEM personnel like the Air Force and Navy.

To resolve these issues, the Army should take actions with both the civilian and military components of the S&T workforce. Recruitment and retention of civilian technical talent must be an Army priority. The Secretary and CSA should support actions to position Army S&T as an employer-of-choice for the best and brightest scientists and engineers, including:

1. Committing to "hiring the best," not just the qualified.
2. Extending the direct (not expedited) hiring authority currently available to laboratory directors for PhDs to include all subject matter experts (SMEs).
3. Establishing a STEM Corps, which recognizes and enables career development and advancement of scientists and engineers (S&Es).
4. Designating ASA(ALT) as the functional chief for career management.
5. Authorizing hiring and retention incentives targeted to increase the ARL S&E PhD population to greater than 50%.
6. Implementing programs to retain the current cohort of S&E talent.

On the military side, there is no well-defined S&E career path in the Army, thus rebuilding a uniformed S&T core of technically competent officers should be an Army priority. The Secretary and CSA should support actions to increase the number and quality of military scientists, engineers and technical leaders, including:

1. Re-establishing the Uniformed Army Scientist and Engineer (UASE) program.[4]
2. Increasing graduate-level STEM education opportunities which support the critical must-do-in-house technologies.
3. Establishing UASE billets as rotational assignments throughout the Army S&T enterprise.
4. Increasing S&E summer intern opportunities for Reserve Officer Training Corps (ROTC) and United States Military Academy (USMA) cadets to encourage future technical career field choices.

SUMMARY

The Army's 2012 S&T Master Plan lacks key elements[5] of a sound strategy or strategic plan. An Army S&T strategy is needed that satisfies strategic objectives in the context of critical environmental factors. Important components of the strategic plan should include portfolio management, technology transition, organizational structure, facilities and personnel. With the predominance of commercial and global technology spending, the portfolio management approach should determine which developments must be done in-house, which should be sponsored and which should leverage work sponsored and performed by external sources. The portfolio should correct the near-term horizon imbalance caused by ten years of war, and foster improved innovation and discovery leading to disruptive new capabilities. Technology transition should be facilitated across a broad time horizon through an integrated prototyping environment managed through a centralized DARPA-like TTIPO office, with decentralized execution. The S&T organization should be restructured to better align with the Army S&T strategy and incorporate beneficial elements of Air Force and Navy organizational designs. A facilities plan should be developed and resourced to ensure world-class capabilities for those efforts that must be conducted in-house, and to divest or reconfigure those facilities that are duplicative or not aligned with must-do in-house technologies. Finally, a personnel plan is needed to re-invigorate uniformed STEM workforce, 'hire the best' and to attract and retain the best civilian STEM workforce within the competitive marketplace.

The study team believes if the following recommendations are implemented by the Army, they will collectively result in a more robust and efficient Army S&T enterprise with substantial savings:

1. Look outside. Significantly improve the Army's ability to identify and exploit disruptive technologies initiated by US commercial and international efforts through partnerships with others.
    a. Reinvigorate international field office activities.
    b. Augment Army S&T through partnership technology projects, bilateral agreements, and international consortia.
    c. Consider "horizon scanning" strategies employed by OSD.
2. Develop a strategic plan with the elements above and perform an independent peer-reviewed, thorough, disciplined analysis of the portfolio to identify work that must be performed in-house, should be sponsored by the Army, and should be monitored and leveraged.
3. More actively interact with industry independent research and development (IR&D) projects.
4. Include a technology transition strategy as part of an overarching Army S&T strategy and plan.

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[4] Thane, John M., "The Future of the Uniformed Army Scientist and Engineer Program," *Military Review*, November-December 2007.
[5] Report of the DSB Task Force on Basic Research, Jan 2012.

5. ASA(ALT) establish a TTIPO that champions and integrates prototyping efforts across a broad time horizon, from rapid prototyping of NDI to accelerated technology insertion into PORs to demonstration of game-changing concepts. This activity should be a management activity with prototyping efforts executed in the requisite RDECs and PORs. An advanced concepts element should be included in this office to work in partnership with TRADOC to develop and demonstrate game-changing "big ideas".
6. Increase the number of exceptional, experienced chief engineers and systems engineers in the Army laboratories, RDECs and PEOs.
7. Realign ARO as Direct Reporting Unit to ASA(ALT):
    a. Expand the role to assist ASA(ALT) in development of a strategic plan, programming, policy and prioritization of the 6.1–6.3 S&T program.
    b. Foster enterprise-wide long-term focus, competition via a peer review process, integration and minimization of redundancies in the S&T program.
    c. Sponsor competitive execution of the 6.1 AMC-wide program with increasing responsibility for integration of the 6.2–6.3 program over time, to increase competition and decrease duplication in the 6.2–6.3 program.
8. Realign ARL as direct report to Commanding General, AMC:
    a. Divest research and customer-directed workload which is unrelated to Army critical technologies.
    b. Focus on long-term goals of senior leadership with increased high-risk research on game-changing technologies.
    c. Improve leverage of global R&D through increased industry, academic and international partnerships.
9. Create and resource a strategic modernization and recapitalization plan that:
    a. Provides periodic assessment and prioritization of facilities.
    b. Justifies Sustainment, Repair and Maintenance and Military Construction (MILCON) requirements.
    c. Reduces redundant capabilities and excess capacity.
    d. Enables strategies for innovative use of Army laboratory facilities, e.g., third party leasing and financing, cooperative use and fee-for-use arrangements.
10. In lieu of investment, leverage facilities of other federal, academic, industry and international partners.
11. Recruitment and retention of civilian technical talent must become a Secretary of the Army/CSA priority.
    a. Establish a technical career path within a science and engineering "corps," with ASA(ALT) as the functional chief for career management.
    b. Authorize hiring and retention incentives targeted to increase the ARL S&E PhD population to greater than 50%.
    c. Implement programs to retain the current cohort of S&E talent.
    d. Extend direct hiring authority for all scientists and engineers.

   e. Create a personnel process to hire and retain "the best," not just the qualified.

12. Rebuilding of a uniformed S&T core of technically competent officers should become a Secretary of the Army/CSA priority.
    a. Reestablish the UASE program to provide technology-competent officers for critical technology development and leadership roles, with sufficient billets to ensure a healthy career progression.
    b. Assure technical billets and personnel are provided to TRADOC.
    c. Increase graduate level education opportunities which support critical must-do in-house technologies.
    d. Increase S&E summer intern opportunities for ROTC and USMA cadets.

CHAPTER 1. INTRODUCTION

On October 28, 2011, the Secretary of the Army tasked the ASB to analyze the current RDECOM portfolio of S&T projects and objectives (see the TOR in Appendix B). The Secretary directed that the analysis should include a comparison of these projects to other U.S. government laboratories, industrial laboratories, and academic institutions.

TERMS OF REFERENCE

From the ASB analysis, specific findings and recommendations were to address the following:

1. Technology thrusts that are Army-specific and not being addressed elsewhere.
2. Why the Army funds >80% of 6.1 and 70% of 6.2 work outside?
3. Is the Army addressing long-term, game-changing ideas?
4. Regarding technology objectives that overlap those in other laboratories:
    a. What are the relative funding levels, Technology Readiness Levels (TRLs) and specific goals?
    b. Should we combine efforts?
    c. Should the Army depend upon the results of the other laboratories?
5. How to achieve better leverage on Army investments by actively managing IR&D funding.
6. Development of a broad technology development "road-map" showing how contributions from all sources ensure open access to better meet the Army's needs.
7. The adequacy of current Army technology transition strategies.

The motivation for this study grew out of a number of recent studies that have analyzed RDECOM missions and have produced conclusions critical of RDECOM accomplishments. In addition, the Secretary of Defense has suggested that the Services take at least a 10% cut in their science and technology spending as part of his efficiency initiatives.

One solution, based upon research and metrics provided by the Corporate Executive Board, and put forward by the Secretary of the Army's Short Term Overhead Reduction Task Force, suggested that the Army consider dividing its RDT&E into a small "corporate" research center, embed product development, developmental and operational test and engineering into the product-focused groups, and increase reliance and leverage from other government (including DOD) and commercial activities.

This solution is similar to the U.S. Navy and many industrial laboratories. If the Army were to adopt this model, the following outcomes would need to be guaranteed:

1. High confidence that the Army has access to all of the technologies required to build its systems.
2. Sufficient technical superiority over adversaries to ensure we retain the technical advantage.
3. In-house expertise to be competent buyers of highly technical products.

STATEMENT OF THE PROBLEM

"If we are unable to work within ourselves and forge a more efficient, agile and effective generating force, then others will likely make those changes for us."[6]

Honorable John M. McHugh, Secretary of the Army

Professionals involved in the U.S. Army's process of transferring technology from the laboratory to acquisition, and ultimately to the field, refer to the process as the "Valley of Death," because of the significant number of promising technologies and PORs that are never successfully fielded. The situation threatens the Army's status as the world's premier ground fighting force, which it has enjoyed since World War II, due in large part to its success in employing advanced technology on the battlefield. To maintain its status as the dominant force, the Army needs to develop a technology strategy that will remain viable in the severe budget environment that is expected to continue for the foreseeable future. The additional pressure of increasing competition in the fields of science and technology from potential adversaries requires a thorough review of the Army's functional and organizational structure for S&T. A comprehensive strategy must also include the priority and means to attract and retain the best personnel, and to develop and maintain "best-in-class" facilities.

Strategic Vision

- The Army has always possessed technological superiority over its adversaries.
  - Any S&T strategy must assure the preservation of technological superiority. Such a strategy does not now exist.

Challenges

- This superiority must be maintained in a fiscally constrained environment.
- The sources of technology are globalized and no longer dominated by the US as in the past.
  - The current business model and organization are not suited to the new technology environment (still doing things the old way)
- There is fierce international competition and challenges for S&T talent.
  - Human Resources policy and practice must assure access to top civilian and military S&T personnel – "Hire-the-Best"
  - Army has been successful in hiring excellent people during the economic downturn , the challenge will be to keep them as the economy recovers.

Figure 1.1 – Objectives and Challenges

STUDY APPROACH

During the course of this study, the team visited S&T, LCMC and PEO/PM organizations (listed in Figure 1.2) to conduct interviews with both laboratory leadership and representatives from the acquisition community. The study team selected organizations based on the presence of subject-matter experts whose work involved activities pertinent to the TOR. In all cases, questions were provided in advance to the organization being visited (lines of inquiry are provided at Appendix E). The study leadership also interviewed selected senior leadership in DOD, sister Services, University-Affiliated Research Centers (UARCs) and Federally Funded Research and Development Centers (FFRDCs) (Figure 1.3).

[6] McHugh (note 1).

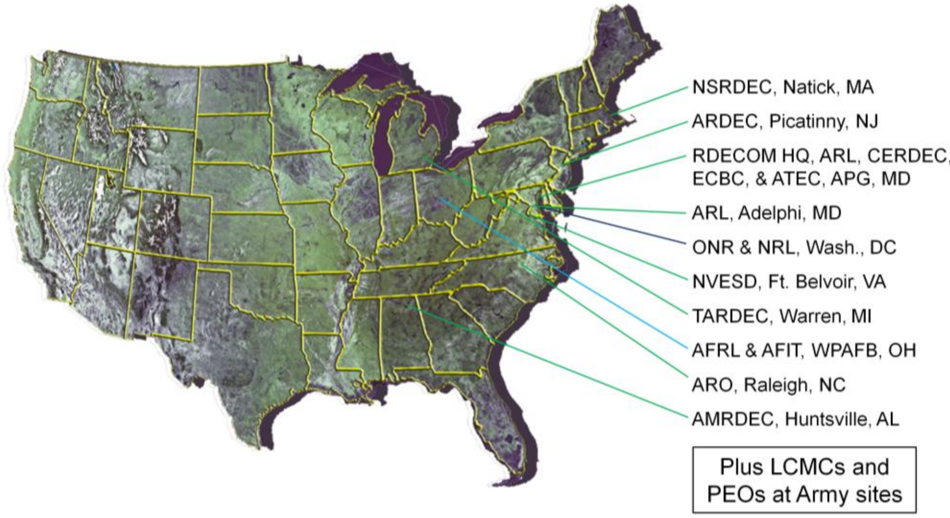


Figure 1.2 – Site Visits

Name	Title
Honorable Frank Kendall	USD(AT&L)/Defense Acquisition Executive
Honorable Zach Lemnios	ASD(R&E)
LTG William Phillips	MILDEP, ASA(ALT)
Dr. Marilyn Freeman	DASA(R&T)
Dr. Leonard Braverman	ODUSA
MG Camille Nichols	PEO Soldier
Dr. Michelle Sams	Army Research Institute for the Behavioral and Social Sciences
Mr. Gary Martin	Deputy CECOM, Former Deputy, RDECOM HQ
Dr. Steve Walker	Deputy Assistant Secretary of the Air Force for Science, Technology and Engineering
Dr. Jacques Gansler	Director, Center for Public Policy & Private Enterprise, Univ. of MD (former USD[ATL])
Paul Kern (GEN, USA-Ret.)	The Cohen Group (former CG AMC, Mil Dep ASAALT & CG 4th ID)
Dr. Paul Nielsen (MG, USAF-Ret.)	Director & CEO, Software Engineering Institute (former CG AFRL)
Mr. Dave Berteau	SVP, CSIS & Director, International Security Program
Dr. Robert McGrath	VP GIT & Director, GTRI
Dr. Sid Dalal	CTO, RAND
Dr. Eric Evans	Director, MIT Lincoln Labs

Figure 1.3 – Study Interviews

The study team experienced the following limiting factors that effected data collection and the degree of detail with which members were able to address tasks requested in the TOR:

1. The team conducted no visits to commercial industry, however, several members of the study team currently work in commercial and defense companies.
2. Study members were not provided access to compartmented technology programs, which often house some of the most innovative research conducted by the military. Judgments about such innovation could not be made in this study.

3. The task of coordinating schedules between S&T organizations and study panel members often constrained the windows of opportunity to gather data. Where necessary, follow-up queries or telephonic interviews were conducted. Certain areas of inquiry requested in the TOR were affected. Specifically, AMC received a more detailed analysis than RDECOM; the comprehensive examination of technology development was limited to the transition through BA 3; and a comparative review of all of the FFRDCs was narrowed in scope.
4. The study did not look at the U.S. Government's laboratories in other departments, such as the world-class facilities in the Department of Energy.

CHAPTER 2. ENVIRONMENT

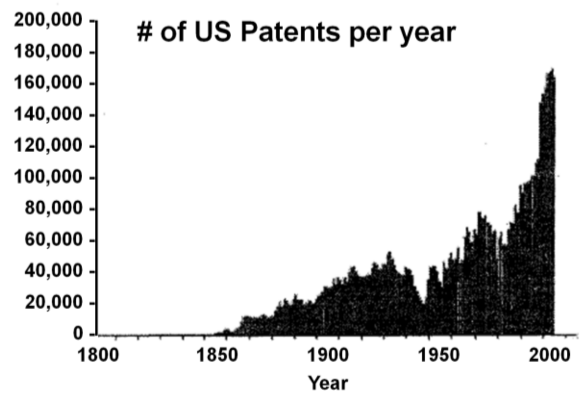
TECHNOLOGY ENVIRONMENT IN THE 21ST CENTURY: WORLD-WIDE R&D

Investment in S&T is increasing at a significant pace. During the Cold War, USG investment in S&T was geared toward national security, with most of the funds going primarily for defense. Patents and awards were primarily given to government scientists. During that time scientists were urged to provide spin-offs to the civilian and commercial world. The situation began to change at the end of the Cold War when U.S. commercial R&D pursuits dominated. Acceleration of world-wide investment in R&D began after the Cold War, and today is comparable to U.S. investment (Figure 2.1).

Today, commercial patents far outnumber government patents, and the subject of "spin-offs" has changed to "spin-ons," the application of commercial patents and products to defense and national security. The pace of investment continues to accelerate with R&D total investment approaching $1.2T.[7]

	Cold War (1965)	End of Cold War (1993)	Today (2009)
US Government	$60B	$75B	$80B
US Commercial	$90B	$200B	$300B
Rest of World	Unk	$300B	$450B

Source: Rand Basic Research Study
DSB 2012 Basic Research Study
Battelle International R&D Summary, Apr 2012



Source: JASON 2009 Summer Study

DoD is no longer a major contributor in technology acceleration

Figure 2.1 – Change of the R&D Environment: Last 50 Years

WORLDWIDE COMPETITION FOR STEM PERSONNEL

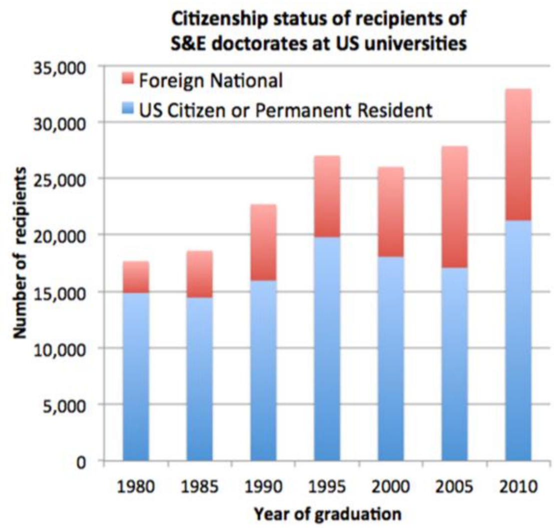
During the early post-Cold War period, the United States led the world in educating scientists and engineers spurred on by the "Sputnik" scare. Today, it is generally held that the U.S. universities are still turning out the best scientists and engineers in the world. However, an increasing portion of these scientists and engineers are foreign nationals who will return to their home countries at the end of their education (Figure 2.2). While the number of STEM graduates is increasing in the United States, the European Union (EU) and Japan, it is not keeping pace with China. There figures are often criticized as it is difficult to compare degrees of Asian universities with those in the United States and EU. The curve in Figure 2.3 was provided by the EU with the notation that the authors did their best to compare equal

[7] References include the *Report of the Defense Science Board on Basic Research (February 2012)*, *Democracy's Arsenal: Creating A Twenty-First-Century Defense Industry* (2011), *Defense Science Board 2006 Summer Study on 21st Century Strategic Technology Vectors (February 2007)* and "R&D Change in the 1990s," *R&D Magazine*, April 2012 (full citations in bibliography).

quality of degrees from all countries. A similar effect can be seen in the right side of Figure 2.3. This curve plots for three years the sources of undergraduate degrees of those who are earning PhD degrees in the United States The chart indicated that there are more students in PhD programs in the United States that earned their BS degrees in China and South Korea than students in PhD programs in the United States that have earned their BS degrees from the University of California, Berkeley, and the University of Michigan, Ann Arbor, the two university campuses that graduate the largest numbers of BS degrees in the United States.

	Cold War (1965)	End of Cold War (1993)	Today (2009)
US Government	$60B	$75B	$80B
US Commercial	$90B	$200B	$300B
Rest of World	Unk	$300B	$450B

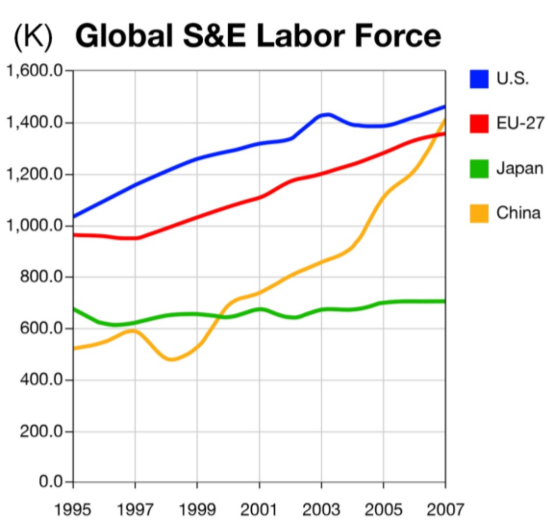
Source: Rand Basic Research Study
DSB 2012 Basic Research Study
Battelle International R&D Summary, Apr 2012



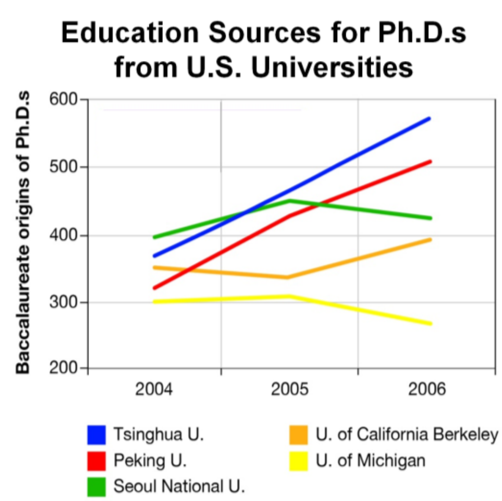
Source: Info Brief NSF 12-303

DoD is no longer a major contributor in technology acceleration

Figure 2.2 – The R&D Environment: Last 50 Years



Source: DoD S&E Labor Force Analysis 2011



Source: JASON 2009 Summer Study

Science and Engineering Workforce is becoming more global and competitive

Figure 2.3 – Global Science and Engineering Labor Force

U.S. immigration policy makes it difficult for non-U.S. students to remain in the United States after graduation. These restrictions, coupled with the difficulty foreign nationals experience in obtaining security clearances, prohibit the Army from actively recruiting and hiring foreign graduates. As a result, new opportunities have emerged for international students in their home countries, and foreign nations are providing additional incentives for graduates to leave the United States

Several bills have been introduced in the U.S. Congress to liberalize immigration policy to allow such students to immigrate to the United States. As of this writing, those bills have not been acted upon.

THE U.S. NATIONAL SECURITY BUDGET ENVIRONMENT FOR THE NEXT DECADE

From World War II, DOD budgets decline from peak wartime levels on the order of 30% to 40%. Generally, these declines have not resulted in declines in the investment accounts of the same magnitude, but 20% reductions are historically realized even after the S&T budget has been “protected” from the worst of the budget cutting. While it cannot be known at this time what the size of the reductions to the S&T account will be after Iraq and Afghanistan, reductions of this order can be expected. Available resources will affect the ability of the Defense and Army S&T communities to compete in the global competition for progress in R&D and in the race for talent.

FINDINGS AND RECOMMENDATIONS

FINDINGS

1. The technology playing field is changing; important technology breakthroughs are principally driven by commercial and international entities. The Army is still doing business as if it dominates the technology landscape.
2. In a world where all have nearly equal access to open technology, innovation is the most important discriminator in assuring technology superiority.
3. Time matters. The Army is not sufficiently agile and lacks a technology transition strategy to rapidly prototype and insert technology, regardless of its origins.

RECOMMENDATIONS

Look outside. Significantly improve the Army’s ability to identify and exploit disruptive technologies initiated by U.S. commercial and international efforts through partnerships with others.

- a. Reinvigorate international field office presence.
- b. Augment Army S&T through partnership technology projects, bilateral agreements, and international consortia.

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CHAPTER 3. THE ARMY SCIENCE AND TECHNOLOGY PROGRAM STRATEGY

OVERVIEW

The U.S. Army is the most technologically advanced army in the world and it has been well-served by the Army S&T community over the past half century. The primary purpose of Army S&T investment is to sustain and even expand this advantage into the future. The rationale for funding S&T is to:

1. Build future warfighter capability
2. Hedge against uncertainties in future threats and opportunities
3. Address today's problems

In the past 10 years of war, the priority has increased for addressing today's problems. This has led to a relatively near-term focus of the S&T portfolio. As budgets become constrained and R&D programs are reduced and/or cut, it is important to realize that an investment in long-term research is critical to maintaining the intellectual capital of the Army workforce, maintaining the technological superiority of our troops and avoiding technology surprise. To achieve these objectives, a healthy S&T portfolio should promote an environment that rewards innovation and risk, expands on the opportunities made available, and be guided by strategic goals to ensure relevance and impact to enhance warfighter effectiveness. These efforts should take place in world-class facilities.

Another key factor is that the quality of any S&T portfolio is highly dependent on having high quality S&T researchers, engineers, program managers and leaders.

With these factors in mind, the study investigated the TOR questions related to technology road mapping, the mix of intramural and extramural research, and the readiness of the S&T portfolio to provide required technologies to Army systems. Our activities included

1. Review related studies (See Appendix F).
2. Analyze Army S&T funding data (See Appendix G).
3. Gather and analyze data from Army and RDECOM Headquarters, ARL (including ARO) and the RDECs.
4. Conduct site visits of Army, Navy and Air Force S&T organizations.
5. Conduct Interviews with selected leaders and SMEs.

These activities and their resultant findings are described in the following sections.

ANALYSIS OF ARMY FISCAL YEAR 2011 SCIENCE AND TECHNOLOGY FUNDING

It should be noted that overall Army S&T (BA 1: Basic Research; BA 2: Applied Research; and BA 3: Advanced Technology Demonstration) funding was $2.0B in Fiscal Year (FY) 2011, with $1.5B allocated to organizations under RDECOM (ARL and the RDECs). The remainder was allocated to the Army Research Institute for the Behavioral and Social Sciences, Army Space and Missile Defense Technical Center, the Army Corps of Engineers Engineer Research and Development Center, and Army Medical Research and Materiel Command. This analysis focuses on the funding allocated to RDECOM organizations.

Within RDECOM, funds are allocated among ARL (including ARO), and the six Research, Development and Engineering Centers (RDECs):

1. Aviation and Missile RDEC (Aviation) (AMRDEC-AV).
2. Aviation and Missile RDEC (Missile)(AMRDEC-MI).
3. Armament RDEC (ARDEC).
4. Communications-Electronics RDEC (CERDEC).
5. Edgewood Chemical Biological Center (ECBC).
6. Natick Soldier RDEC (NSRDEC).
7. Tank Automotive RDEC (TARDEC).

A small amount is allocated to RDECOM headquarters. Figure 3.1 displays the allocation of funds among these organizations, including the split between in-house and external spending. It should be noted that most funding for ECBC comes through funding lines at the Defense Threat Reduction Agency, rather than the Army, and this funding is not included in this discussion.

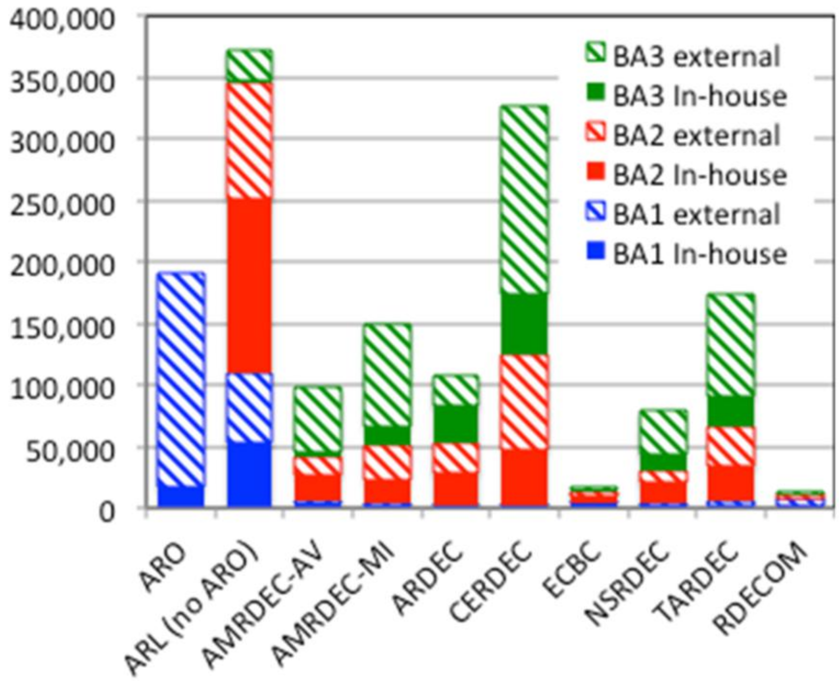

Figure 3.1 – Allocation of RDECOM S&T Funding

The TOR asks why more than 80% of BA 1 funds are spent externally. In FY2011, 73% of BA 1 funding to RDECOM organizations was spent externally. Within BA 1, ARO spends approximately 90 per cent of their funds externally, primarily within academia. ARL (other than ARO) is divided between Defense Research Sciences and University and Industry Research Centers. The latter is almost entirely spent externally while the former is primarily spent in-house. Additional details are provided in Appendix G.

The TOR also asks why 70% of BA 2 funds are spent externally. In FY2011 48% of BA 2 funding to RDECOM organizations was spent externally. As shown in Figure 3.2, ARL BA 2 in-house spending is approximately 40%. For the RDECs, BA 2 in-house funds are between 37% (CERDEC) and 68% (NSRDEC).

In BA 3, ARL has minimal funding ($27M) and it is primarily spent externally. For the RDECs, BA 3 funds are less than 30% in-house except for ARDEC (57%). This is consistent with the idea that funds should shift to external spending as projects move to BA 3 in order to prepare for production. Additional discussion is provided in Appendix G.

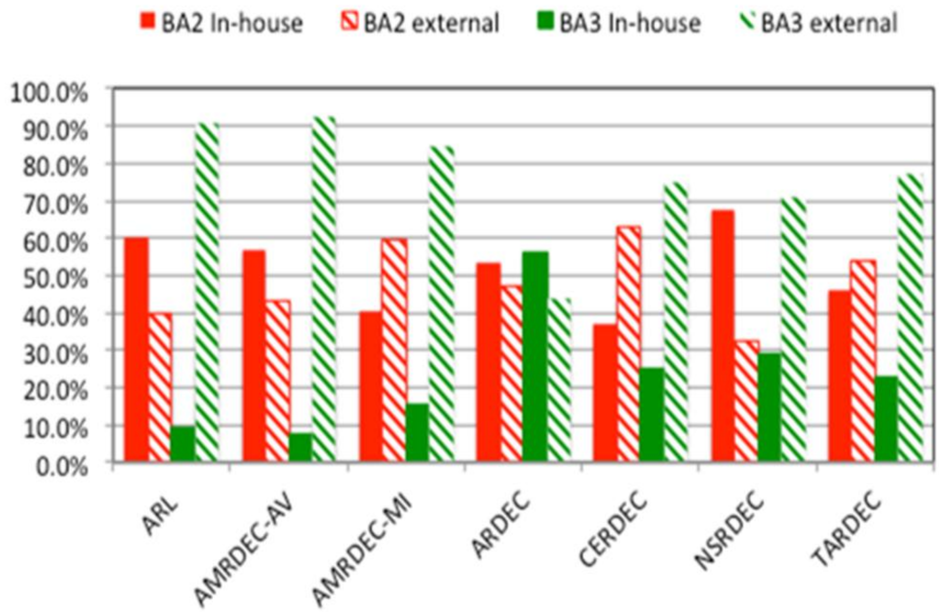

Figure 3.2 – BA 2 and BA 3 In-house and External Funding Percentages

NEED FOR A SCIENCE AND TECHNOLOGY STRATEGIC PLAN

The above analysis provides a snapshot of how the RDECOM organizations are currently spending S&T funds. But portfolio management cannot be based on percentages across an organization, but rather must assess how funds are spent in specific technology areas. Such an assessment must be based upon a strategic plan.

Given limited and likely declining resources, it is particularly important that Army have a thoughtful and robust strategic plan to guide its science and technology (S&T) effort for the next 10–15 years. Because resources are limited and it is not possible to pursue any and all research areas, an Army S&T strategy is needed to assure preservation of technological superiority. In its extensive visits and interviews, the ASB did not find evidence of a top-level S&T strategy or roadmap. This is not to say that there wasn't planning (the ECBC roadmap is an example). But there was an absence of a clear and well-coordinated and understood vision and strategy for execution of an Army S&T plan. Characteristic of what the ASB found instead was the 2010 Army S&T Master Plan,[8] which is an extensive list of tasks, assignments and organization charts, but does not communicate a clear vision or meet the other key elements of a strategy as defined by the Defense Science Board (DSB).[9] The ASB also learned of an effort to attach S&T efforts to capability gaps through the Technology Enabled Capability Demonstrations (TECDs), but such an approach is not a substitute for strategy, rather, it is an integrated, near-term demonstration of technologies.

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[8] Army Science and Technology Master Plan, Office of the DASA(R&T), HQDA, Washington DC, 2012.
[9] *Report of the Defense Science Board on Basic Research (note 6 and bibliography).*

The Army can more effectively leverage its S&T investment through strategic management of its portfolio. As stated about DOD-wide basic research strategy in the DSB report:

> "A list of critical technologies does not constitute a technology strategy; nor does a summarizing description of ongoing activities and funding. What's needed are objectives expressed with clarity, quantification, priority and timing, credible if unproven technical ideas with promise for achieving the objectives; demonstration of the system and mission consequences of achieving – or not achieving – the objectives; and actionable plans for developing the credible ideas in pursuit of the objectives." [10]

The Army Science Board agrees. Pulling together Army S&T is a daunting job, but it can be done as many other organizations have demonstrated. Regardless of the effort involved, a strategic plan is essential to the success of Army S&T in the current environment.

One of the key elements of such a plan is that it identifies realistic objectives that are credibly prioritized and quantified to the fullest extent possible. An important consideration with respect to prioritization, particularly in the face of limited resources and anticipated budget cuts, is establishing an approach to the execution of S&T work that more nearly optimizes the use of resources and strives to ensure that the knowledge and products derived from the broad range of supported activities are developed by the most efficient and effective means. Depending on the technical thrusts of the work, the capabilities of executing Army organizations and technical personnel, the level of relevant expertise in industrial organizations and/or academia, and the availability of required facilities, specific efforts may be most appropriately conducted by the Army in-house or by external organizations under Army sponsorship. An additional prioritization factor involves knowledge of work that is recognized as being of considerable importance to the development of future Army capabilities, but where the work is likely to be supported by other sponsors; such work should be closely monitored by knowledgeable Army personnel for potential future Army exploitation and application.

Based on extensive information gained through briefings by Army S&T program leaders, during visits by study team personnel to most of the organizations responsible for the execution of Army S&T activities, and comprehensive responses to numerous written questions submitted to each organization, the study team conducted an assessment of many of the activities being conducted by these organizations to help guide future prioritization decisions (see Appendix H). The information-gathering and assessment exercise considered S&T work being conducted by all of the Army's RDECs and all of the directorates comprising the ARL. Three specific execution categories consistent with the study TOR were considered: (1) work that must be conducted by the Army in-house, (2) work that should be conducted under Army sponsorship, and (3) work being conducted by others that the Army should closely monitor. For all three categories, technology efforts should be limited to technology that is important to the Army. The three categories are further defined as follows:

(1) <u>Work that must be performed in-house (by government personnel or on-site contractors)</u>. This category includes work in areas of paramount importance to Operating Force capabilities where Army personnel have the comprehensive and in-depth expertise and critical required facilities, and where relevant expertise and experience in industry/academia may be limited. It also includes work where loss of expertise would be extremely detrimental to the Army as well as efforts in which it is

[10] *Report of the Defense Science Board on Basic Research (note 6 and bibliography).*

faster and more cost-effective to do the work in-house. Lastly it includes work that industry is not (and cannot be) motivated to pursue.

(2) Work that should be sponsored in private industry, academia, or other government organizations. This category includes work complementary to Army in-house activities where contractor organizations have significant expertise/experience, appropriate facilities, and can be expected to make significant contributions to specific capabilities being pursued by the Army. It also includes work where Army personnel lack the level of expertise and/or facilities required to conduct the work in-house, as well as basic research work where principal expertise in selected technical areas of interest resides in academia, industry research laboratories, or other government organizations. Army support is required because Army needs are unlikely to be met if such support is not provided.

(3) Work being supported and conducted by others. Research conducted by Navy, Air Force, DARPA, national laboratories, other government agencies, and more broadly, industry and academia should be closely monitored by knowledgeable Army technical and program management personnel and leveraged as appropriate. For these technologies, the expertise is outside the Army and another organization is supporting it at a level consistent with meeting Army needs. Such work is of considerable potential importance to the development of future Army capabilities.

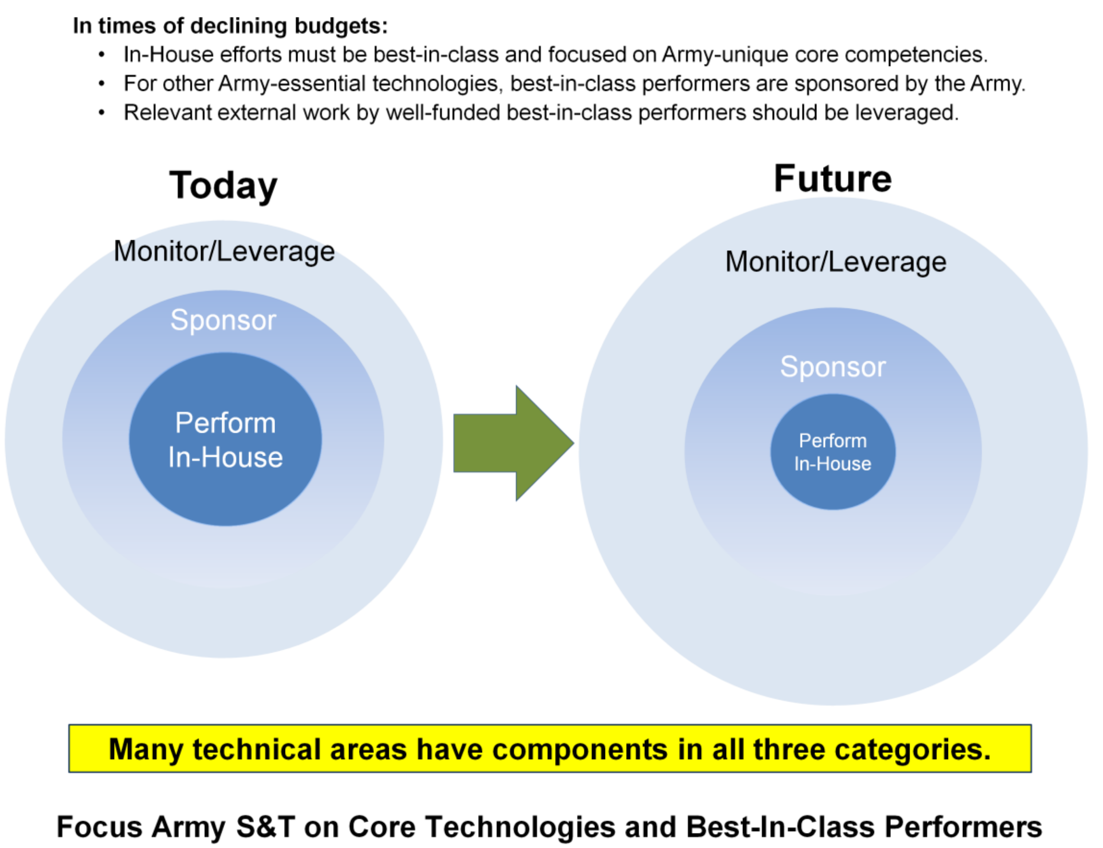

Figure 3.3 – Army S&T Focus on Core Technologies and Best-In-Class Performers

Figure 3.3 provides a schematic illustration of this categorization of S&T activities important to Army interests in the form of a concentric circle or "bulls-eye" chart, where the two images depict Army S&T Today and Army S&T Future to reflect anticipated reductions in S&T expenditures overall and reductions in both the extent of work conducted in-house and sponsored efforts, as well as greater future reliance on monitoring and leveraging useful results of work supported and conducted by others. In times of declining budgets, in-house efforts must focus on Army-unique core competencies and work by others should be monitored and leveraged to the maximum extent possible.

It is important to note that the S&T execution categories defined for this ASB study are not mutually exclusive; there can be and typically will be considerable overlap across the boundaries (Figure 3.4). For example, work that must be performed by the Army in a particular high-priority technology area does not mean that all such work in that area must be performed in-house. Work in another specified technology area that should be supported by the Army does not imply that performing limited related work in-house should be disallowed, viewed as inefficient use of resources, or representing an unwarranted duplication of effort. In addition, technologies may change categories as they mature; for example the primary effort may shift from in-house to supported work in order to position industry for production of the envisioned system. Decisions with respect to establishing an effective balance between work executed in the cited categories must be made on a case-by-case basis and consistent with current Army priorities and a sound overall Army S&T strategic plan.

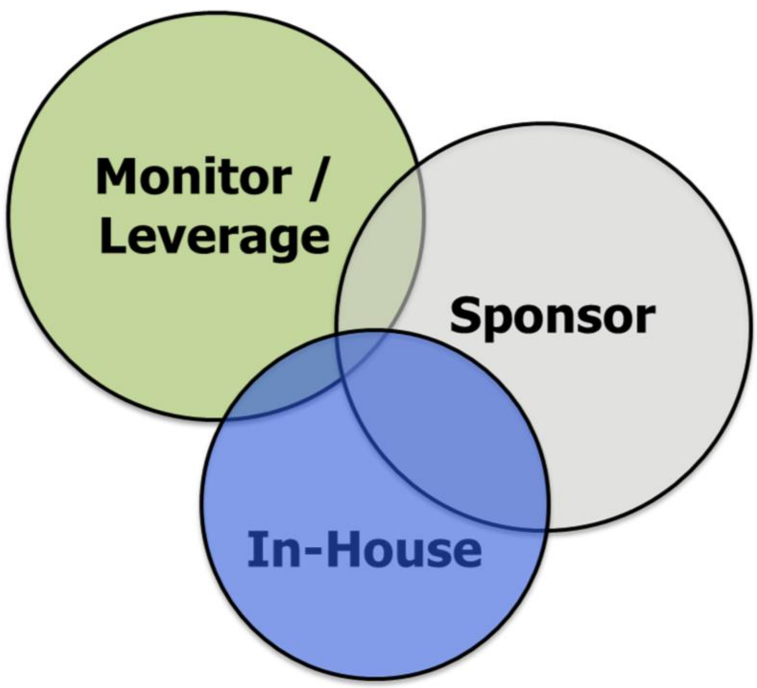

Figure 3.4 – ASB Categorization of Army S&T activities

For any Army S&T organization, finding the proper balance between work conducted in-house and work that should be supported, as well as work by others that should be monitored and leveraged, is key to achieving desired enhanced generating force efficiencies. In addition, the balance among these categories is likely to vary significantly among the numerous technical areas comprising the Army S&T program.

Selected examples of S&T activities of importance to the Army in each of the noted S&T execution categories identified above are provided in Appendix H for each of the RDECs and for all of the directorates comprising ARL. The analyses for the individual organizations were done by study team members having comprehensive and in-depth relevant knowledge and expertise. The categorization criteria adopted and applied were based on the category descriptions provided above. Table 3.1 provides examples for the RDECs. It is important to note that this compilation is intended to reflect the findings of an ASB analysis based on its broad but not deep review of Army S&T activities. The examples are not offered as specific recommendations but are intended to demonstrate the output that results from an analysis of this kind. The cells marked with a star indicate a change from the current status and highlight potential efficiencies available from such an analysis.

The overall approach and the cited examples are intended to promote the formulation and execution of a more thorough, more detailed analysis of this kind. The study team strongly recommends that the Army conduct such an analysis, with particular focus on achieving enhanced efficiencies in the execution of its S&T program and eliminating and avoiding redundant efforts.

Organization	Must Do In-House	Should Support	Should Leverage
AMRDEC – Aviation	Evaluation of critical components (structural, ballistic protection, IR suppressors, ASE equipment) and flight testing.	Rotorcraft drive (gears, tribology, multi-speed) and active rotor technologies.	Alternative fuels, batteries, and energy storage technology. ★
AMRDEC – Missiles	Development of overt, high-bandwidth millimeter-wave/terahertz navigation radar and communication/data links.	Advanced electronic and opto-electronic materials and device fabrication.	Information sciences research relevant to Army missile system needs. ★
ARDEC	Munition systems technologies, including energetics (propellants and explosives), warheads (KE, SC, EFP), and fuzing.	Novel advanced high-performance materials for warheads and gun systems. ★	Hypervelocity impact research and technology developments. ★
CERDEC	Model development and validation for characterization/testing of imaging sensors (EO/IR, countermine, etc.).	Power systems R&D: electro-chemical, power electronics, renewable energy devices. ★	Image and signal processing technology. ★
ECBC	Advanced concepts in chemical and biological sensing and signaling, novel threat agent synthesis and characterization.	Chemical and biochemical computational methods based on processes in nature.	R&D in the areas of nano-technology, microfluidics, aerosols, and metamaterials. ★
NSRDEC	Advanced fiber and textiles, including smart, responsive, or other multifunctional types, for extreme environments.	Power technology for the individual soldier and small units.	Nanomaterials, fiber-reinforced composites, flexible displays. ★
TARDEC	Ground vehicle systems design tools, analysis (M&S), and testing; concept development, component integration, testing.	Unmanned ground systems technology, robotics technology. ★	Fuel economy technology (e.g., hybrid drive), water purification ★

★ reflects change from current state

Table 3.1 – Proposed Execution for RDECs

MAKING BASIC RESEARCH COMPETITIVE

With respect to the TOR question "Are we addressing long-term, game-changing ideas" the 2010 RAND study found that: "The AMC basic research program is increasingly too near-term in its focus, with declining discovery and invention. In particular, the panel does not find mechanisms that stimulate staff to undertake high-risk but potentially transformational research in areas relevant to the Army."[11]

In many respects, civilian technology is more advanced than military technology. (The Apple iPhone serves as a recent example.) Innovative civilian products are introduced rapidly, whereas military technology development is typically paced by the requirements and acquisition bureaucracy, which -- beyond operational security considerations -- oftentimes manages for risk-avoidance over cost and schedule. Ultimately Army needs industry to build technology for use by its Soldiers. Whereas once the defense industry was characterized by state-of-the-art technology and innovation, now it is also known for bureaucratic encumbrances and consolidation. In contrast, commercial industry is forced to develop technology quickly, as the global marketplace is acutely competitive. Creation of a competitive environment within the Army would both render Army S&T more robust and better support S&T innovation.

At present, Army's S&T organization is not suited to the new technology environment. The Army has the most complex S&T organization of the military services. Basic research is budgeted through ASA(ALT) with policy guidance through DASA(R&T). Program management is done almost entirely through RDECOM, largely but not exclusively through the ARL and its current component, ARO. This is in contrast to the Navy, which coordinates both its intramural and extramural S&T efforts through the Office of Naval Research (ONR), and Air Force, which also coordinates its intra/extramural basic research efforts through the Air Force Office of Scientific Research (AFOSR).

In basic research, the Army should cast a wide net for discoveries, many of which occur through funding research in academia. This broad, high risk approach to funded research is best achieved with a robust single investigator program, augmented by multi-disciplinary programs such as the Multidisciplinary University Research Initiative program. In recent years, the Army has committed a significant portion of its 6.1 funds (28% in FY2011) to UARCs and Collaborative Technology Alliances. The funding for each organization is specified in budget documents and thus is not easily adjusted. This reduces the flexibility and portfolio turnover that allows the Army to explore new areas of research.

Linkages across the Army 6.1/6.2/6.3 organizations appear to be weak, from a transition perspective. This creates multiple valleys of death. Examples include a stark lack of evidence that ARL researchers are willing to pick up ARO basic research (6.1) for transition to 6.2, and evidence that ARL generally does not have uncommitted 6.2 funds when ARO programs are ready to move beyond 6.1. Most of the examples of ARO basic research transitions identified were to industry (Small Business Innovation Research) or DARPA. In addition, little evidence was observed that RDECs are incentivized to work with ARL to transition its 6.2 to 6.3. ARL has to push their ideas to the RDECs, and only isolated pull on ARL 6.2 program outcomes was observed.

INNOVATION

Major shifts in the global distribution of research and invention over the past several decades have resulted in a decline in relative U.S. Army superiority in innovation. Technological and educational centers of excellence have spread across the globe, and as a result innovation now requires a substantial effort to maintain awareness of global S&T activities, especially in technical areas important to the Army where offshore research productivity rivals that of the United States.

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[11] Decker, Gilbert, et al., *Improving Army Basic Research: Report of the Panel on Future Army Laboratories*, RAND Corporation, Santa Monica CA, 2012.

Restrictions on international travel and collaboration hinder innovation and competitiveness of Army S&T. Repeatedly, administrators and technical program managers associated with Army S&T described substantial barriers to timely and efficient foreign travel. Such restrictions and impediments to foreign travel will reinforce the relative isolation of Army S&T programs, accelerating losses in innovation leadership.

GAME-CHANGING TECHNOLOGIES

Game-changing technologies have the ability to transform the way the military operates and typically afford unprecedented tactical overmatch advantages. Dr. Alex Roland from Duke University and Dr. Wayne Lee from University of North Carolina at Chapel Hill compiled the following list of ten exemplar technologies that changed war and the course of history:

1. The chariot.
2. Gunpowder.
3. Rifled gun barrels.
4. Internal combustion engine.
5. Airplanes.
6. The radio.
7. Radar.
8. Nuclear weapons.
9. Reconnaissance satellites.
10. Global positioning system.[12]

The ability to innovate and realize game-changing technologies is critical to the success of our future force and, as such, the ASB attempted to assess whether Army S&T is sufficiently focused on potential game-changing technologies. The ability to directly ascertain whether a research thrust area has the possibility of having a game-changing impact on the future force is, however, very difficult because the game-changing impact is oftentimes not observable in advance. Furthermore, predicting which constituent technologies are likely to realize the game-changing breakthroughs is equally challenging. As a result, the panel believes that a measure of game-changing investments can be based on (1) an organization's track record of achieving game-changing results, (2) to what extent a culture of innovation exists, (3) the level of investment in high-risk/high-payoff research, and (4) relevant advanced concept visions and their assumed operational impact.

Although the Army S&T organizations have been credited with some game-changing technology developments (e.g., night vision, proximity fuses, and guided munitions), in general, the track record of producing game-changing results over time is not strong. Given the level of S&T invested annually, it is expected that a greater number of game-changing innovations would have been realized.

The Army S&T enterprise does attempt to foster a culture of innovation. An example of this is the Army Greatest Inventions program that recognizes Army top inventions annually. Although many of the

[12] Ogg, Erica, "How Apple Gets Away with Lower R&D Spending," GigaOM Pro, 30 Jan 2012, http://gigaom.com/apple/how-apple-gets-away-with-lower-rd-spending.

inventions recognized in the Army Greatest Inventions Program represent excellent research and innovation, there is little evidence that any of them will transform military operations in the future.

Because of the focus over the last decade on solving near-term warfighter problems, DOD has become risk averse and reduced support for longer-term development. The level of investment in high-risk/high-payoff technologies appears to be less than adequate to achieve game-changing results. When asked, ARL/ARO cited more than $92M of annual investment in “game-changing” technologies (see Appendix I). The ASB recognizes that several of the cited technologies are high-risk/high-payoff, but has reservation that many of the technologies cited truly have the potential to be game changing. Albeit these technologies are not inclusive of all “high-risk/high-payoff” technologies being explored by Army S&T, it is noted that the selected technology investments cited by ARL/ARO represents less than 20% of the ARL/ARO 6.1 investment.

Finally, there is limited evidence that Army S&T had a clear strategy with game-changing visions. Army S&T has a series of research focus areas that have the potential to realize broad evolutionary and limited revolutionary results. But the goals of these efforts do not stretch the researchers and most of the visions are loosely coupled, at best, to operational impact and quantified objectives. In order to better track progress, the ASB believes the Army could document key game-changing technology visions with specific objectives and measure performance towards achieving the goals.

Based on these qualitative measurements, it appears that Army S&T could do better at achieving game-changing results.

FINDINGS AND RECOMMENDATIONS

FINDINGS

1. The Army has a history of a strong S&T program with a long record of accomplishments. However the international playing field is changing and the Army must respond to this new environment.
2. We did not see a top level S&T strategy or roadmap. The 2012 S&T Master Plan does not meet the key elements of a strategy:
    a. A vision
    b. An assessment of emerging areas of S&T
    c. Realistic objectives
    d. An approach to achieving the vision and objectives
    e. Detailed plans to achieve the objective
3. There has been some progress in portfolio management, but the S&T portfolio is neither integrated nor efficient.
4. The Army lacks sufficient innovation to keep up with growing Army mission challenges.

RECOMMENDATIONS

1. The Army should develop a strategic plan that includes the key elements above. As part of that strategic plan it should perform a thorough analysis of its portfolio applying the following criteria:
    a. Work that must be performed in house
    b. Work that the Army should sponsor
    c. Work the Army should monitor
2. The Army should move responsibility for all 6.1 basic research into a single organization that manages competition for both extramural and intramural projects. It should create a competitive environment within the Army to promote innovation and the highest caliber of innovative science and technology.
3. The Army should more actively interact with industry IR&D projects.
4. The Army should reassess its priorities and approach to international engagement.

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CHAPTER 4. THE ARMY TECHNOLOGY TRANSITION STATEGY

STUDY APPROACH AND FOCUS

The TOR requires an assessment of the "adequacy of current Army technology transition strategies." There is no formal documented Army strategy for technology transition. While no formal integrated strategy exists, it is clear that Congress, DOD and Army leadership are all well aware of the need to improve the effectiveness of technology transition, particularly in resolving the difficulties in moving technology from S&T to acquisition programs. The inadequacy of current processes for moving technology from the laboratory to the field has been highlighted in several recent studies. For example, a GAO Report entitled "Stronger Practices Needed to Improve DOD Technology Transition Processes" states that:

> "Although the United States has produced the best weapons in the world, its acquisition programs often incur cost overruns, schedule delays, and performance shortfalls that undermine DOD's buying power. This dilemma is due in part to DOD's difficulty transitioning technologies from a technology development environment to an acquisition program." [13]

In the absence of a formal technology transition strategy, this study examined the key issues that such a strategy should address and formulated some basic elements of a strategic framework for effectively resolving these issues. Elements of the S&T technology transition strategic framework for this study are illustrated in Figure 4.1.

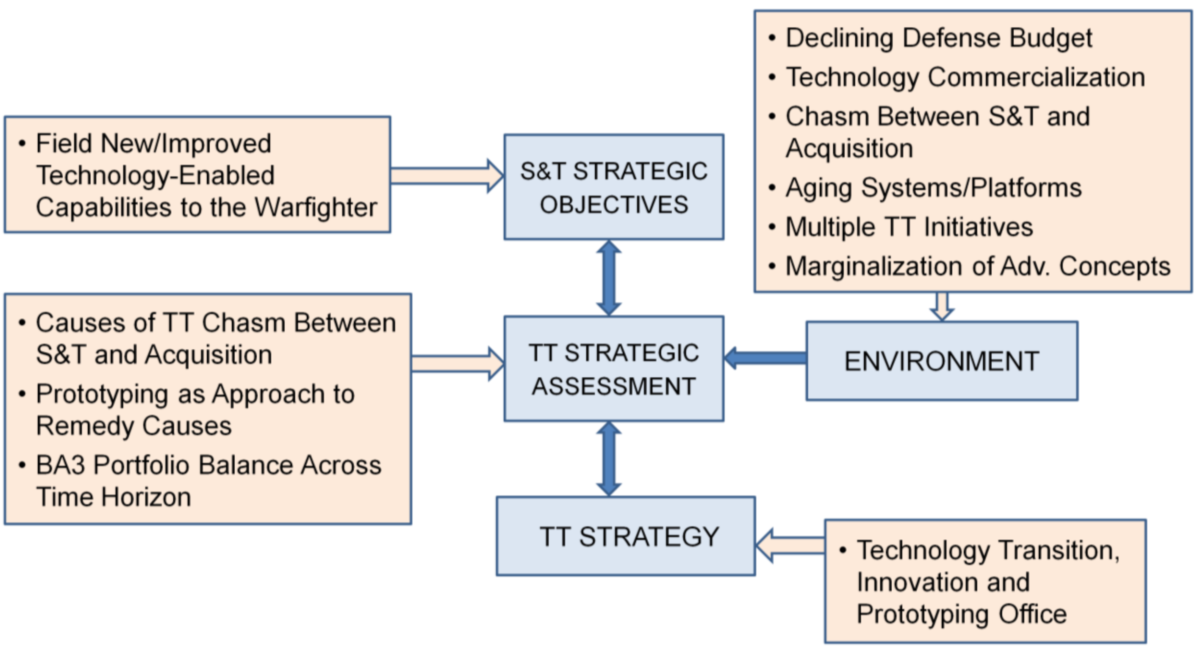

Figure 4.1 – Study Framework for Technology Transition Strategy

A strategy is a means to an end (strategic objectives) and is about making choices on how to allocate scarce resources (funding, people, facilities and time) to best achieve the objectives within the context of relevant environmental forces. While the end objectives should be fairly enduring, the strategy must

[13] GAO Report 06-883: *Stronger Practices Needed to Improve Technology Transition Processes*, 1996.

adapt to the environment. Thus, an effective Army S&T technology transition strategy must be directed toward accomplishing S&T strategic objectives while recognizing and adapting to changing environmental forces (external and internal) that positively or adversely impact the Army's ability to achieve these objectives through technology transition within its scarce resource constraints.

A technology may be considered to "transition" every time it is handed off from one organizational element to another. For example, a technology transitions from a BA 1 basic research program at ARO to a BA 2 applied research program at ARL. It transitions again when it moves from BA 2 at ARL to a BA 3 program at one of the RDECs. These transitions are within the S&T funding elements (BA 1 to BA 3). A technology undergoes a final transition when it exits S&T and is handed off to an acquisition program via BA 4 to BA 7 funding.[14]

Each transition in this chain has its own challenges. Those challenges associated with the transitions *within* S&T (i.e., BA 1 to BA 2 and BA 2 to BA 3) are discussed in chapters 3 and 5 of this report. This chapter focuses on the transition *from* S&T to acquisition (i.e., from BA 3 to BA 4–BA 7), which is generally recognized as the most difficult and is often referred to as the "valley of death."

The Assistant Secretary of Defense for Research and Engineering emphasized this point in addressing the subject of technology transition in his testimony to Congress this year, "We remain committed to technology transition to ensure new technologies have an impact on system procurements when they've reached a sufficient level of maturity."[15]

This capability is realized by fielding the technology on a product or service supplied through the acquisition system. The effectiveness and return on investment of Army S&T is dependent on bridging the transition chasm between S&T and acquisition. Without an effective S&T technology transition strategy, the value of S&T spending is diminished.

This chapter of the report is organized as follows: Army S&T strategic objectives; Paths that can be taken for a technology to transition from S&T to a fielded capability; External and internal environments affecting a transition strategy for the Army to best satisfy the strategic objectives; An assessment of the strategic issues generated by the environment; A prototyping approach that can address many of the strategic issues; and Principal findings and recommendations on technology transition.

ARMY SCIENCE AND TECHNOLOGY STRATEGIC OBJECTIVES

An Army S&T technology transition strategy must start with a clear definition of strategic objectives that the strategy is intended to satisfy. The strategic objectives for Army S&T have remained fairly constant over the years. While slight revisions in wording have been made with leadership changes, the vision for Army S&T over the years is generally consistent with the latest statements by the current DASA(R&T):

> Army S&T *raison d'être*: "foster invention, innovation, maturation and demonstration of technologies to enable future force capabilities while exploiting opportunities to transition technology enabled capabilities to the current force."

[14] Not all transitions occur in serial fashion from BA 1 to BA 4. A technology may sometimes skip a budget activity if sufficient maturity has been demonstrated and/or if there is an urgent need to accelerate it.
[15] Lemnios, Honorable Zachary J., Statement before U.S. House Committee on Armed Services, Subcommittee on Emerging Threats and Capabilities, 1 March 2012.

Army S&T Vision: "Provide technology enabled capabilities that empower, unburden and protect our soldiers and warfighters in an environment of persistent conflict." [16]

Consistent in these and other stated leadership positions is that S&T must serve the needs of the warfighter and provide our soldiers with new/improved capabilities to perform their missions against current and future threats. Getting a technology out of the laboratory and into the hands of the warfighter is the essence of this objective.

TRANSITION PATHS

The paths that can be taken to transition a technology from a research environment to a fielded capability are illustrated in Figure 4.2. As indicated, each path fills a niche within the time horizon spectrum. Note that the time lengths are merely illustrative and should not be construed as a precise determination of duration.

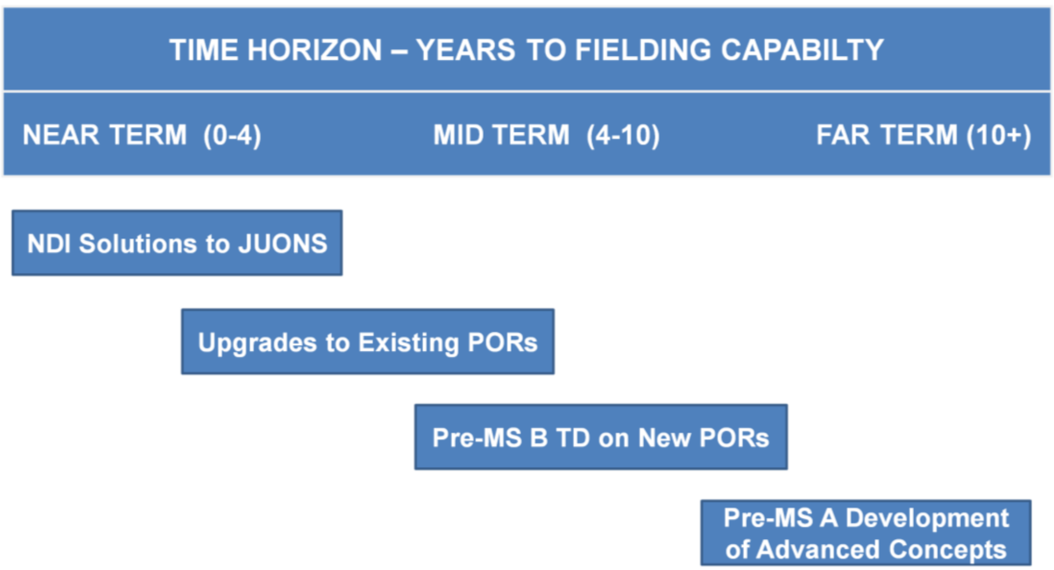

Figure 4.2 – Paths for Technology Transition Span Broad Time Horizon

The nearest term path is the direct fielding of mature technologies to a theater of conflict in response to an urgent operational need. Often, these technologies are in the form of an NDI that is adapted from a commercially developed application. This path typically bypasses formal acquisition and is not subject to DOD 5000 series acquisition regulations. The benefit of this approach is the rapid fielding of a capability. The Army Rapid Equipping Force has been successful in rapidly fielding capabilities to Operation Enduring Freedom (OEF) and Operation Iraqi Freedom (OIF) theaters of operation.

The downside of this path is that the capability is usually rushed to the theater without the full complement of DOTMLPF infrastructure. For those capabilities that prove to have significant operational utility that is judged to be enduring, the capability must ultimately be integrated into an acquisition POR, on which all elements of a fully supported DOTMLPF capability are developed. Another downside is that this approach is funded primarily through Overseas Contingency Operations (OCO) funding, which will likely terminate after OEF/OIF operations cease. However, the value of such a rapid

[16] Freeman, Marilyn, Statement before the Senate Armed Services Committee Subcommittee on Emerging Threats and Capabilities, 17 April 2012.

insertion approach to technology transition is well understood within DOD and efforts may be made to institutionalize this approach to provide an enduring means during peace-time operations.

The next path in terms of time horizon is the insertion of a technology into an existing (Post–MS B) POR. Modernization of most of the Army's deployed systems and platforms are reliant on this path. Upgrades to existing systems/platforms must follow DOD 5000 Series acquisition regulations. The DOD acquisition system actually consists of three interdependent decision making processes, each owned by different organizations within DOD and the military services:

1. Requirements are established by the Joint Capabilities Integration and Development System, which is owned by the Joint Staff, with G3 validating Army requirements and TRADOC in the lead for development.
2. Budgets are developed, approved and appropriated through the Planning, Programming, Budgeting and Execution process, which is owned by OSD (CAPE) and Comptroller, with G8 in the lead for the Army.
3. Program execution is managed through the DOD 5000 series Defense Acquisition System processes, owned by USD (AT&L) and delegated to the respective military service senior acquisition executives.

In this report, we refer to the composite of these processes as the Requirements-Budgeting-Acquisition (RBA) process.

These processes are slow and cumbersome, resulting in a technology insertion timeline that takes years to field a capability. A typical timeline for the insertion of a technology into a POR is illustrated in Figure 4.3. As indicated, it is not unusual for the RBA process to cause a 2 or 4 year delay from initial identification of a technology insertion opportunity to the obligation of funding and contractual Authorization to Proceed (ATP) for the development and engineering effort; another 2 to 4 years from ATP to completion of full scale development; and another 2 to 4 years for operational test and evaluation (OT&E) before the technology is fielded. The timeline for non-major systems can be less, but still lengthy.

The next path is technology insertion into new (Pre-MS B) PORs. This path must follow the same slow deliberate RBA processes as existing PORs. The timeline for technology insertion is therefore roughly the same as shown previously for existing PORs. However, the Pre-MS B timeline (i.e., time prior to a MS B decision and contractual ATP) usually involves a more lengthy technology demonstration period to satisfy statutory requirements for Pre-MS B competitive prototyping.[17]

[17] Pre-MS B competitive prototyping for major acquisition programs is a statutory requirement of the Weapon Systems Acquisition Reform Act of 2009 (Section 203 of Public Law 111-23), unless waiver can be justified.

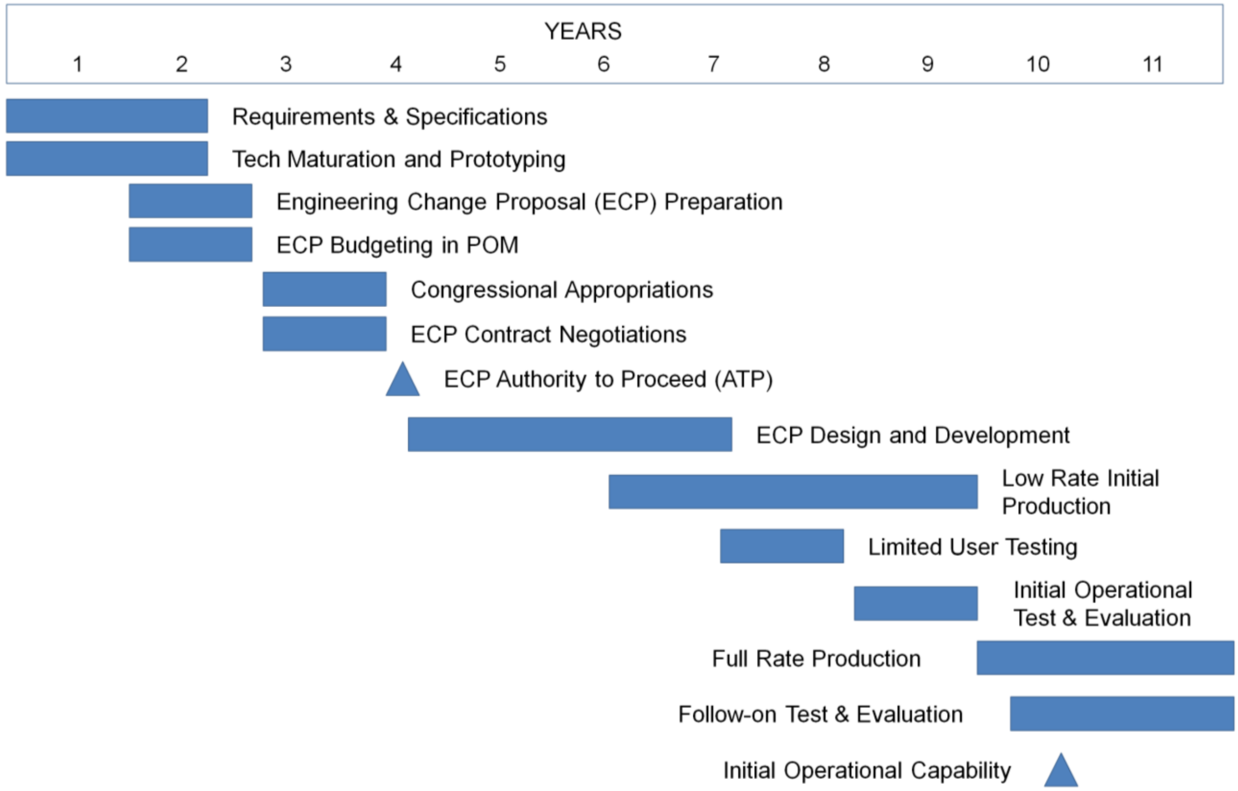

Figure 4.3 – Typical Timeline for Technology Transition to Programs of Record

Methods for compressing this timeline have been the subject of several acquisition reform studies, initiatives and alternate acquisition strategies over the past 30–40 years. On new PORs, attempts to reduce the time (and cost) of conducting Pre-MS B ATP activities by minimizing requirements trade studies and/or by not conducting competitive prototyping have proven problematic. Unrealistic or volatile requirements and/or immature technologies are often the main contributors to failed acquisition programs.[18] While trimming these Pre-MS B efforts reduces time and cost by some known amount, it increases the risk of unknown cost/schedule growth Post-MS B. Historically, these unknown costs and schedule delays often exceed the Pre-MS B cost/schedule savings.

Schedule can also theoretically be reduced by means of concurrency of the activities shown in Figure 4.3. However, concurrency also adds risk, and is generally not favored as an acquisition strategy, unless urgency of need demands it. One strategy that has proven value for new programs is evolutionary acquisition, in which technology is incrementally inserted in pre-planned blocks to improve system performance over time from initially fielded threshold capabilities to objective levels. Although, strictly speaking, evolutionary acquisition applies only to new PORs, existing PORs can follow a similar incremental block upgrade approach for technology insertion. Such an approach is facilitated if the system has a modular, open systems architecture.

[18] Decker, Gilbert F., Louis C. Wagner, Jr., et al., *Army Strong: Equipped, Trained and Ready*, Final Report of the 2010 Army Acquisition Review, Chartered by the Secretary of the Army, Washington DC, January 2011.

The final path for technology transition and the one with the longest time horizon is the demonstration of feasibility and utility of technology-enabled solutions for advanced concepts. Advanced concepts are system concepts that have not yet entered into formal acquisition processes (Pre-MS A). This path is shown on the far right of the time horizon in Figure 4.2 because it usually requires time for technology maturation before it becomes a POR (i.e., prior to a MS A decision), and then must follow the same slow timeline as any POR. However, this does not necessarily need to be the case, if during the Pre-MS A demonstration phase, it is determined that the capability satisfies an urgent need. Advanced concepts, particularly disruptive or game-changing concepts, are important to providing a time-horizon balance for technology transition.

ENVIRONMENT AND IMPLICATIONS

The Army technology transition strategy must be responsive to external and internal environmental forces that impact the Army's approach for achieving the strategic objectives. External environmental forces affecting the strategic direction of Army S&T were discussed previously in chapter 2 of this report. Among these trends, the ones that have the most direct influence on Army technology transition strategy for achieving S&T strategic objectives are: (1) declining DOD budgets and (2) globalization and commercialization of technology.

In addition to these externally-driven environmental factors, there are several important environmental forces internal to the Army (and DOD) that must be recognized within an Army S&T technology transition strategy. These include: (1) the chasm between S&T and acquisition programs, (2) the aging of many Army systems and platforms, (3) the proliferation of technology transition initiatives and coordinating mechanisms and (4) the marginalization of capabilities within S&T to develop advanced concepts.

DECLINING DOD BUDGETS

It is generally acknowledged that the DOD budget will decline in the future, after more than 10 years of warfare. It is also generally accepted that the S&T budget will not be immune from the anticipated cuts. Moreover, the declining DOD budget will have a profound negative impact on acquisition programs, resulting in a shift of the opportunities for transition of S&T to fielded capabilities. This shift, while external to the S&T community, should directly influence how budgets are allocated within S&T.

The declining DOD budget may have the most direct and adverse impact on the first transition path discussed previously; namely the direct fielding of a technology by means of rapid acquisition of NDI. This approach has been funded by OCO funding over the past decade. However, with the winding down of OIF and OEF conflicts, OCO funding will be terminated or severely diminished. Consequently, tech transition opportunities via this path will be significantly reduced, although some opportunities will still be available through initiatives such as Joint Capability Technology Demonstrations (JCTDs) and DOD efforts to institutionalize rapid fielding during periods of peace.

Also, in the declining DOD budgetary environment, there will be few new platform program starts. So technology transition opportunities via this path will decline and will be limited to just a few programs, such as Ground Combat Vehicle and Joint Light Tactical Vehicle. Therefore, over the next decade or two, insertion onto existing PORs represents a more viable transition path than onto new PORs. On existing PORs, most technology transition opportunities will be at component/subsystem level. As discussed later in this chapter, existing systems and platforms that have been designed with modular open systems architecture will be able to take better advantage of these transition opportunities for modernization than older systems that pre-dated the introduction of open systems.

GLOBALIZATION AND COMMERCIALIZATION OF TECHNOLOGY

With the exception of certain military-unique technologies, many important technologies are now principally driven by domestic and international commercial enterprises. This is particularly true for consumer-driven electronics, information and communications technologies. These have rapid maturation cycles, with a new generation often turning over in two years or less. One of the important implications of this factor is that timeliness of technology transition matters more now than ever. The slow technology insertion cycle times on DOD and Army acquisition programs inhibits the ability of DOD to fully capitalize on opportunities afforded by these technologies and to quickly respond to rapid threat exploitation of them. As discussed in more detail below, Army systems and platforms with modular open system architectures are in the best position to frequently refresh with rapidly maturing technologies while minimizing the expense associated with hardware and software modifications to insert these technologies.

CHASM BETWEEN S&T AND ACQUISITION PROGRAMS

In terms of internal environmental forces, the chasm between S&T and acquisition is the most significant factor that needs to be addressed in an Army S&T technology transition strategy. This issue is not Army unique, but DOD-wide (and, in fact, industry as well). The implications of this factor as a roadblock to transition are well understood; however, the causes of the chasm and the strategies for resolving the issues are not as well understood. The study assessment of the causes and potential remedies gleaned from interviews with the S&T and acquisition communities are discussed in the technology transition strategic assessment, later in this chapter.

AGING OF ARMY SYSTEMS AND PLATFORMS

The second major internal environment issue is the aging of Army systems and platforms. The Army is increasingly reliant on major systems and platforms that were designed during the cold war era. This is particularly true of ground combat vehicles and aviation platforms. For example, within the aviation portfolio, the basic designs for the UH-60, AH-64 and OH-58 are all approaching 40 years and the CH-47 design exceeds 50 years. No new aviation PORs are in the Program Objective Memorandum (POM), so that these aging platforms are expected to continue to provide the backbone of Army aviation for the next two decades.

Upgrades to these aging systems through technology insertion have been and will continue to be essential to maintaining the operational effectiveness of the systems. ECPs to upgrade these systems requires BA 7 funding, which the POR PM must obtain and execute via the RBA processes and timelines discussed previously.

As mentioned above, a complicating factor for these aging systems is that the designs pre-date the introduction of modular open system hardware and software architectures (and, for some platforms, analog systems are still in use). Modularity and open systems facilitate technology insertion, particularly of electronic components at the board level. With analog and/or digital non-integrated, closed and/or proprietary architectures, the insertion of technology is more difficult and often relies on an "appliqué" approach, in which a new technology-enabled subsystem is placed over existing subsystems as opposed to integrated into the existing subsystems. For example, an improved situational awareness capability requiring a display of new information may rely on its own dedicated computer rather than being integrated into existing computers. Such appliqué approaches result in duplication of functionality, added complexity and have adverse impacts on size, weight and power (SWAP).

Another factor influencing technology transition strategy associated with aging systems is that some of these systems, such as Bradley and Abrams, will move from an acquisition program to a post-production sustainment program. The systems engineering expertise needed on a program to successfully accomplish upgrades is not typically staffed and funded through Army Operations and Maintenance.

MULTIPLE TECHNOLOGY TRANSITION INITIATIVES AND COORDINATING MECHANISMS

The third internal environmental factor of importance to technology transition is the multiple number of initiatives and coordinating mechanisms that have been established over the past decade to help bridge the transition chasm. Bridging the chasm between the S&T and acquisition communities requires a significant amount of coordination between several organizational entities, including TRADOC, the PEOs and PMs, the RDECs, and OSD and the Joint Staff for joint programs. ASA(ALT) and DASA(R&T) generally provide the leadership and oversight to bring these entities together through several coordinating mechanisms, including a variety of senior review groups, working groups, technology roadmaps and technology transition agreements (TTAs).

While the need for such coordinating mechanisms is generally accepted by all stakeholders, the type and number of review groups seem to have proliferated. Each review group represents another level of management and oversight that can result in unnecessary and inefficient layers of bureaucracy. Also, the effectiveness of the mechanisms in facilitating transitions is questionable. In particular, in the study interviews, it became evident that TTAs are generally considered as useful by the S&T community, but less useful by the PEO/PMs.[19]

PEOs/PMs generally perceive the S&T organizations to lack accountability, while the S&T organizations perceive the PEOs/PMs lack commitment. There is an element of truth in both perspectives.[20] The study assessment is that the root cause underlying both perspectives is the fact that work required to implement the TTA is usually not fully funded, or is subject to the vagaries of annual budget reviews and cuts. Any plan or agreement which relies on unfunded work suffers from this same malady. This is likewise true of the technology roadmaps. While providing useful guidance, they cannot be relied upon to deliver on schedule for the same reason that they are not fully funded and/or are subject to changing budget priorities.

In addition to these coordinating mechanisms, a number of funded initiatives for promoting more rapid or effective transition have been congressionally mandated and/or established by DOD and the Army. These initiatives are summarized in Figure 4.4 and described in more detail in Appendix J.

[19] There is a similar agreement between 6.2 and 6.3 organizations, known as technology planning agreements (TPAs). These suffer from the same dichotomy of perspective between the supplying and receiving parties.
[20] This issue is not unique to the Army, but is common across DOD. DARPA, for example, has similar complaints about the military services not planning and budgeting for transition of their technologies and products.

Initiative	Office	Funding BA and PE	Purpose
Quick React Special Projects	OSD USD(AT&L), DDRE	BA3 0603826D8Z	To provide rapid funding to expedite new development and transition of new technologies to the warfighter; Includes QRF, RRF, TTI and JRAC
Rapid Innovation Fund	OSD USD(AT&L)	BA4 0604775DZ	To accelerate the fielding of technologies from phase II SBIR projects, the defense laboratories, and other innovative technologies
Joint Capability Tech Demo	OSD USD(AT&L)	BA4 0603648DZ	To evaluate the capability of mature and maturing technologies to satisfy near-term capability needs of COCOMs and to concurrently develop CONOPS
Tech Enabled Capability Demo	Army DASA(R&T)	BA3 (no single PE)	To demonstrate near term integrated technology-based solutions that enhance the effectiveness of an existing capability or enable a new capability
BA4 Technology Maturation Initiative	Army DASA(R&T)	BA4 0604115A	To mature promising near-term technologies and subsystems to Technology Readiness Levels (TRLs) greater than 6 and to expedite capability transitions through competitive prototyping

Table 4.1 – Summary of Current Technology Transition Initiatives

Table 4.1 provides a summary of current technology transition initiatives. While there is no one-to-one correlation of these initiatives to the transition paths discussed earlier in this chapter, they do tend to align with and support the different paths, as shown in Figure 4.4 (as in Figure 4.2 above, the time lengths are merely illustrative). The Quick Reaction Special Projects (QRSP), Rapid Innovation Fund (RIF) and JCTDs are generally aligned with the rapid and direct insertion of technology into the field, by-passing the normal acquisition processes associated with PORs. The Army DASA(R&T) recently established the BA 4 Technology Maturation Initiative to directly address the S&T to acquisition valley of death issue. Another DASA(R&T) initiative, TECDs, does not neatly align with any one of the paths, but are generally supportive of all of them. It is the one initiative that can be supportive of the longer horizon advanced concepts path.

With the multitude of these coordinating mechanisms and separately funded and managed initiatives, there is ample opportunity for duplicative efforts and/or unnecessary duplication of oversight. A more integrated approach could pay dividends, as discussed later in the section on technology transition strategic assessment.

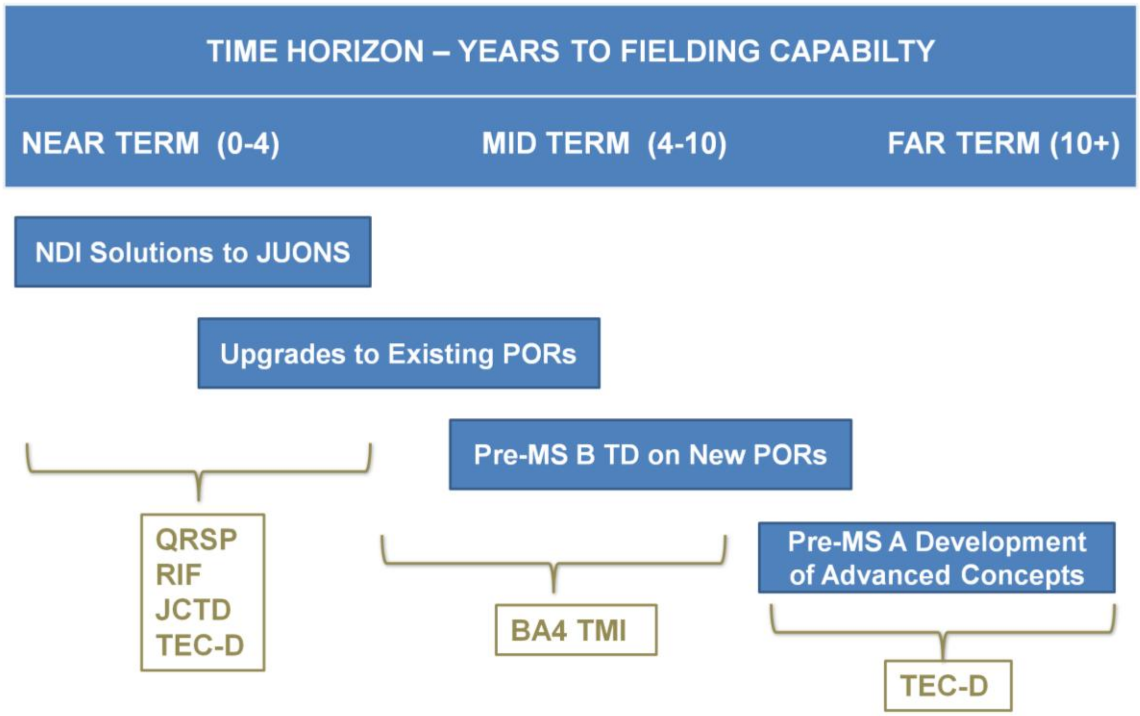

Figure 4.4 – Technology Transition Initiatives Support Each of the Transition Paths

MARGINALIZATION OF ADVANCED CONCEPTS CAPABILITIES

Advanced concepts are important to ensure that the BA 3/BA 4 portfolio is not overly focused on the near to mid-term. Advanced concepts provide the means for directing a portion of the S&T portfolio to the longer term needs of the Army and for providing a focal point for innovative and/or disruptive technology development. A robust advanced concepts capability is needed within the S&T community to work closely with TRADOC ARCIC to identify game-changing operational concepts and to translate these operational concepts to technology-enabled system concepts. Over the past decade, the advanced concept organizations within the Army RDECs have undergone reductions in staffing and capabilities. This was a principal finding of the recent Army Acquisition Review:

> "The Army should have an organic capability to lead Pre-MS A development planning, including: systems concept formulation, exploration of promising advanced technology concepts, formulation and advocacy of advanced programs before there is a Program Manager assigned, and an honest broker for the prioritization of required technology programs. The Advanced Systems and Concepts Offices in the RDECs were created to do this, but have been either eliminated or marginalized to where they are incapable of performing their traditional, critical advanced concept development, parametric design and analysis, technology assessment and RDT&E planning functions." [21]

TECHNOLOGY TRANSITION STRATEGIC ASSESSMENT

An effective technology transition strategy must address the environmental roadblocks identified in the prior section. The study team conducted an assessment of the issues affecting Army S&T technology

[21] Decker, Wagner, et al. (note 16).

transition strategy, based on these external and internal environmental forces. Because of the interdependencies among the issues, a composite assessment was conducted, rather than an individual evaluation of each issue in isolation.

CAUSES OF S&T TO ACQUISITION CHASM

The single most pressing and fundamental issue that must be resolved is the chasm between S&T and acquisition. It is important to understand the principal causes of this chasm to determine how best to bridge it. Following is the study assessment of causes based on interviews with parties on both sides of the chasm.

A root cause of the technology transition chasm between the S&T and acquisition communities is the fundamental difference in risk paradigms between the two. The job of an acquisition program manager (PM) is to execute his or her contracts on cost and schedule, while meeting all key performance parameters. The PM is reluctant to take any unnecessary risk that could prevent him or her from meeting contractual obligations. Taking risk, on the other hand, is inherent in world-class S&T. Innovation and inventions rely upon pushing the boundaries and accepting the risk associated with the search for new technologies. Few world-class S&T managers are incentivized to play it safe.

Adding to this fundamental difference in risk paradigms is the limitation in technology maturity that can be achieved through the budget authorities available to the two communities. BA 1 to BA 3 is available to fund S&T, while acquisition programs are funded via BA 4 to BA 7. Fundamentally, BA 3 funded efforts cannot deliver the level of technology maturity required by acquisition programs to meet the risk aversion thresholds. Within the limits of BA 3 funding, the S&T community can generally demonstrate only the basic functionality of a technology by means of representative prototype hardware/software in a representative environment in the laboratory. This level of technology maturity is typically labeled as Technology Readiness Level (TRL) 6.[22] To insert this technology into his program, however, the program manager generally requires that the technology has been demonstrated to meet critical performance thresholds with actual prototype hardware/software in a realistic environment for his or her product, with all critical system interfaces systematically exercised. This TRL 7 level of prototyping generally requires BA 4 or BA 7 budgetary authority.

Army major systems and platforms are complex and becoming increasingly more complex. A subsystem or component being developed for a POR must interface with numerous other subsystems and integrated within size, weight and power (SWAP) limitations of the host system. Also, many subsystems have embedded software that must be integrated with mission or control software of the host system. The functional, hardware and software interfaces must be well understood in the design, development and prototyping of subsystems for subsequent integration into the system. Systems engineering and integration skills within the S&T community are essential to ensure that the system interfaces are well defined and exercised during technology development. It is also important for the chief engineers within S&T organizations to have systems engineering and integration skills and experience with systems integration on large complex systems. POR PMs often cite lack of appreciation of the magnitude of the

[22] In this study, TRL is used as a representative measure of technology maturity and readiness for insertion into a POR (see Appendix K for definitions). It should be noted that TRL is not universally accepted as a valid or complete measure of readiness. TRL can be and should be supplemented by other measures of readiness, such as manufacturing readiness level, software readiness level and measures of systems integration readiness. Also, it should be recognized that TRL assessment, despite well formulated definitions, is subjective and dependent on the judgment of well-informed subject matter experts.

systems integration challenges[23] and lack of systems engineering and integration skills within S&T as a barrier to technology transition.

Another factor that contributes to the chasm is organizational in nature. Organizationally, S&T is conducted by RDECOM, which reports to AMC. Acquisition programs report to the ASA(ALT). Organizational boundaries are always difficult to bridge. The extent to which these difficulties can be overcome is a strong function of the people and personalities on each side of the boundary. The right people with good attitudes can make almost any organizational structure function well, and vice versa.[24] The need for control is one of the central attitudinal factors contributing to failure to bridge organizational boundaries. Lack of control often leads to a lack of "buy-in", in which efforts on the part of providing party (in this case S&T) are rejected simply because they were not conducted under the control of the receiving party (in this case a PM). If personalities and behaviors cannot be modified, a fix is the use of processes that remove or mitigate the personality factor. Processes that demand collaboration are essential to ensure successful bridging of organizational boundary issues.[25]

Yet another factor involved in creating the chasm is the tight relationship between the POR PM and the prime contractor. For existing PORs that have passed MS B, the down-select to a single prime contractor has normally already occurred. After a down-select, a strong interdependency between the Army program office and the prime contractor develops. The success of one is dependent on the success of the other. Therefore, for technology insertion upgrades to a POR, it is not unusual for the PM to rely on the contractor for technology maturation and prototyping, generally using a contactor capitalized systems integration laboratory or a government-owned contractor-operated systems integration laboratory. There are exceptions to this rule, generally when a POR and the relevant RDEC are co-located. In either case, a strong collaborative environment between the POR, the contractor and the RDEC is required to ensure successful transition from an Army S&T organization to a POR. A secondary, but important, factor associated with the POR-contractor relationship is that innovative technologies from small defense and non-defense businesses are seldom solicited or evaluated to meet capability needs.

Finally, complicating the TRL and funding elements of the chasm are the cumbersome and time-consuming processes that an acquisition Program of Record (POR) must follow to obtain BA 4–BA 7 funding authority and subsequently to execute the contract, as discussed earlier in this chapter, under environment and implications.

PROTOTYPING AS APPROACH FOR ADDRESSING CAUSES OF CHASM

Prototyping is widely recognized as an essential means for bridging this chasm. Prototyping directly addresses the first two causes of the chasm: the different risk paradigms and the inability of S&T to

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[23] The Program Manager is concerned with the Total Package Fielding of operational capabilities. Total Package Fielding involves all the aspects of delivering operational relevant systems. This includes (but not limited to) technology integration, systems software updates, spare part provisioning, technical manual updates, maintenance manual updates, test sets and/or BIT/FIT updates, operator and maintenance Program of Instruction updates, and system drawings updates.

[24] Of course, even good people cannot always compensate for poor organizational designs in which responsibility, accountability and authority are not well defined or in which unnecessary organizational layers add bureaucratic barriers to efficient work flow.

[25] Collaborative processes should not be confused with burdensome and/or redundant coordination mechanisms that create work but result in no real collaboration. Program managers often bemoan the burden of participating in "alignment" exercises that easily degenerate into misaligned efforts afterwards.

satisfy POR required technology maturity. As illustrated in Figure 4.5, prototyping of a technology to a TRL 7 is essential for transitioning a technology to a POR within the context of the risk-adverse nature of DOD contracting, while S&T can deliver technology only at TRL 6 within the constraints of BA 3 funding.

S&T

can get technology to TRL 6 with 6.3 funds

- ***Representative*** prototype system for field experiments and/or tests in a ***relevant or simulated*** environment

ACQUISITION

Needs technology at TRL 7

- ***Actual*** prototype system in a ***high fidelity and realistic operating*** environment specific to that product/system

6.4 and 6.7 prototyping efforts are necessary to bridge the TRL 6-7 gap for new and existing acquisition programs

Figure 4.5 – Prototyping Bridges the Chasm between S&T and Acquisition

Defining a prototyping environment that effectively addresses all of the causes of the chasm should be considered an important element of the Army S&T technology transition strategy. In defining this environment, it is also important to recognize that prototyping is a means for not only bridging the S&T to acquisition chasm, but also for facilitating transition for all four of the transition paths. The type of prototyping is not the same for each path, but must be tailored to the unique needs of each, as illustrated in Figure 4.6. (While each type of prototyping is different, an integrated prototyping environment that operates across the entire time horizon could offer some significant advantages in terms of efficiency and sharing of best practices.)

For near-term insertion of technologies directly to theater operations, rapid prototyping is required. At the other end of the time spectrum, advanced concept prototyping should focus on demonstration of the feasibility and utility of technology-enabled systems that satisfy the operational capability needs of the concepts.

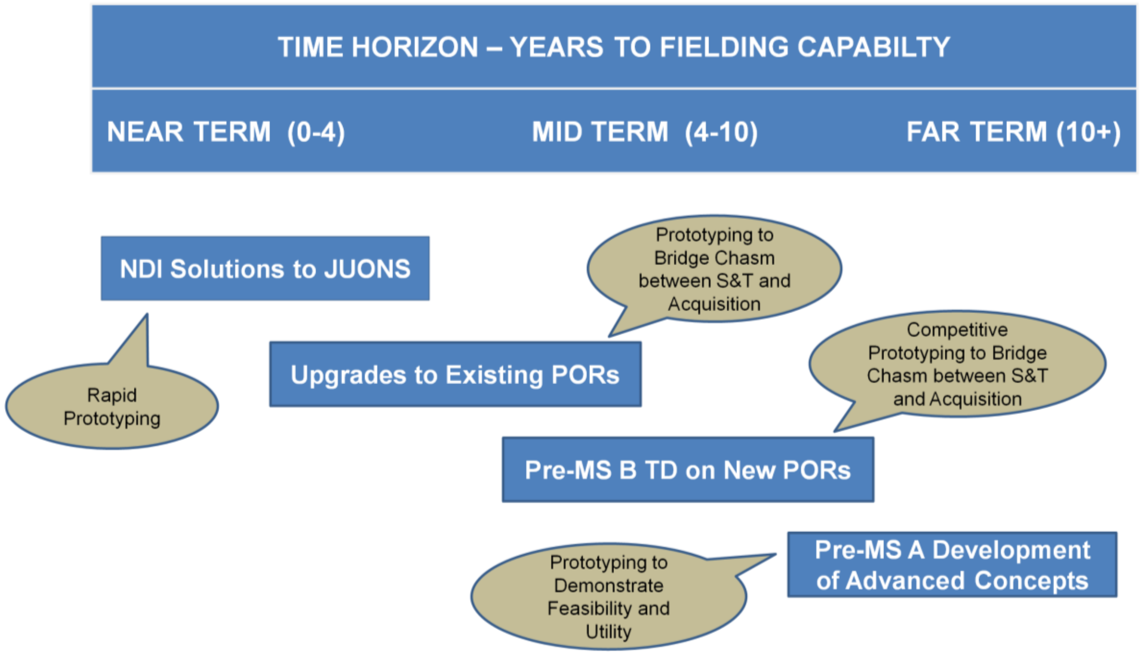

Figure 4.6 – Type of Prototyping Varies Across Time Horizon

In the mid-term portion of the time spectrum, for technology upgrades to existing PORs or insertion into new PORs, rapid prototyping does not significantly reduce the overall timeline (Figure 4.3) to a fielded capability. These prototyping opportunities must focus on maturing technologies and reducing system integration risk on the PORs. For new PORs, during the TD phase prior to MS B, such prototyping should be conducted competitively to the maximum extent possible within time and resource constraints to allow for alternative approaches to be tested and matured. Indeed, competitive prototyping prior to MS B is required by statute, unless a waiver can be justified. The purported benefits of competitive prototyping include technology maturation, improved basis for cost estimates, design validation and realistic requirements refinement. While competitive prototyping is generally acknowledged to have some of these benefits on a case by case basis, a 2012 Competitive Prototyping Study sponsored by USD(ATL) concludes that competitive prototyping does not always produce the expected benefits and should be applied judiciously. On the other hand, the advantages of competitive prototyping were highlighted in the 2010 Army Acquisition Review chartered by the Secretary of the Army:

> "Numerous acquisition studies and DOD directives have recommended competitive prototyping at the component, subsystem and even system level prior to EMD as a proven means to reduce technical, schedule, cost and performance risk. Pre-EMD prototyping was a major factor in the success of many of the programs studied, including, but not limited to the following: the Advanced Attack Helicopter (later Apache), the Utility Tactical Transport Aircraft System (later Black Hawk), the T700 engine, the T800 engine, the Main Battle Tank (later Abrams), the M9 Armored Gun System and Advanced Anti-Tank Weapon System—Medium (later Javelin). Coupled with system integration laboratories and state-of-the-art advanced computing and simulation, prototyping is a powerful method to understand and eliminate technological risk and mitigate engineering risk. Unfortunately, too often acquisition strategies omit this in order to shorten schedule and lower development cost, only to result in more development time and

> life cycle cost due to technical problems during EMD that could have been prevented with competitive prototyping." [26]

For Post-MS B existing PORs, a competitive prototyping environment would have similar advantages, but is more difficult to accomplish because there is normally a single contractor team in place after MS B. As discussed previously, once a down-select to a single prime contractor is made, a tight interdependency between the PM and the prime develops. The prime contractor, in turn, has similar tight relationships with its subcontractor team. Dual sourcing of subsystems is usually not cost effective. The PM and his prime seldom look outside the contractor team to identify and prototype new technologies for system upgrades. In some cases, the POR PM also has a strong relationship with the RDEC (usually when co-located) that develops its relevant technologies, in which case the POR benefits from technologies from both sources (prime contractor team and RDEC). The best situation for technology insertion, short of an open competitive prototyping environment, is a strong collaborative environment among all three parties — the POR, its RDEC and its prime contractor team.

Since most of the technology transition opportunities in the future will be upgrades to existing PORs, it is important to find a means for establishing a Post-MS B collaborative prototyping environment that encourages competition for technology insertion from all relevant sources (i.e., the prime contractor team, the RDECs, FFRDCs, small defense businesses and non-traditional and/or commercial businesses).

Among other environmental factors that must be considered in defining an effective prototyping environment is the impact of declining DOD budgets on the opportunities to transition technologies. While there will continue to be a few new major acquisition programs over the next decade (e.g., Ground Combat Vehicle and Joint Light Tactical Vehicle), most technology transition opportunities over the next decade will be associated with the upgrade of existing PORs. The impact of aging systems and platforms on the ability to effectively prototype on existing PORs is an important consideration. As discussed previously, some of these systems/platforms pre-date the introduction of modular open systems. Indeed, a few platforms still have analog architectures and subsystems.

Compounding the issue associated with aging systems is the slow cumbersome RBA processes for PORs. As discussed previously, these processes can result in a 2–4 year period from identification of a technology insertion opportunity until contractual ATP and another 4–8 years from ATP to Initial Operational Capability of a fielded capability. For consumer-driven electronics, information and communications technologies, the time for maturation of the next generation of the technology can be 1–2 years. Therefore, there is a mismatch between technology maturation cycle and the technology insertion cycle for major system PORs. This mismatch can result in technology obsolescence before it can be inserted and fielded. And perhaps worse, because adversaries are unencumbered by RBA processes, they can field these technologies, which are often commercially available and/or open source, in less time that the Army can.

To effectively address this issue, it is important for the prototyping environment to facilitate fast track incorporation of rapidly maturing technologies. This can only be accomplished through modular open systems architectures, which allow quickly maturing electronic technologies (usually at the board level) to be constantly refreshed without the need to re-qualify the entire subsystem and to re-code and regression test the entire software load. It may be worth an up-front investment in converting old systems that predate open systems architecture to digital open system architecture and standards to subsequently save money for continuing modernization updates to the platforms.

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[26] Decker, Wagner, et al (note 16).

ALLOCATION OF S&T BA 3 FUNDING

From the perspective of what can be done inside the S&T portfolio to facilitate technology transition, the allocation of S&T BA 3 resources is probably the most critical issue. BA 3 is used to support several of the technology transition initiatives discussed previously. These include the Army TECDs and OSD JCTDs and QRSP. Warfighting experiments (including Network Integration Evaluations) are also supported with BA 3 and provide a mechanism for identifying technologies that should be considered for transition. These BA 3 initiatives typically do not mature an individual technology to TRL 7 for a single targeted POR, but instead serve to demonstrate that a mature technology can operate effectively in a warfighting environment with interfacing systems. The BA 3 funding for these system integration demonstrations must compete against BA 3 activities directed toward executing a TTA and that bring individual technologies as far along the TRL 6 to 7 gap as possible within BA 3 constraints. Also competing for BA 3 funds are prototyping efforts in support of the demonstration of feasibility and utility of advanced concepts. The correct balancing of BA 3 allocation across these mechanisms in response to the shift in technology transition opportunity space should be considered as an element of the technology transition strategy.

The DASA (R&T) is well aware of the need for this balance of the Army S&T BA 3 portfolio, as indicated in recent testimony:

> "In order to maintain a balanced portfolio, we must also have clearer priorities for the mid-term and far- term investments. Therefore, this year we are also working to define and develop a set of programs to meet the mid-term needs of the Acquisition community. Having these needs identified and then prioritized by leadership will enable us to better focus the remainder of our BA 3 dollars and a portion of our BA 2 dollars on near- to mid-term solutions to critical emerging needs. Simultaneously, we are identifying technologies that have high potential to “bridge gaps” or achieve “leap ahead” capabilities."[27]

TECHNOLOGY TRANSITION, INNOVATION AND PROTOTYPING OFFICE

In summary, some of the key strategic issues that must be addressed and the attributes required of a prototyping environment to effectively resolve the issues are as follows:

1. Within the constraints of BA 1–BA 3 funding, S&T funded development generally cannot satisfy the technology maturity levels required by acquisition programs because of the program manager's risk-adverse focus on contract execution. To remedy this issue, a prototyping environment funded via dedicated BA 3 and BA4 program elements (PE) is needed which can take selected technologies from TRL 6 to TRL 7.
2. Systems integration maturity is as important as technology maturity to the POR PM. The lack of a systems integration mindset and skill set within S&T contributes to lack of acceptance of an S&T technology by the POR. The prototyping environment must require (indeed, force) collaboration between S&T and acquisition communities to ensure that all critical system interfaces are well understood and exercised as an integral part of the prototyping. One approach to accomplish this is for the dedicated PE funding to be allocated on the basis of competitive proposals from PM/S&T/industry teams, in which a collaborative systems integration plan is required. Proposal preparation should be funded via the dedicated PE.

[27] Freeman, Marilyn (note 14).

3. Organizational seams often result in lack of buy-in from the POR for technologies prototyped by the S&T community. The prototyping environment must require collaboration. But also, subsequent to source selection of the competitive proposals, execution of the prototyping effort should be controlled by the receiving POR. Also, to ensure buy-in, source selection may require commitment on the part of the receiving POR in the form of partial funding of the prototyping effort.
4. The tight interdependent relationship between an Army PM and his or her prime contractor team may inhibit the inclusion of innovative technologies from sources outside the team, including small and non-traditional businesses. Source selection of the competitive proposals should emphasize innovation and inclusion of ideas/technologies from all relevant sources.
5. The slow cumbersome requirements, budgeting and acquisition processes required for PORs inhibit the timely insertion of rapidly maturing technologies. The dedicated PE for the prototyping environment must therefore be outside of DOD 5000 series acquisition to provide the flexibility needed to prototype and integrate technologies on a fast track basis, without the encumbrances of the POM budgeting and appropriations cycle in advance of ATP. Also, for older systems and platforms, some funding may be required to modify architectures to digital open systems to allow for subsequent frequent and cost effective refresh of the rapidly changing technology.
6. A focus only on POR transition can result in the prototyping environment being too focused on the mid-term. The prototyping environment should include opportunities across the entire time horizon, including rapid prototyping of near-term technologies for direct fielding and longer term prototyping of advanced concepts that can lead to disruptive capabilities.
7. While the type of prototyping is different for each segment of the time horizon, an integrated prototyping environment could avoid unnecessary oversight and duplication of separately managed efforts and reduce the burden of multiple coordinating mechanisms. It could also improve efficiency through the sharing of best practices.

It is the study's assessment that this integrated competitive prototyping environment would be best managed by a single office: the TTIPO. Some Key features of the TTIPO are illustrated in Figure 4.7.

The TTIPO would serve as a proactive agent for bridging the S&T to acquisition chasm. DARPA-like project officers would continuously monitor the environment and look for opportunities to marry an emerging technology within the S&T community, an operational need within the requirements community and a system need within the acquisition community. The project officers would broker an agreement among the relevant parties and approve the budget from dedicated core funding for the parties to develop a proposal. The TTIPO Director would select proposed projects for implementation based on source selection criteria that emphasize innovation, need, timing, and commitment, including partial or matching funding.

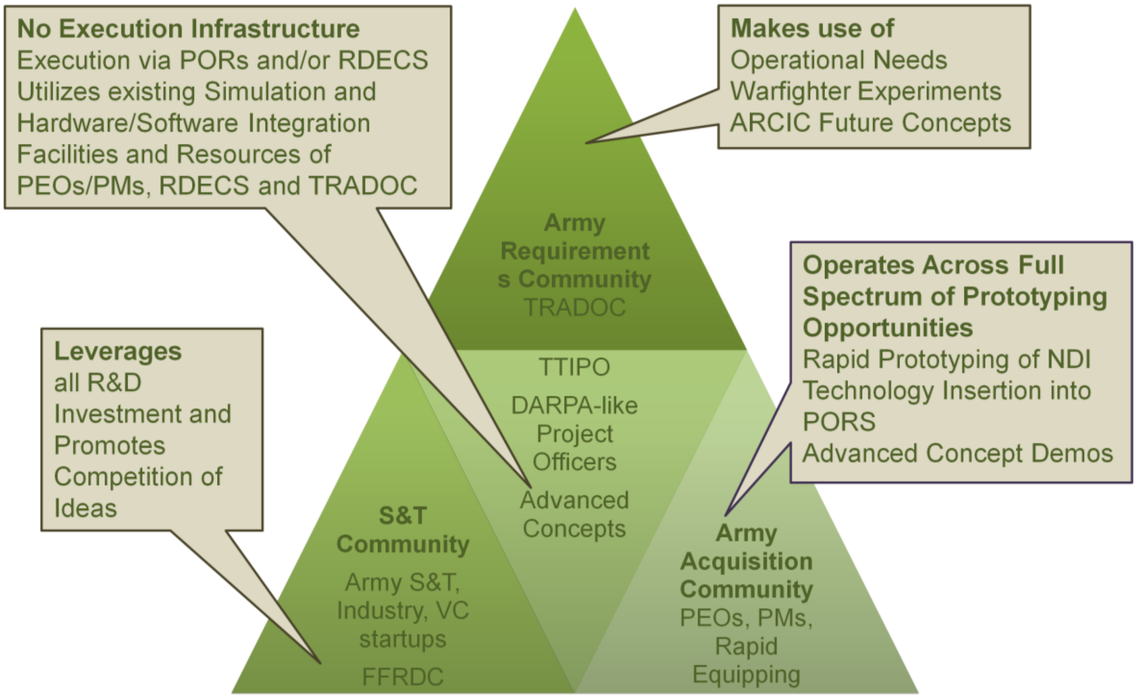

Figure 4.7 – Technology Transition, Innovation and Prototyping Office (TTIPO)

The TTIPO would serve as the transition champion and a single point of contact with other DOD transition offices, including OSD and the other services. It would also serve as the champion for the Army requirements, S&T and acquisition communities to find partners for transition opportunities that are not naturally occurring. It would serve as a clearing house for transition opportunities identified through warfighting experiments or for transition proposals from sources outside of the Army. By providing a single POC with these agencies, the TTIPO would improve integration of transition initiatives across the Army and across DOD. It would also improve Army competitiveness for funding available through OSD initiatives.

The TTIPO would conduct prototyping across a broad time horizon, including rapid prototyping of mature technologies, technology insertion on PORs and concept feasibility demonstrations for game-changing concepts. In operating across all of these types of prototyping, the office would avoid overlap/duplication of separate prototyping initiatives and would provide a means for the consistent application of best practices.

The TTIPO would operate in a way similar to DARPA, as a management office with no dedicated execution infrastructure. The project officers would be required to broker agreements among the participating parties in which each party utilizes existing infrastructure, including simulation capabilities, hardware/software integration laboratories, and other equipment. The use of these facilities would be credited as matching funding. However, commitments to partially fund people and other resources would be encouraged and would be considered in source selection.

In addition to the project officers, the TTIPO would include an Advanced Concepts Group. The Advanced Concepts Group would work closely with TRADOC Army Capabilities Integration Center (ARCIC) to identify game-changing operational concepts. It would translate these operational concepts into technology-enabled system concepts and prototyping proposals that would compete for core funding.

It would have a small organic capability to conduct small hands-on experiments to test out concepts prior to proposal submittal to the TTIPO director.

The TTIPO would be supported through dedicated budget PEs not tied to any specific POR and therefore outside of DOD 5000 procurement regulations. It is expected that the PEs would consist of a combination of BA 3 and BA 4 funding. It is also expected and suggested that the office be implemented within Army existing resources and TOA. The cost to implement is difficult to determine without a detailed implementation plan, but it is estimated that a 6–8% re-allocation of $1,700M BA 3/BA 4 portfolio (20 year average) would be adequate for a TTIPO initiative. Staffing could be an issue since the POs would need to be entrepreneurs having a broad skill set, including systems engineering skills. A DARPA-like approach in which POs with these capabilities are brought in on a rotational basis might work to satisfy these unique skills. The staffing billets would need to be reassigned from other similar initiatives that might be combined to form the TTIPO.

Benefits of a single office with these attributes include better integration of prototyping efforts, reduced burden of multiple transition coordinating mechanisms and initiatives, a single outlet for the vetting and funding of concepts and ideas emanating from warfighting experiments and other sources of innovation, a balancing of transition opportunities across a broad time horizon, and the efficiencies gained from sharing of best practices. Another compelling benefit is that the promotion of prototyping opportunities provides a means for building and retaining critical program development skills within Army S&T, acquisition, FFRDCs and industry that could easily suffer atrophy as the defense budget declines and new program acquisitions decline. It also provides a training environment for the broad-based chief engineers and systems engineers that are so vital to ensuring that the return on Army S&T investment is fully realized.

ASB advocates placing the prototyping activity in ASA(ALT) to address Army leadership's requirements for both new concepts and expenditures in prototyping. Placing the TTIPO function at the Assistant Secretary level would also facilitate partnerships with the Service laboratories, DARPA, and other agencies within DOD.

FINDINGS AND RECOMMENDATIONS

FINDINGS

1. No Army technology transition strategy currently exists.
2. The principal issue that the strategy needs to address is the chasm between S&T and acquisition.
3. Prototyping needs to be a key element of the strategy for bridging the chasm:
    a. Successful Programs of Record historically have benefited from prototyping activities.
    b. The Weapons Systems Reform Act and OSD policy requires that competitive prototyping be addressed before progressing to MS B.
4. Systems engineering and integration skills are critical for effective prototyping.
5. Advanced system concepts are important to ensure that prototyping efforts are not all near-term focused in order to achieve game-changing results.
6. With few new starts, prototyping provides opportunities for RDECs and industry engineers to hone their skills and experimentation venues for user/PEO/contractor teams to rapidly exploit technology opportunities.

7. DASA(R&T) has proactively developed initiatives that address many of the transition issues.

RECOMMENDATIONS

1. Include a technology transition strategy as part of an overarching Army S&T strategy and plan.
2. ASA(ALT) establish a TTIPO that champions and integrates prototyping efforts across broad time horizon, from rapid prototyping of NDI to accelerated technology insertion on PORs to demonstration of game-changing concepts. This activity should be a management activity with prototyping efforts executed in the requisite RDECs and PORs. An advanced concepts element should be included in this office to work in partnership with TRADOC to develop and demonstrate game-changing "big ideas".
3. Increase the number of exceptional, experienced chief engineers and systems engineers in the Army laboratories, RDECs and PEOs.

CHAPTER 5. ARMY SCIENCE AND TECHNOLOGY ORGANIZATION

A recurring observation from interviews with current and past Army S&T leadership is that neither RDECOM nor ARL have fully achieved the expectations set when these organizations were formed, and several recent studies have recommended changes to the Army research, development and acquisition (RDA) organization.[28] Furthermore, DOD science and technology spending will most likely face at least a 10% funding reduction, with potential for as much as 30% over the current POM years. In lieu of allocating the reductions across all subordinate organizations and programs, a different or modified organizational model could provide efficiencies and savings which would preserve the Army S&T budget to protect and reinforce essential core programs and capabilities. The TOR directs assessment of two courses of action regarding organizational structure: (1) "fix RDTE under the current strategy" and (2) "form a small corporate research center."

Fixing RDTE under the current strategy would preserve the current organizational model, with process improvements. With regard to the formation of a small corporate research center, the TOR specifically directs attention to a recommendation of the Secretary of the Army's Short Term Overhead Reduction Task Force, which suggests dividing the Army RDTE into (1) a small "corporate" research center, and (2) embed product development, testing (developmental and operational) and engineering into product-focused groups, with increased reliance and leverage from other government and commercial activities. This is a strategy similar to many industrial models, and to a large extent the Navy and Air Force RDA organizations.

In many respects, civilian technology is more advanced than military technology (Apple's iPhone serves as a recent example). Innovative civilian products are introduced rapidly, whereas military technology development is typically paced by the requirements and acquisition bureaucracy, which -- beyond operational security considerations -- oftentimes manages for risk-avoidance over cost and schedule. Ultimately, the Army needs industry to develop technology for use by its Soldiers. The defense industry was once characterized by state-of-the-art technology and innovation, but now it is also known for bureaucratic encumbrances and consolidation. In contrast, commercial industry is forced to develop technology quickly, as the global marketplace is acutely competitive. Rapid prototyping in manufacturing industry is *de rigueur*; indeed, rapid prototyping services are now commonly offered for those manufacturers too small to support it in-house. Companies also join partnerships and consortia like SEMATECH for collaborative strength over their competitors. These behaviors are motivated by the carrot-and-stick of high profits and harsh competitive pressures. The carrot for the Army is superior weaponry in a field environment. Creation of a competitive environment within the Army would better render Army S&T more robust and would better support high caliber S&T innovation.

In the Army, basic research funding is dispersed, instead of being coordinated by a central office. For example, the Army has five UARCs designed to maintain expertise in key technologies. Most, but not all, of these have line item funding associated with the Army Research Office (the exception is Georgia Tech Research Institute). At the same time, small (and possibly sub-critical) funds are spent on basic research at AMRDEC, ARDEC, ARI, CERDEC, ECBC, ERDC, NSRDEC and TARDEC. While the Army spends the least on basic R&D when compared to the Navy and Air Force, the Army has almost two times the number of S&T PEs as Navy or Air Force. This high parsing implies less program flexibility.

As outlined in chapters 2 and 3 above, global trends in the science and engineering labor force also do not favor Army S&T, although they have been obvious for years. While the USA once dominated the

[28]Decker et al. (note 9). Decker, Wagner, et al. (note 16).

global S&T workforce, other countries have been catching up, especially China (see chapter 2). Furthermore, an increasing percentage of PhDs in the hard sciences that are granted in the United States go to foreign nationals, many of whom now return to their home countries after their degree work. U.S. industry has long recognized these trends, and many companies, including GE, 3M, Shell Oil, and others are now locating research laboratories overseas to avail themselves of foreign talent. The Army can and should exploit extensive globally-created S&T. However, to be successful, the Army needs to appreciate that competitive opportunities are transitory. Army S&T must become nimble to stay current and to exploit discoveries from around the world.

CURRENT ARMY S&T ORGANIZATION

This study was directed to analyze the RDECOM portfolio of S&T projects and objectives. The RDECOM was established in 2004 as a component of AMC in response to the 2002 Realignment Task Force. RDECOM consolidated several activities including the Army Research Laboratory (ARL) and the commodity-focused Research Development and Engineering Centers (RDECs) into a single activity. The goal was to coordinate activities to better support both S&T and systems development. Today, through RDECOM, AMC manages about 80% of the Army S&T program. The balance of Army S&T is executed by four separate organizations: the U.S. Army Medical Command (10%); the U.S. Army Corps of Engineers (5%); the U.S. Army Space and Missile Defense Command (3%); and U.S. Army Research Institute for the Behavioral and Social Sciences (2%), which reports to the HQDA G-1.

ASSISTANT SECRETARY OF THE ARMY FOR ACQUISITION, LOGISTICS & TECHNOLOGY

In response to the Goldwater-Nichols Department of Defense Reorganization Act of 1986, PMs for programs of record were organized into PEOs reporting to the Army Acquisition Executive. DOD realigned the S&T executive structure to make it similar to the Defense Acquisition Executive Structure, established after the Goldwater-Nichols Act. For the Army, the DASA(R&T) was appointed the Army S&T Executive. Within the office of the DASA(R&T), the Director for Research and Laboratory Management is responsible for the basic research and laboratory management portfolio.

ARMY MATERIEL COMMAND

Over 80% of Army S&T is executed within AMC, which has the mission to develop, deliver and sustain Army materiel. Since its activation in 1962, the AMC had ownership of the Army's entire materiel lifecycle, to include basic and applied research, product development, program management, product lifecycle support, plus general maintenance and sustainment. The command has since undergone a number of organizational changes in response to the Goldwater Nichols Department of Defense Reorganization Act of 1986, the Army Realignment Task Force 2002, and the Gansler Commission of 2007.

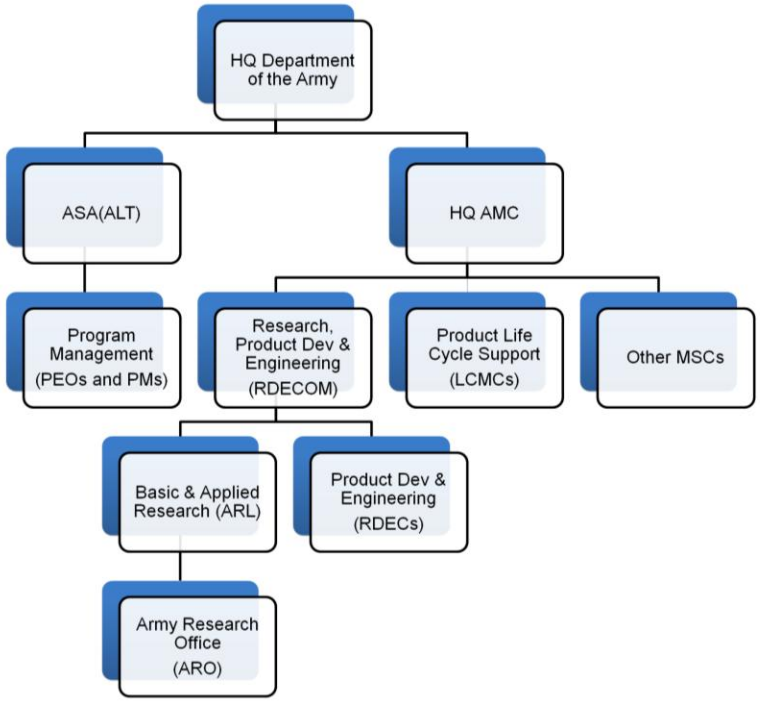

Figure 5.1 – Army Current S&T Organization

RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND (RDECOM)

The RDECOM performs basic and applied research, development and engineering, and analysis of technologies within a framework of four business focus areas: integration of research, development and engineering activities across the command, acceleration of technology to the Warfighter, advanced research and technology in support of Army modernization, and engineering services and support. In FY2011 the RDECOM S&T funding profile consisted of $333M in basic research, $609M in applied research, and $570M in advanced technology development for a total S&T program of $1,512M.[29] In FY2011 RDECOM received $3,398M in customer funding, or 58% of the total $5,886M RDECOM program. RDECOM has had five Commanding Generals since its inception and is currently led by a Department of the Army Senior Executive.

RESEARCH, DEVELOPMENT AND ENGINEERING CENTERS (RDECs)

The RDECOM headquarters manages six commodity-focused Research, Development and Engineering Centers (RDECs), and the Army Research Laboratory (ARL) (Figure 5.2) The Army Research Office is an element of ARL. The RDECs are 6.1–6.7 funded, with roughly 12–15% in 6.1–6.3 to support applied research and advanced technology development, which is generally commodity-focused (see Appendix G). The Edgewood Chemical and Biological Center (ECBC) is an exception in that most of its S&T funding is allocated by the Defense Threat Reduction Agency. The majority of RDEC work is engineering support to acquisition program managers, the lifecycle management commands, and other Army and DOD agencies. Each of the RDEC directors is a Department of the Army Senior Executive.

[29] RDECOM response to S&T Panel questions, December 2011

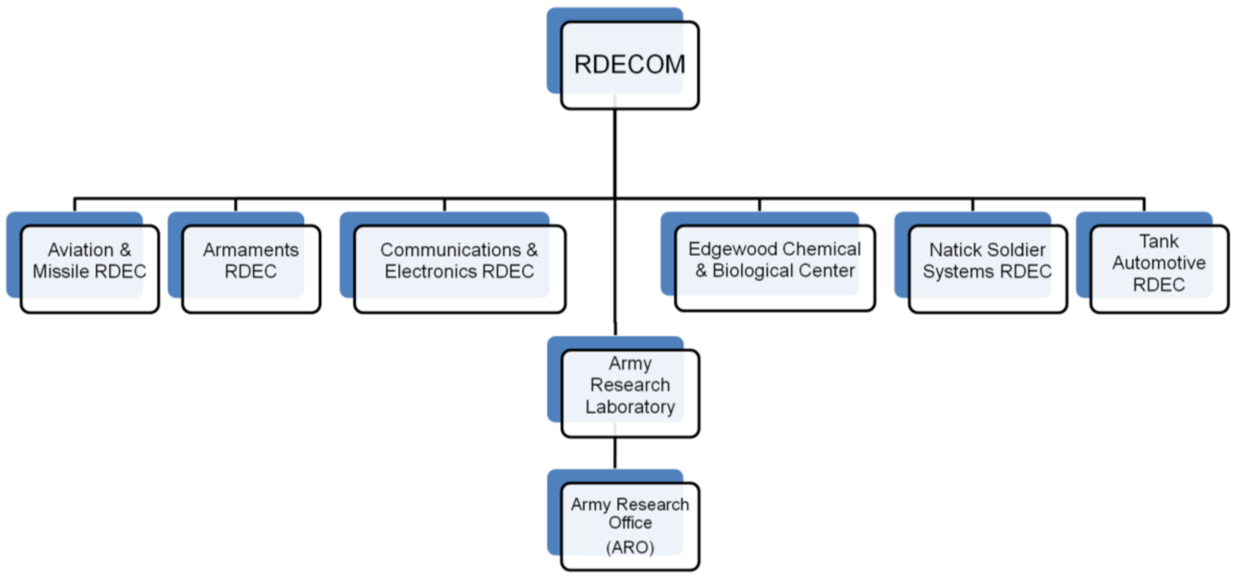

Figure 5.2 – Research Development and Engineering Command

ARMY RESEARCH LABORATORY (ARL)

The ARL is mission funded for basic (6.1) and applied (6.2) research, with minimal funding for advanced technology development (6.3): $300M in 6.1; $235M in 6.2, and $27M in 6.3 for FY2011. ARL and its directorates that perform external work, receive about 43% of total funding from external customers: $394M of a total $906M FY2011 funding profile (excluding ARO funding). When including directed customer funds from DARPA, OSD and direct cite, the percentage of external funding is 62%. The percentage of BA 1, BA 2 and BA 3 performed in-house is 28%, 68% and 26%, respectively, excluding ARO. The ARL internal organization is shown in Figure 5.3. ARL is led by a Department of the Army Senior Executive.

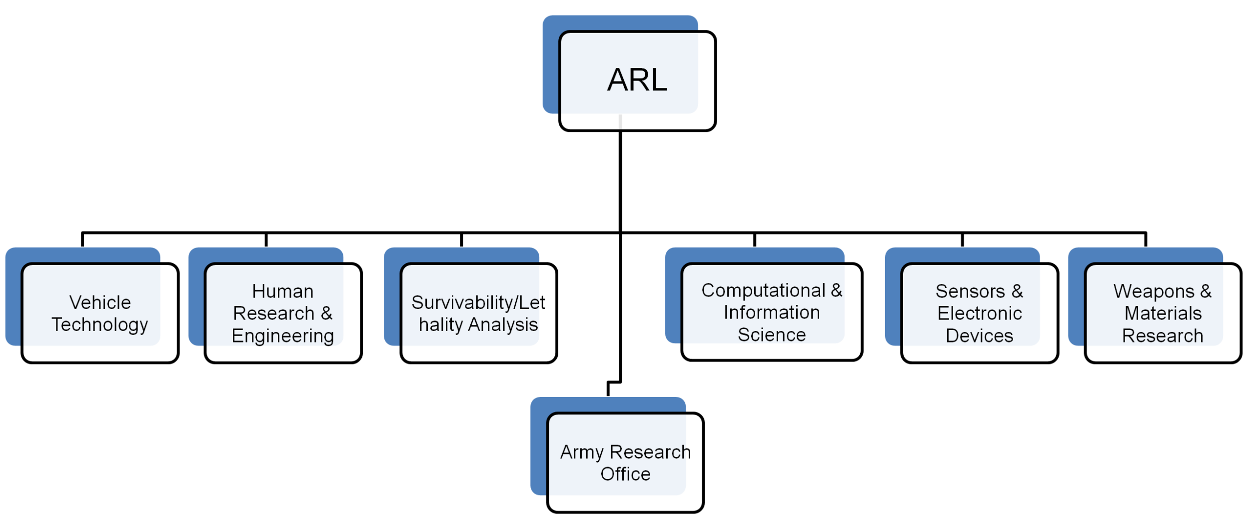

Figure 5.3 – Army Research Laboratory

ARMY RESEARCH OFFICE (ARO)

ARO is embedded in ARL, and is mission funded with basic research funding to manage the Army's extramural basic research program (see discussion and funding profile in chapter 3).

LIFE CYCLE MANAGEMENT COMMANDS (LCMCs)

Product life cycle support is managed by the four major LCMCs within AMC, each headed by a 2-star Commanding General: the Aviation and Missile LCMC, the Communication and Electronics LCMC, Joint Munitions Command, and the Tank and Automotive LCMC. These LCMCs support commodity-focused item management and product support throughout the life cycle through the myriad activities necessary to qualify, field and support Army systems.

PROGRAM EXECUTIVE OFFICES (PEOs) AND PROGRAM MANAGERS (PMs)

Programs of record are managed by PMs in the 12 Army PEOs, reporting to the Army Acquisition Executive. The PEOs and PMs are technology sponsors for RDECOM, and employ a large percentage of each RDECs workforce for engineering services and program support on a matrix basis. The PEOs are led by a mix of Army one or two-star General Officers and Department of the Army Senior Executives.

ALTERNATIVE S&T LABORATORY MODELS

The mission of research laboratories is to extend knowledge in areas of relevance to the parent organization. The transition from basic research to applications is often a push/pull event and sometimes involves several iterations. The researcher must be able to envision the future and persuade the developer how the innovation and or technology can address his needs. The laboratory must be willing to take risks because not all endeavors will lead to new products or research.[30] While there is definitely not a one-size-fits-all organizational model, there are several examples within the industry and DOD S&T enterprise to compare and benchmark.

INDUSTRY MODELS

Increased competition in the modern global economy has streamlined many U.S. industries. Basic research that is generally perceived as high risk, and that requires a long term investment, has not always survived this streamlining. Many high profile industrial organizations, such as Bell Laboratories, no longer exist, or exist as a shadow of their former stature. DOD cannot expect the same basic and applied research output from industrial R&D as in the past.[31]

Driven by near term profitability considerations, many corporations have shed much of the costly infrastructure necessary to support in-house basic research, and have increased leverage of external partners in pursuit of technology development. In response to the changing nature and increased globalization of R&D, many corporate research laboratories have become smaller and more federated, or completely eliminated. A federated corporate laboratory is more of a coordinator and integrator of innovation both within and outside the company walls, leveraging innovative work by universities, startups, business partners and government laboratories, in lieu of extensive in-house capability

[30] Decker et al. (note 26).
[31] Jason Program Office, *S&T for National Security*, Report Number JSR-08-146, The Mitre Corporation, McLean VA, May 2009.

supported by large technical staffs and costly facilities.[32] These trends have generally driven a shift toward a more near-term research horizon.

There are countless variations of industry laboratory models. For the purpose of illustration and contrast, we chose two successful, but distinctly different industry models: Apple and General Electric.

APPLE CORPORATE RESEARCH MODEL

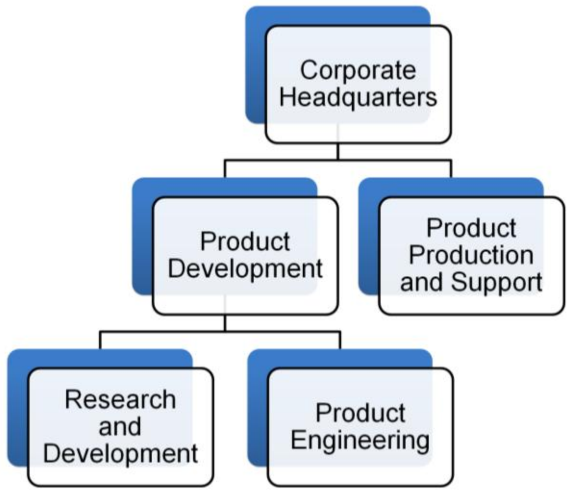

Figure 5.4 – Apple R&D Model

Apple operates without a centralized corporate research laboratory. Research is embedded into the product organizations, and is focused on a limited number of critical technologies at a time, with maximum leverage of the work of external partners and global R&D.[33] Without a corporate laboratory, Apple excels in technology-to-product transfer, and leads the industry in time to market. Today Apple has the most powerful patent portfolio of any consumer electronics company.[34]

In contrast to DOD S&T, the Apple corporate objectives do not require an extensive in-house research capability, and are served well with a near-term research horizon. The Apple model demonstrates leverage of outside work in lieu of internal investment, and the value in narrowing focus to only those technologies which directly support corporate objectives. By Apple standards, the Army has a bloated and inefficient multi-tiered structure which will be difficult to maintain in the face of declining budgets.

GENERAL ELECTRIC (GE) CORPORATE RESEARCH MODEL

The GE R&D model is more similar to the Service laboratories, with a distinct corporate research laboratory. At GE, the research laboratory director reports to the Chief Technology Officer, who in turn reports to corporate headquarters. This relationship provides high level visibility of the research portfolio, with minimum administrative levels between the S&T activity and the chief executive, and enables top level support and influence on setting research priorities in support of corporate objectives.

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[32] Lohr, Steve, "Corporate R&D as a Ringmaster for Innovation," 15 August 2009, www.nytimes.com.
[33] Ogg (note 10).
[34] Thomas, Patrick, and Anthony Breitzman, "Apple Has the Most Powerful Patent Portfolio in Consumer Electronics," *IEEE Spectrum*, November 2011.

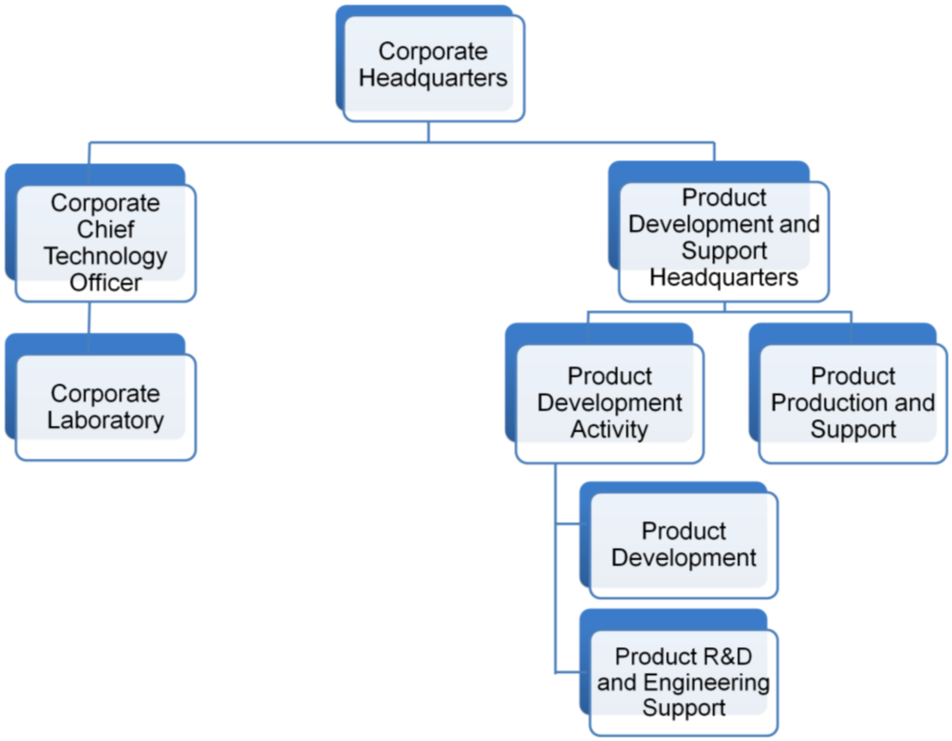

Figure 5.5 – General Electric R&D Model

The majority of GE corporate laboratory funding is research-focused, with a high degree of collaboration with academia and international laboratories, and intent to enable high-risk research focused on future market dominance. The research horizon is set beyond the next market cycle, and is not encumbered by outside customer funding. The director has sufficient discretionary funding for investment in new concepts and initiatives. Another important component of GE's success is capitalization of facilities and equipment to enable exploration and development of new concepts and processes.

On the down side, GE's investment in staff and infrastructure to support the corporate research laboratory is a much higher cost burden than at Apple. Also, the fact that the corporate laboratory reporting chain is separate and independent of the product development activities produces the classic technology transition gap between research and product engineering (see chapter 4 discussion).

INDUSTRY LABORATORY OBSERVATIONS

A key element of success for both GE and Apple is that they successfully compete for best in class talent by offering competitive compensation, recruiting at the top universities and maintaining a corporate research reputation for excellence. The result is a staff that is recognized by peers for state of the art research accomplishments. The widely recognized stature is also attributed to the presence of academia from leading universities. Periodic review of research projects, with competition for funding, is credited with enhancing creativity and leading the field in those areas where they choose to compete.

An industry R&D model can only be judged good or bad to the degree it supports and enables a particular company's business strategy and unique requirements set by the corporate leadership. Apple, with minimal in-house research investment and near-term horizon, excels at technology transfer and time to market. General Electric's centralized approach provides a longer horizon in support of corporate objectives, with the burden of more cost and some inherent problems in technology transition. These models, as well as all industry R&D, are generally driven by financials and business sustainability considerations, and are subject to change with market conditions and new corporate directions.

SERVICE SCIENCE AND TECHNOLOGY MODEL COMPARISON

In stark contrast to industry, the DOD Service Laboratories are driven by current and future war-fighting capability requirements, not the bottom line of profitability. Each of the services implemented the Goldwater-Nichols mandates in a different manner, and each has since evolved into distinctly different PEO/PM and RDA models.

The Study team chose several criteria specified in the TOR as points of comparison between the Army, the Navy and Air Force S&T organizational models:

1. A long-term research horizon addressing game-changing technologies.
2. Effectiveness of technology transition strategies.
3. Leverage of investments through competition of ideas.
4. Ability to maintain technical superiority, with access to required technologies and in-house competent buyer expertise.

EVALUATION OF CURRENT ARMY S&T ORGANIZATION

Research Horizon. The Army S&T program is increasingly too near-term in its focus, driven in large part by OCO-funded customer work, which has shortened the research horizon, and resulted in declining discovery and invention. The ASB also found little evidence of incentives encouraging staff to engage in high-risk research. This lack of incentives has limited pursuit of high-risk, but potentially transformational and game-changing technologies.

Transition Strategies. Although a primary mission of the ARL and the RDECs is to generate and transition technologies to programs of record, technology transition throughout the S&T enterprise is persistently problematic. ASB interview teams perceived gaps not only between 6.3 and programs of record, but also gaps between 6.1–6.2 and 6.2–6.3. Much of the transition problem is attributed to stovepipes among major commodities, which is somewhat mitigated in the Navy and Air Force through integrated management of the 6.1–6.3 program.

Leverage Investments Through Competition of Ideas. Through the ARO, the Army competes a percentage of the AMC basic research program. Little of the in-house 6.2 and 6.3 programs is competed. While there is some value in the consistency and predictability of base mission funding, the ASB believes that is outweighed by the benefits of a broader competition for resources throughout the S&T program.

Technological Superiority. The quality of research at ARL has steadily improved since its inception, however, the stature and extent of the recognition of ARL research within the external research community has not improved commensurately. RDECOM, ARL and ARO all engage with domestic and international partners, but that engagement appears to be very small and unfocused, without a specific objective to leverage the work of others toward critical Army S&T requirements. Also, the Army maintains a much smaller uniformed science and engineering workforce, which results in lack of balance between uniformed and civilian technical leadership apparent in the Navy and Air Force (see discussion in chapter 7).

EVALUATION OF NAVY S&T MODEL

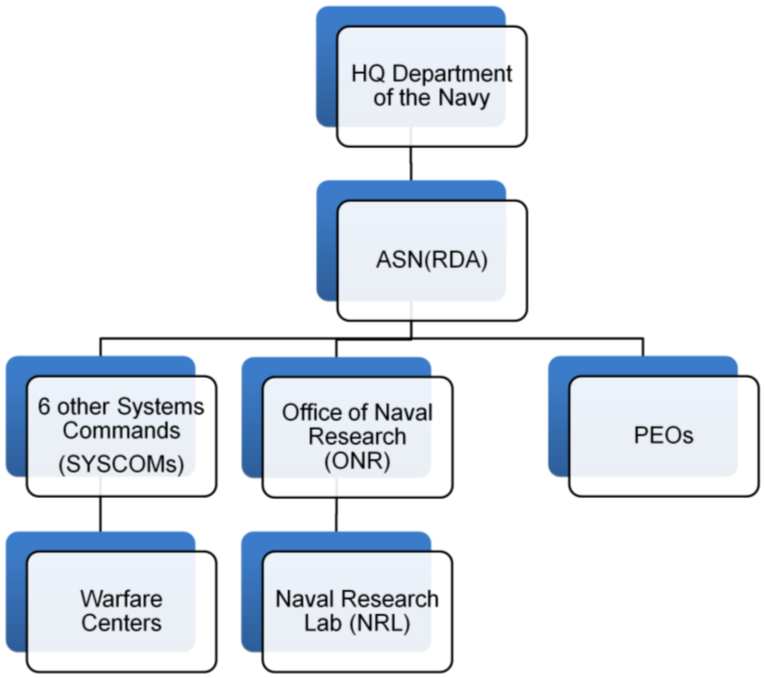

Figure 5.6 – Navy S&T Model

In response to Goldwater-Nichols and other reform efforts, the Department of the Navy eliminated its four-star Materiel Command in 1985. Later, it created seven two- and three-star Systems Commands (SYSCOMS) with responsibility for materiel development and lifecycle support, and PEOs responsible for acquisition, all reporting to the Assistant Secretary of the Navy for Research, Development and Acquisition. Within the SYSCOMS, the Naval Warfare Centers are the technology laboratories. Much like the RDECs, the Warfare Centers perform some S&T, but their primary responsibilities are to act as the principal RDT&E assessment activity for external S&T.

The Office of Naval Research (ONR) has responsibility for execution of the total Naval 6.1–6.3 portfolio. ONR sponsors scientific research efforts that will enable the future operational concepts of the Navy and the Marine Corps. ONR is also responsible for development and execution of the Naval S&T Strategic Plan which shapes the investment portfolio and reflects the priorities of the Secretary of the Navy, Chief of Naval Operations and Commandant of the Marine Corps. ONR is commanded by the Chief of Naval Research, a two-star admiral.

The Naval Research Laboratory (NRL) is a subordinate command to ONR. NRL is the corporate research laboratory for the Navy and Marine Corps and conducts a broad program of scientific research, technology and advanced development. The broad-based core scientific research at NRL serves as the foundation that can be focused on any particular area of interest to rapidly develop technology from concept to operation when high-priority, short-term needs arise. The lines of business at NRL include: sensors, electronics and electronic warfare, materials, battlespace environments, undersea warfare, information systems technology, space platforms and technology transfer. NRL is commanded by a

Navy Captain, while an SES Director of Research is responsible for the technical integrity of the laboratory.

Research Horizon. The Navy's benefit from an integrated 6.1–6.3 program is a more effective maturation of promising technologies from basic research through advanced technology development. To counter the tendency toward a shorter research horizon inherent in consolidating 6.1–6.3 management, ONR segments the portfolio into Discovery and Invention (6.1 and early 6.2), Leap Ahead Technologies (primarily 6.2) and Acquisition Enablers (primarily 6.3). The Discovery and Invention programs are peer-reviewed annually by external panels to ensure that the fundamental work is of high quality and taking appropriate risk.

Transition Strategies. To address the 6.3 to 6.4 gap, the Transition Enabler portfolio at ONR has instituted a Future Naval Capability program. This program requires that enabling capabilities have a formal TTA with an acquisition POR. Proposals for enabling capabilities are reviewed, prioritized and approved by a technical oversight group that includes Acquisition and Office of the Chief of Naval Operations stakeholders.

Leverage Of Investments Through Competition Of Ideas. With the exception of base program funds to NRL (~25% of the fundamental research budget) and ILIR, ONR uses a competitive process to award its research funds. This approach is driven by the philosophy that ONR's job is to sponsor the best research available in support of Navy needs. This portfolio level management approach serves to minimize redundancies in research investments.

Technological Superiority. The Naval S&T Strategic Plan guides ONR's investments and ensures that their research objectives are aligned with Navy needs. A Navy S&T leadership objective is to ensure the portfolio is flexible enough to recognize and respond to technology opportunities and/or unexpected threats. As in any S&T organization, its success in these endeavors is highly dependent on talented personnel. Since S&T elements compete for funding the Navy model, poor performers are weeded out. The study found NRL to be the best of the service laboratories.

EVALUATION OF AIR FORCE S&T MODEL

The Air Force response to the Goldwater-Nichols era reforms placed the S&T enterprise entirely within the four-star Air Force Materiel Command (AFMC), with product development and lifecycle support organized into commodity-focused systems commands, similar to the Navy model. The PEOs were located with the SYSCOMS, but retained a direct reporting relationship to the Air Force Acquisition Executive for acquisition matters in accordance with Goldwater-Nichols requirements. At the time of this study, the Air Force is engaged in a major efficiency initiative to reorganize the AFMC materiel enterprise into a functional alignment, streamlining from twelve reporting entities to five. The SYSCOMS are consolidating as a single three-star LCMC, with PEOs retaining a reporting relationship to the Air Force Acquisition Executive for acquisition decision authorities. The other functional commands reporting to AFMC will be sustainment, test, nuclear weapons, and the Air Force Research Laboratory (AFRL) for S&T. The new organization was scheduled to stand up on 1 Oct 2012, and is projected to yield $109M in annual cost avoidance.

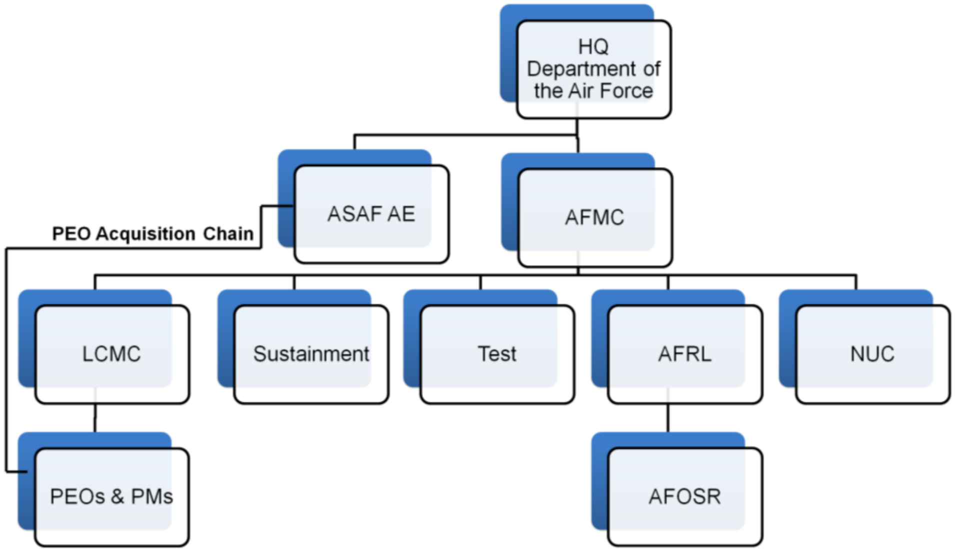

Figure 5.7 – Air Force S&T Model

All S&T within the Air Force is conducted or managed through AFRL, either internally by researchers in AFRL's eight technical directorates and the Air Force Office of Scientific Research, or externally via contract, cooperative agreement, etc. The lines of business in the technical directorates include: aerospace systems, space vehicles, sensors, information, munitions, directed energy, human effectiveness and materials and manufacturing. In each of these technology areas AFRL manages an integrated 6.1–6.3 program to develop promising technologies and approaches to meet current or likely future warfighting needs. AFRL is a two-star command, with an SES Technical Director.

The Air Force Office of Scientific Research (AFOSR) is the directorate within AFRL responsible for all Air Force basic research, both internal and external. While the other directorates perform research in-house or under contract to external entities, AFOSR invests in basic research efforts for the Air Force by funding investigation in relevant scientific areas. This work is performed by private industry, academia, and other organizations in the DOD and AFRL Directorates. AFOSR's research is organized along the lines of business of its three scientific directorates: aerospace, chemical, and material sciences; mathematics, information, and life sciences; and physics and electronics.

Research Horizon. The Air Force organizational structure, with management of the entire AF S&T program at AFRL, allows for clear near and mid-term "horizon scanning" and pursuit of the best technologies as they become available. Longer-term focus is addressed as department policy, in that "Air Force will manage Air Force S&T as an integrated set of programs that invest in the future while strengthening current capabilities… and to carefully balance the investment portfolio in basic research, applied research and advanced technology development to produce both evolutionary and revolutionary increases in capability."[35]

Transition Strategies. The Air Force S&T structure enables technology transitions from 6.1–6.2 and 6.2–6.3, but does not specifically address transfer of technologies from 6.3 to 6.4 and PORs. However, as a matter of policy, in addition to the conduct of research and technical response to urgent problems, AFRL

[35] Air Force Policy Directive 61-1, "Management of Science and Technology," 18 August 2011.

has an explicit mission to develop and transition new technologies for Air Force weapon systems and their supporting infrastructure.[36] Inherent transition problems are also mitigated by having a cradle-to-grave lifecycle in one command with four-star advocacy.

Leverage of Investments Through Competition of Ideas. The AFRL benefits from competitive R&D funding, in which researchers compete for S&T 6.1–6.3 resources. Within this competitive environment, many AFRL scientists and engineers have become recognized world-wide as leaders in their respective fields.

Technological Superiority. Air Force manages S&T capability through a set of core technical competencies, each defined by key skills and capabilities among people, information, facilities, equipment and programs. The core technical competencies span basic and applied research and advanced technology development, and collectively provide the capability and technical leadership to address critical AF problems. Also, AFRL/AFOSR maintain several foreign technology offices, which coordinate with the international scientific and engineering community to maintain access to global R&D.

A RECOMMENDED ARMY S&T ORGANIZATION

The course of action to "Fix RDTE under the current strategy" described in the TOR would preserve the current organizational model in which ARL (including ARO) is subordinate to RDECOM, which is subordinate to AMC. Process improvements with the current structure could include initiatives such as: Army-wide portfolio management in which each RDEC would retain a modest commodity-focused 6.1–6.3 mission, incentives for increased collaboration, a campaign to reduce redundancies, plus other efficiency initiatives. It is the ASB's view that while this approach has potential for incremental improvements, adoption of best-in-class features of other S&T organizational models could provide Army leadership with much greater potential for increased efficiency and performance.

A successful Army S&T organization should enable the three-fold focus described earlier in this report:

1. Ensuring capability to conduct in-house efforts in technologies critical to the Army and not available elsewhere.
2. Sponsor technology efforts in industry, academia and FFRDCs to achieve required capabilities, without corresponding investment in infrastructure and staff.
3. Monitor and leverage the broader domestic and global R&D activity.

In consideration of the strengths enabled by the different S&T organizational alignments of the Navy and Air Force, the Army should take measures to foster technology transition and minimize S&T redundancies through consolidated and integrated management of the 6.1–6.3 S&T program. The current institutional funding approach should be transitioned to a competitive approach over a period of several years, with an objective of awarding all 6.1 and at least a majority of the 6.2–6.3 program on a competitive basis. An integrated 6.1–6.3 management approach should establish policies to enable a focus on critical technologies in the corporate laboratory, and to maintain an enterprise-wide balance between near-term objectives and a longer-term research horizon. The corporate laboratory (ARL) should be positioned to maintain a core focus on basic and applied research in the critical technologies, while maintaining a sufficient amount of funding to be used at the laboratory director's discretion to capitalize on emerging opportunities. To lengthen research horizon, customer-funded work not

[36] Air Force Research Laboratory Mission, Air Force Materiel Command Mission Directive 420, 14 November 2011.

supporting critical core technologies should be offloaded to other laboratories. To ensure responsiveness to Army leadership goals and objectives, the corporate laboratory (ARL) should report at a four-star level (Commanding General, AMC), with access to and direction from HQDA through the ASA(ALT). Furthermore, a realigned S&T organization should include enablers to improve technology transition, especially at the 6.3–6.4 gap.

The ASB believes the potential for major increases in performance and efficiency justifies three organizational adjustments:

1. The ARO should be realigned as a Direct Reporting Unit to ASA(ALT), with an expanded role under the direction of DASA(R&T) to develop and maintain a strategic S&T plan and to manage the policy, programming and prioritization of the 6.1–6.3 program. ARO should continue to sponsor competitive execution of the AMC-wide 6.1 program, both extramural and intramural, and, with additional staffing, assume responsibility for integration of the 6.2–6.3 program over a period of time to increase competition and decrease research duplication.
2. The ARL, the corporate research laboratory, should report directly to the Commanding General , AMC, with a dotted line relationship to ASA(ALT). ARL should divest its current customer-funded 6.3 workload, and thereby become smaller and more research-focused, with a longer-term horizon, and focus on basic and applied research on the critical technologies. ARL should also organize and staff internally to increase leverage of other government and industrial activities and global R&D.
3. Also, in accordance with earlier discussion (chapter 4), the Army should establish a TTIPO reporting to ASA(ALT), to enable technology transitions, advanced concepts and innovation.

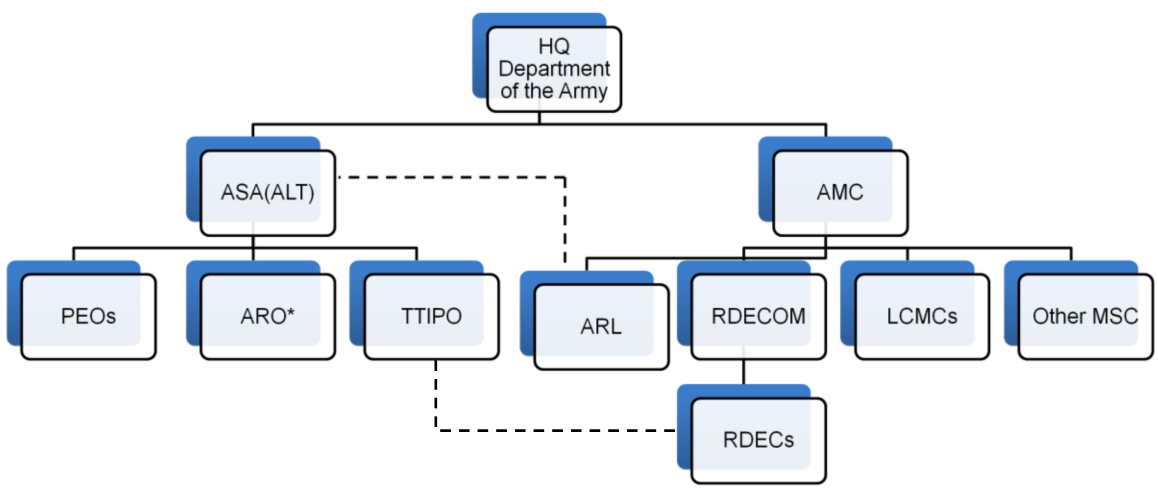

Figure 5.8 – Recommended Army S&T Model

FINDINGS & RECOMMENDATIONS

FINDINGS

1. The Army requires an S&T structure that has a long-term horizon, fosters competition throughout the 6.1–6.3 program, is integrated and avoids redundancies, and provides a robust

capability to support basic and applied research on those technologies identified as critical "must-do-in-house".

2. After reviewing industry models, we found they are less relevant to Army S&T than peer service S&T organizations, however, in most successful industry models the corporate laboratory reports to the Chief Executive Officer or Chief Technology Officer.

RECOMMENDATIONS

The ASB recommended model addresses shortcomings in the current Army S&T organization.

1. Realign ARO as a Direct reporting Unit to ASA(ALT).
    a. Expand the role to assist ASA(ALT) in development of a strategic plan, programming, policy and prioritization of the 6.1–6.3 S&T program.
    b. Foster enterprise-wide long-term focus, competition via a peer review process, integration and minimization of redundancies in the S&T Program.
    c. Sponsor competitive execution of the AMC-wide 6.1 program, with increasing responsibility for integration of the 6.2–6.3 program over time, to increase competition and decrease duplication in the 6.2–6.3 program.
2. Realign the ARL as a direct report to Commanding General, AMC.
    a. Divest research and customer directed workload which is unrelated to Army critical technologies.
    b. Focus on long-term goals of senior leadership with increased high-risk research on game-changing technologies.
    c. Improve leverage of global R&D through increased industry, academic and international partnerships.
3. Establish a TTIPO reporting to the ASA(ALT).

CHAPTER 6. FACILITIES AND EQUIPMENT

Availability and maintenance of state-of-the-art facilities and equipment is a universally accepted standard for high quality research organizations, be they public, industrial, government or academic institutions. It is a standard by which organizations are judged in terms of global competitiveness.[37] Furthermore, a world-class workforce needs world-class facilities and equipment. State-of-the-art equipment and facilities are a major factor in recruiting, retention and recognition of best of class scientists and engineers, and a critical factor in achieving and maintaining a world class reputation for Army S&T.

BACKGROUND AND DISCUSSION

If the Army is to maintain technical superiority, it must program sufficient resources to refresh existing and establish new facilities and equipment. However, Army annual spending on S&T facilities across the entire laboratory system has been less than needed to maintain a competitive edge. Moreover, spending on new S&T equipment has been shrinking.[38] Other than BRAC funding that has delivered state-of-the-art facilities, MILCON spending has been minimal for the Army laboratories. Similar results are evident for Navy and Air Force, in that all three services historically have had difficulty competing for laboratory facility funding through the MILCON process.[39]

Observations during the study team site visits evidenced a wide spectrum of facilities readiness. There are very impressive new state-of-the art facilities from recent BRAC rounds, as well as varying degrees of readiness in older facilities. All Laboratory Directors commented on challenges with maintenance and repair, and noted they are forced to rely on use of mission or customer funds for some critical maintenance and repair requirements. The Common Level of Support provided under . U.S. Army Installation Management Command regulations falls short of providing the services and upkeep needed in a high-tech laboratory enterprise, and each of the Army laboratories uses a significant amount of RDT&E funding to supplement Common Level of Support.[40] The study team did not observe any enterprise-wide assessment and prioritization of these requirements above the local level.

The study team also noted some similar facilities among ARL and the different RDECs. We recognize that each separate laboratory must maintain core capabilities for general technology work and staff development, so some degree of redundancy is necessary and unavoidable. However, the group noted some duplication of specialized facilities, e.g., multiple dry-rooms for battery research, and multiple software engineering facilities. There was also an observation of investment in some facilities and equipment not essential to the performance of the critical must-do-in-house technologies. Any facilities and equipment supporting non-critical technologies should be candidates for consideration as excess. A rigorous inventory and assessment is required to identify unnecessary duplication and excess facilities, and enable divestiture or redirection of use over time of unneeded facilities, which would free up additional investment for critical infrastructure supporting “must-do” technologies.

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[37] 1991 Federal Advisory Commission on Consolidation and Conversion of Defense Research and Development Laboratories, Report to the Secretary of Defense

[38] Decker et al. (note 9).

[39] Decker et al. (note 9). Department of Defense, Report of the DoD Laboratory Joint Analysis Team (draft), 27 January 2010.

[40] Freeman, Marilyn (note 14).

IMPERATIVE FOR A STRATEGIC MODERNIZATION PLAN

Implementation of a comprehensive strategic modernization and recapitalization plan for Army S&T could potentially address all the issues described above. Such a plan should require periodic inventories and assessment of the status of Army laboratory facilities and equipment. After initial assessment, this activity could provide Army S&T leadership with a running infrastructure readiness assessment. An enterprise-wide assessment would identify gaps and shortfalls, and justify the programming of resources necessary to support the critical technologies that must be conducted in-house, as well as the general laboratory capability necessary for normal operations and staff development. It should also identify capability gaps and provide POM justification for adequate sustainment, restoration and modernization funding, as well as MILCON justification where needed for new or replacement facilities, and prioritize accordingly. The analysis should identify redundancies and excess facilities, and over time eliminate or repurpose excess or unneeded infrastructure, thereby shifting that amount of investment to support critical technologies. When MILCON is not available or sufficient, such a plan would also position Army S&T for future BRAC opportunities, and should identify opportunities to incorporate innovative alternative funding and partnership strategies, e.g., fee-for-use and third party leasing opportunities.

As discussed earlier in the report, the current state of domestic and global R&D dictates development and leverage of domestic and international S&T partnerships. However, the study team could not find a policy or Army-wide objective to leverage the facilities of others (e.g., other Service and Federal agency laboratories, the National Laboratories, universities, industry and international partners). Also noted is lack of policy or stated objective to leverage use-by-others of Army facilities. Such arrangements could provide revenue for Sustainment, Repair and Maintenance through fee-for-use agreements, and would also enhance technology partnerships.

FINDINGS AND RECOMMENDATIONS

FINDINGS

1. Although Army S&T infrastructure benefited greatly from several rounds of BRAC over the past two decades, the Army S&T enterprise historically does not compete well for other MILCON funding.
2. Army laboratories are investing significant RDTE funding to maintain facilities at mission-ready levels.
3. Army has not identified the facilities and equipment necessary for development of the critical must-do-in-house technologies, and those that are not. There is some amount of unwarranted duplication, redundancy and underutilization in facilities and equipment among the various laboratories in ARL and the RDECs as discussed above. There is also laboratory capability which does not support those critical technologies requiring in-house development. Divestiture or redirection of use of excess or underutilized facilities over time will allow a shift of resourcing to support development of the must-do-in-house technologies.
4. The Army does not currently have an enterprise-wide strategic modernization or recapitalization plan to identify and prioritize gaps and shortcomings in Army S&T facilities and critical equipment. Such a plan would address issues through assessment, definition and prioritization of gaps and shortfalls, and provide more effective justification and programming of resources.

5. The Army at large does use some innovative facilitation strategies, such as enhanced-use leasing of on-post contractor buildings, privatization of Army housing, lodging and many utilities. However, regarding S&T facilities and equipment, the Army has not and currently does not seek innovative alternative funding and partnership strategies. Examples include, but are not limited to cooperative agreements for access to industrial facilities, fee-for-use, and third party leasing as is used throughout industry and many of the FFRDCs.

RECOMMENDATIONS

1. ASA(ALT), through DASA(R&T), should create a resourced long-term strategic modernization and recapitalization plan which provides periodic assessment and prioritization of Army S&T facilities and equipment, identifies critical facility and equipment needs, provides justification for sustainment and new construction funding, and over time reduces redundant capabilities and excess capacity. This plan should include alternative funding and utilization strategies used by many other S&T organizations, such as third party leasing, financing, and cooperative use agreements. This becomes even more essential when MILCON is not available.
2. In lieu of new investment, the Army should take full advantage of existing regulations and policy to pursue opportunities to leverage the facilities of other service laboratories, national laboratories, universities, industry and global partners. Likewise, Army should seek to increase utilization of its own available facilities through fee-for-use and other partnering arrangements.

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CHAPTER 7. PERSONNEL

With the drawdown of two wars and tightening of resources, Army S&T is at a transition point. Moving forward successfully will require not only measures to increase and leverage global innovation and collaboration, but will require a rethinking of investments in people. As described elsewhere in this report, domestic and international R&D investments today far outpace the DOD S&T budgets and create much more competition for S&T talent than in recent decades. Foreign students are earning a significant percentage of advanced degrees in science and engineering in U.S. universities, while the percentage of U.S. born scientists and engineers is declining.[41] Army S&T will become less competitive if it does not recognize and respond to these changes and trends in global R&D.

BACKGROUND AND DISCUSSION

Recruitment, development and career management of scientists and engineers are of paramount importance in maintaining world-class laboratories and technological advantage. It is also important to have military personnel who are well-educated and trained in technical disciplines as enablers for technology and systems development. The combination of expert civilian and military technical personnel has proven to be a key factor in successful technology development and transition to superior weapons systems.[42]

Most of the scientific work now done in the United States lies outside the purview of the DOD, and thus the competition for the Nation's best and brightest is more intense now than it was during the Cold War. With an improved economy the competition for available talent will increase, private industry will be able to pay more in salaries, and the ability to attract talent to Army S&T will further diminish. Another noteworthy trend is that most of the younger workforce does not share the career commitment of older generations, and are much more likely to transition among different employers throughout a career. We cannot assume that without a focused and determined effort, the human resources needed for global military competition will be available, and can be hired and incentivized to stay in Army S&T.[43] A concerted effort is necessary to position Army S&T as an employer-of-choice.

In a competitive market for the best and brightest, recruiting and hiring should be as streamlined as possible. However, even with current "Lab Demo" authorities, most of the laboratory directors report frustrating delays in hiring. They also report excessive bureaucratic delays in management of SES and ST positions, which are controlled by the Civilian Senior Leader Management Office. The percentage of PhD-level S&E in ARL is trending up, but still below 40%, while most world class laboratories are greater than 50%. The percentage of PhDs among S&E at the RDECs is between 2–5%.[44] There is also a perception in the DOD research community that ARL lags in stature behind the other service research laboratories.[45] A concerted effort to reduce S&E management constraints, increase percentage of PhD, and to recognize and promote Army S&T successes and contributions would increase research stature, and help position ARL and the RDECs as a first choice for S&E talent.

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[41] Decker et al. (note 9).
[42] Decker et al. (note 9). Also, private communication, Dr. Lester Martinez-Lopez, MG (Ret), USA.
[43] *Report of the Defense Science Board on Basic Research* (note 6).
[44] Decker et al. (note 9).
[45] Decker et al. (note 9). Decker, Wagner, et al. (note 16). Also referencing Army Acquisition Review; Decker, Wagner, et al. 2010

The Army uniformed S&T workforce is a fraction of what it was three decades ago. After a downward trend in uniformed S&Es through the 1990s, the Uniformed Army Scientist and Engineer (UASE) program was created within the Army Acquisition Corps in 2003, with intent to reverse the trend.[46] However, it was not well-supported within the Acquisition Corps, where emphasis is on development of program managers and contracting officers, and the program was discontinued in 2010.[47] Today, the few uniformed Army scientists are managed within the Acquisition Corps as Functional Area 51S, Research and Engineering. They are expected to pursue certification in at least one other area of concentration, and to seek a range of assignments across multiple areas of concentration, as well as occasional operational assignments. They compete for promotion with the broader pool of Acquisition Corps officers, who generally have more experience in program management and contracting. Advanced degrees in science and engineering and multiple S&T assignments, at the expense of program management and contracting experience, can actually be a disadvantage in that promotion pool.[48] The study recognizes that the uniformed S&Es are crucial for their operational experience and understanding of the operational Army, and maintains the career path needs to be moved outside the acquisition corps.

Army can look to the other services and at least one internal example to benchmark strategies to integrate civilian and military S&E expertise. Organizations like DARPA employ best of class in both civilian and military technical program managers and office directors to address, develop and demonstrate new concepts and approaches for military systems. The AFRL has always been commanded by a General Officer with a technical background. Air Force officers can pursue a technical path throughout their career, including attendance at graduate schools. Their career path typically involves moving into more technical management or oversight at the senior levels. The NRL has a Navy Captain as Commanding Officer and a civilian Director of Research. These uniformed S&Es at senior levels make technical decisions based on technology and scientific insights accumulated during a balanced technical career,[49] and the integrated organizations have the advantage and leverage of technical contributions from both civilian and uniformed personnel.

An example of an Army organization which does in fact integrate civilian and military researchers is the U.S. Army Medical Research and Materiel Command.[50] At the Medical Research and Materiel Command, 30% of principal investigators are uniformed military personnel. All laboratories are commanded by uniformed scientists, while chief scientists are career civil servants. Career paths for uniformed researchers involve operational as well as laboratory assignments. Uniformed researchers are required to complete all military schools and deploy as required in support of operational requirements. All researchers are incentivized to earn acquisition certification to enable better understanding of the DOD acquisition program. Civil service researchers often stay in the same laboratory and become experts in a particular field, while uniformed researchers typically rotate through several laboratories and other assignments throughout a career.

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[46] Thane, John M., "The Future of the Uniformed Army Scientist and Engineer Program," *Military Review*, November-December 2007.
[47] Thane (note 45).
[48] Thane (note 45); JASON Report Number JSR-08-146 (note 29).
[49] Private communication, Paul Nielsen Maj. Gen. (Ret) USAF.
[50] Martinez-Lopez (note 40).

IMPROVING ARMY SCIENCE AND TECHNOLOGY TALENT

If the Army is to attract and retain top talent in the S&T work force, the recruitment, retention, career development and leadership of scientists and engineers all require more attention and innovation. While the Army is making some progress in refreshment of its civilian S&E career field (e.g., recent hiring of young S&Es) the usual time to hire is still lengthy and in many instances prohibits gaining important staff additions as they have other options which they will exercise . As a result, the Army has not transformed the S&E workforce rapidly enough in the fast changing research areas such as network, information and social sciences, which are integral to future distributed systems.[51] Of further concern is the perception that the stature of ARL research is less than peer service laboratories, as this serves as a potential negative factor in attracting and retaining high quality staff.[52] A further concern is the impact of the perception that the stature of ARL research is less than peer service laboratories. This negative perception is a factor in not being able to attract and retain high quality staff.[53] By contrast, at NRL there is an environment which to a greater extent encourages and recognizes publications, citations, honorary memberships and acceptance to professional societies.[54] And unlike the other service laboratories, there are no members of the national academies at ARL.[55]

First and foremost among necessary actions is that recruitment and retention of civilian technical talent must be an Army priority, and must include a personnel process to hire and retain “the best,” not just “the qualified.” Improving the ARL stature within the research community will also require significant attention from Army S&T leadership. The Secretary and CSA should support a set of actions to enhance the stature of Army S&T with renewed emphasis on technical excellence, and to position Army S&T as an employer-of-choice for the best and brightest scientists and engineers.

An initial enabling action should be to establish a STEM Corps, which recognizes and enables career development and advancement of scientists and engineers, and to designate ASA(ALT) as the functional chief for S&E career management, with management authority delegated to DASA(R&T). Near-term initiatives should include extension of the direct (not expedited) hiring authority currently available to laboratory directors for PhDs to include all SMEs, MS and BS candidates, with retention incentives such as funded post-graduate education, mentorship programs, and selective bonuses, with special emphasis on retention of recently-hired S&Es. Army should also authorize hiring and retention incentives targeted to increase the ARL S&E PhD population to > 50%, and implement programs to retain the current cohort of S&E talent. To enhance recognition of Army S&E achievements, emphasize increased memberships in professional societies, publications, patents, citations and honorary awards, as well as a broader program of internships, post-doctoral positions and exchange programs with other government, industry and academic laboratories.

REBUILDING A UNIFORMED SCIENCE AND TECHNOLOGY PROGRAM

Uniformed military scientists and engineers can exploit emerging technologies to achieve new and game-changing capabilities. However, the military presence in Army S&T, as measured by the number of military technical staff, is notably low. More generally, the Army is the least technically qualified of the military services, which adversely affects the responsiveness of the S&T program to meet Army

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[51] Decker et al. (note 9).
[52] Decker et al. (note 9).
[53] Decker et al. (note 9).
[54] NRL Briefing to ASB March 20, 2012
[55] Decker et al. (note 9).

needs. The lack of technically informed military perspective reduces opportunities to influence new directions and limits approaches to cost/performance trade-offs, transition, and test and evaluation.[56] Unfortunately, technology development is not currently a legitimate career path for Army officers. As stated above, the UASE program was terminated in 2010.[57] Within the Army Acquisition Corps, priority is on program management and contracting, with no viable S&E career path. Advanced technical degrees appear to be more highly valued in other services, particularly the Air Force, where less time and energy is expended justifying S&T education expenditures.

Rebuilding a uniformed S&T core of technically competent officers should be an Army priority. The Secretary and CSA should support a set of actions to increase the number and quality of military scientists, engineers and technical leaders. Army should reestablish the UASE program to recruit, develop and advance technology competent officers for critical technology development and leadership roles with enough UASE billets of sufficient rank to ensure a viable career path.

Near-term initiatives should establish UASE billets as rotational assignments throughout the Army S&T enterprise, as well as the U.S. Military Academy (USMA), other service laboratories, industry, and selected international partners. In particular there must be sufficient technical billets and personnel provided to TRADOC to ensure technical competence in the requirements processes. Army should also increase graduate-level education opportunities targeted to support the critical must-do-in-house technologies. And to establish a base for a future UASE corps pipeline, Army should increase science and engineering summer intern opportunities for ROTC and USMA cadets to encourage future technical career field choices.

The study team recognizes that a uniformed UASE program will compete for resources with other Army requirements and that size and numbers will be a direct function of emphasis from the Secretary and CSA, balanced with the broader personnel requirements scheme for Army officers. At a minimum, a revitalized UASE program should provide a corps of technically-competent uniformed officers to fill development and leadership positions relative to Army-critical technologies. It must also include the designation of sufficient science and engineering billets to support professional development and career progression within a healthy career field. The program must provide graduate-level education opportunities in critical technologies, and should also leverage rotational opportunities with the USMA, other service laboratories, and selected international partners.

FINDINGS AND RECOMMENDATIONS

FINDINGS

1. Recruitment, retention, development and leadership of scientists and engineers require more attention if the Army is to attract and retain top science and engineering talent.
2. The stature and recognition of ARL in the external research community is considered less than peer-Service laboratories, which is a factor in attracting and retaining high quality staff. The best research laboratories have more than 50% PhDs —ARL has less than 40%.

[56] Decker et al. (note 9).
[57] Thane (note 45).

3. Military presence in Army S&T is notably low. The UASE program was terminated in 2010. There is no legitimate technology career path for Army officers.

RECOMMENDATIONS

1. Recruitment and retention of civilian technical talent must become a Secretary of the Army/CSA priority.
    a. Establish a technical career path within a science and engineering “corps,” with ASA(ALT) as the functional chief for career management.
    b. Authorize hiring and retention incentives targeted to increase the ARL S&E PhD population to more than 50%.
    c. Implement programs to retain current cohort of S&E talent.
    d. Extend direct hiring authority for all scientists and engineers.
    e. Create a personnel process to hire and retain “the best,” not just the qualified.
2. Rebuilding of a uniformed S&T core of technically competent officers should become a Secretary of the Army/CSA priority.
    a. Reestablish the UASE program to provide technology-competent officers for critical technology development and leadership roles, with sufficient UASE billets to ensure a healthy career progression.
    b. Assure technical billets and personnel are provided to TRADOC.
    c. Increase graduate level education opportunities which support critical must-do in-house technologies.
    d. Increase S&E summer intern opportunities for ROTC and USMA cadets.

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CHAPTER 8. EFFICIENCIES

The study team is fully aware of the difficulty in implementing well intentioned but resource-intensive recommendations. The savings gained by efficiencies should out-weigh the net costs of implementation. The findings and recommendations restated below will have the most potential for significant efficiencies.

OPPORTUNITY FOR BROADER EFFICIENCIES

Although beyond the scope of the S&T charter and our TOR, the study team notes an opportunity for consolidation across the entire RDT&E enterprise that became evident from our visits and discussions in performing this study.

The Army's unique response to the Goldwater-Nichols era reform efforts established independent PEOs, separated from the S&T staff, which have grown significantly in size and scope, especially over the past decade, which we believe has created a significant amount of duplication of function among the PEOs, RDECs and the LCMCs. With the current quest for efficiencies and cost savings, the Army should consider the option of combining all product development activity into a commodity-aligned, but integrated materiel enterprise. This construct is along organization lines with the Navy and Air Force SYSCOMs. We note that the Air Force is currently reorganizing to combine its SYSCOMs into a single acquisition/lifecycle enterprise. Army product development, program management, and lifecycle support could be combined to create several commodity-focused centers, under the aegis of single Army acquisition/lifecycle command, potentially at the three-star level, reporting to the AMC. For Goldwater-Nichols compliance, PEO reporting relationships to the Army Acquisition Executive would be preserved in a manner similar to the Navy and Air Force implementations. Such an organization would offer huge potential for reductions in staff and General Officer/Senior Executive billets, as well as other efficiencies, while preserving core product development and lifecycle support capabilities.

FINDINGS AND RECOMMENDATIONS

FINDINGS

1. Implementation of the S&T Strategy will permit improved, superior S&T program while reducing in-house and sponsored research, leading to a better focused, smaller ARL. Implementing the strategy is pre-requisite to a technologically-superior force in today’s fiscal environment.
2. Creating a TTIPO will allow for efficient, timely modernization of existing hardware in an era of minimum platform new starts. Creation and operation of this office can be done with existing resources. Further this office will assist ASA(ALT) in managing its existing prototyping activity.
3. RDECOM Headquarters has not demonstrated significant value added to the S&T community and our recommendation includes removal of some of its S&T functions.
4. The proposed organizational changes will allow for creation of an S&T strategy within existing resources by employing ARO as office of record for creating and maintaining this strategy.
5. These changes will permit improved performance and cost reduction by creating constructive competition for basic research activity. These efficiencies will allow for a smaller RDECOM.
6. S&T efficiencies require a responsive acquisition community as a receptor. Air Force obtains a responsive interaction by ‘dual-hatting’ the PEO structure.

7. Hiring and retaining best-in-class personnel is best assurance of an effective, efficient S&T program.

RECOMMENDATIONS

1. Implement reassignment of ARO to create and assist in execution of the S&T Strategy.
2. Create and resource TTIPO to assist in efforts to efficiently modernize current platforms.
3. Implement a study to consider placing the PMs/PEOs within AMC and 'dual-hatting' them to the Army Acquisition Executive for POR acquisition decisions. Study should include assessment of RDECOM contributions to S&T and acquisition activities. Such a study was not within the scope of this study's TOR.
4. Army leadership must assure implementation of a human resources strategy to hire and retain best S&T civilian talent and a technically qualified uniformed cadre.

CHAPTER 9. IMPLEMENTATION

The report recommendations, which have been presented topically thus far, are here regrouped by recommended responsible agent.

SECRETARY OF THE ARMY

Sponsor the creation of a scientist and engineer "STEM career field" and supporting management systems.

CHIEF OF STAFF, ARMY

Direct the creation and implementation of the Uniformed Army Scientist and Engineer (UASE) program.

ASSISTANT SECRETARY OF THE ARMY FOR ACQUISITION, LOGISTICS & TECHNOLOGY

1. Develop and promulgate the Strategic S&T Plan.
2. Manage the Army Research Office (ARO).
3. Establish a Technology, Transition, Innovation Prototyping Office (TTIPO), including advanced concepts.
4. Reinvigorate the international S&T presence/participation.
5. Serve as the proponent for scientist and engineer "STEM career field."

ARMY LABORATORIES (GIVEN EXPANDED RESPONSIBILITIES)

1. To assure execution of a Strategic S&T Plan based on the approach outlined in this presentation.
2. For authority to direct hire personnel with STEM graduate degrees and manage careers in order to assist retention.
3. To significantly increase the number of exceptional, experienced chief engineers and system-of-systems engineers.

ARMY MATERIEL COMMAND (AMC) AND THE COMMODITY COMMANDS (GIVEN EXPANDED RESPONSIBILITY)

1. Execution of rapid prototyping in response to the Technology, Transition, Innovation Prototyping Office (TTIPO).
2. Management of the Army Research Laboratory (ARL).

ARMY G-1

Reestablish policy for a Uniformed Army Scientist and Engineer (UASE) program and develop the UASE program (selection, training and career development).

ARMY G-3/5/7 AND ARMY G-8

Develop and promulgate the Uniformed Army Scientist and Engineer (UASE) program.

ARMY TRAINING AND DOCTRINE COMMAND

Participate in development of advanced concepts and prototype experimentation programs.

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Appendices

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Appendix A – Abbreviations and Acronyms

A	AAH	Advanced Attack Helicopter
	AAWS-M	Anti-Armor Weapons System—Medium
	AFMC	Air Force Materiel Command
	AFRL	Air Force Research Laboratory
	AFOSR	Air Force Office of Scientific Research
	AMC	Army Materiel Command
	AMRDEC	Aviation and Missile Research, Development and Engineering Center
	AMRDEC-AV	Aviation and Missile Research, Development and Engineering Center—Aviation
	AMRDEC-MI	Aviation and Missile Research, Development and Engineering Center—Missiles
	APG	Aberdeen Proving Ground
	ARCIC	(TRADOC) Army Capabilities Integration Center
	ARDEC	Army Armament Research, Development and Engineering Center
	ARL	Army Research Laboratory
	ARO	Army Research Office
	ASA(ALT)	Assistant Secretary of the Army for Acquisition, Logistics and Technology
	ASB	Army Science Board
	ASN(RDA)	Assistant Secretary of the Navy for Research, Development and Acquisition
	ASTWG	Army S&T Working Group
	ATEC	Army Test and Evaluation Command
	ATP	Authority to Proceed
B	BA	Budget Activity
	BA 1	Basic Research (6.1)
	BA 2	Advanced Research (6.2)
	BA 3	Advanced Technology Development (6.3)
	BA 4	Advanced Component Development and Prototypes (6.4)
	BA5	System Development and Demonstration (6.5)
	BLUF	Bottom-line Up Front
	BRAC	Base Realignment and Closure
C	C2	Command and Control
	C4ISR	Command, Control, Communications, Computers, Intelligence, Surveillance and Reconnaissance
	CERDEC	Communications-Electronics Research, Development and Engineering Center
	CJCS	Chairman of the Joint Chiefs of Staff
	CNO	Chief of Naval Operations
	COCOM	Combatant Commander

	CONOPS	Concept of Operations
	CONUS	Continental United States
	COTR	Contracting Officer's Technical Representative
	COTS	Commercial off the shelf
	CSA	Chief of Staff of the Army
D	DARPA	Defense Advanced Research Projects Agency
	DASA R&T	Deputy Assistant Secretary of the Army for Research and Technology
	DOD	Department of Defense
	DOTMLPF	Doctrine, Organization, Training, Materiel, Leadership and education, Personnel and Facilities
	DSB	Defense Science Board
E	ECBC	Army Edgewood Chemical Biological Center
	ECP	Engineering Change Proposal
	EMD	Engineering Manufacturing Design
F	FFRDC	Federally Funded Research and Development Center
	FY	Fiscal Year
G	G-1	Deputy Chief of Staff for Personnel
	G-3	Deputy Chief of Staff for Operations
	G-4	Deputy Chief of Staff for Logistics
	G-8	Deputy Chief of Staff for Programs
	GE	General Electric Company
	GIT	Georgia Institute of Technology
	GTRI	Georgia Tech Research Institute
H	HQDA	Headquarters, Department of the Army
I	ICDT	Integrated Concept Development Team
	ILIR	In-house Laboratory Independent Research
	IPT	Integrated Product Team
	IR&D	(Industry) Independent Research and Development
	ISR	Intelligence, Surveillance and Reconnaissance
J	JCTD	Joint Capability Technology Demonstration
	JRAC	Joint Rapid Acquisition Cell
	JUON	Joint Urgent Operational Needs
K	KPP	Key Performance Parameter
L	LCMC	Life Cycle Management Command
	LDRD	Laboratory Directed Research and Development
	LRIP	Low Rate Initial Production
M	MBT	Main Battle Tank

	MCWL	USMC Warfighting Laboratory
	MEDEVAC	Medical Evacuation
	MEP	Mobile Electric Power
	MILCON	Military Construction
	MIT	Massachusetts Institute of Technology
	MOS	Military Occupation Specialties
	MS	Milestone
N	NAVSEA	Naval Sea Systems Command
	NDI	Non-Developmental Item(s)
	NRL	Naval Research Laboratory
	NSRDEC	Natick Soldier Research, Development and Engineering Center
	NVESD	Night Vision and Electronic Sensors Directorate
O	OCO	Overseas Contingency Operations
	OEF	Operation Enduring Freedom
	OIF	Operation Iraqi Freedom
	ONR	Office of Naval Research
	OSD	Office of the Secretary of Defense
	OT&E	Operational Test and Evaluation
P	PA&E	Program Analysis and Evaluation
	PEO	Program Executive Office
	PM	Program Manager
	POM	Program Objective Memorandum
	POR	Program of Record
Q	QRSP	Quick Reaction Special Projects
	QRF	Quick Reaction Fund
R	R&D	Research and Development
	RBA	Requirements-Budgeting-Acquisition
	RDEC	Research, Development and Engineering Center
	RDECOM	Research, Development and Engineering Command
	RDT&E	Research, Development, Test and Evaluation
	RIF	Rapid Innovation Fund
	ROTC	Reserve Officer Training Corps
S	S&E	Science and Engineering/ Scientists and Engineers
	S&T	Science and Technology
	SASC	Senate Armed Services Committee
	SES	Senior Executive Service
	SME	Subject Matter Expert

	STEM	Science, Technology, Engineering and Mathematics
	SYSCOM	Systems Command
T	TARDEC	Tank Automotive Research, Development and Engineering Center
	TD	Technology Demonstration
	TECD	Technology Enabled Capability Demonstrations
	TOA	Total Obligational Authority
	TOR	Terms of Reference
	TPA	Technology Program Agreement
	TRADOC	Army Training and Doctrine Command
	TRL	Technology Readiness Level
	TTA	Technology Transition Agreement
	TTI	Technology Transition Initiative
	TTIPO	Technology Transition, Innovation Prototyping Office
U	UARC	University-Affiliated Research Center
	UASE	Uniformed Army Scientist and Engineer
	USD(AT&L)	Under Secretary of Defense for Acquisition, Technology, and Logistics
	USAFA	United States Air Force Academy
	USMA	United States Military Academy
	USMC	United States Marine Corps
W	WSARA	Weapons Systems Acquisition Reform Act of 2009

Appendix B – Terms of Reference

SECRETARY OF THE ARMY
WASHINGTON

OCT 28 2011

Mr. George T. Singley III
Chairman, Army Science Board
2511 Jefferson Davis Highway, Suite 11500
Arlington, Virginia 22202

Dear Mr. Chairman:

As you may already be aware, I have launched a multi-year, Army-wide effort to review and reshape the institutional Army, which prepares, trains, educates and supports our forces for current and future fights. By modeling industrial and other government best practices, I believe we can transform the institutional Army – the Generating Force – to make it as adaptive and effective as the Army's operating Force.

In support of that effort, I request the Army Science Board (ASB) conduct a FY2012 study on ***The Strategic Direction for Army Science and Technology (S&T) (Budget Elements: Basic Research (6.1), Applied Research (6.2) and Advanced Technology Development (6.3))***. The study should be guided by, but not limited to the Terms of Reference (TOR) described below.

Research, Development, Test and Engineering (RDT&E) is vital to the Army's success. Our strategic vision is based upon a decisive technological superiority to any potential adversary. Recent studies show that we are not achieving the goals that we have set for ourselves. This study should analyze the current Research, Development and Engineering Command (RDECOM) portfolio of S&T projects and objectives; compare them to other U.S. Government laboratories, industrial laboratories, and academic institutions; and provide findings and recommendations on the following:

- Technology thrusts that are Army-specific and not being addressed elsewhere
- Why are we funding >80% of our 6.1 and 70% of 6.2 work outside?
- Are we addressing long-term, game-changing ideas?
- Technology objectives that overlap those in other laboratories
    a. What are the relative funding levels, Technology Readiness Levels and specific goals?
    b. Should we combine efforts?
    c. Should the Army depend upon the results of the other laboratories?
- Achieving better leverage on Army investments by active management of our IR&D funding
- Existence of a broad technology development "road-map" showing how contributions from all sources ensure open access to better meet the Army's needs
- Adequacy of current Army technology transition strategies

There have been a number of recent studies that have formed the basis for the missions of RDECOM and have been critical of their accomplishments. In addition, the Secretary of

Defense has suggested that the Services take at least a 10% cut in their science and technology spending as part of his efficiency initiatives. Based upon research and metrics provided by the Corporate Executive Board, the Secretary of the Army's Short Term Overhead Reduction Task Force suggested that the Army consider dividing its RDT&E into a small "corporate" research center, embed product development, developmental and operational test and engineering into the product-focused groups and increase reliance and leverage from other government (including Department of Defense) and commercial activities. This strategy is similar to the U.S. Navy and many industrial laboratories.

If the Army decides to proceed with this strategy, we need the following:

- High confidence that we have access to all of the technologies required to build our systems
- Sufficient technical superiority over our adversaries that we always have the technical advantage
- In-house expertise to be competent buyers of highly technical products

If the Army instead decides to fix RDT&E under the current strategy, then we will need to know much of the same information.

The output of this study will be a detailed, quantifiable, transparent, external analysis of the Army Science and Technology program including:

- Analysis of the Army's portfolio of RDT&E programs with respect to their competitiveness with industry, other government laboratories and academia
- Programs that need to be driven by the Army and have only military-related benefits
- Programs of such strategic importance that the Army must be cognizant of, and contributing to, their outputs
- Programs that need to be classified in nature

From this data, the Army will be able to develop a more effective and efficient S&T plan I am the sponsor for this study and direct that the ASB present a comprehensive briefing to me and the senior Army leadership by July 2012. The final report should be provided by September 15, 2012.

Thank you for your support of our Army.

Sincerely,

John M. McHugh

Appendix C – Study Team Participants

Study Chairman
Dr. James Tegnelia

Research and Technology Panel
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Dr. Robert Atkins
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Technology Transition & Integration Panel
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Appendix D – ASB Approved Findings and Recommendations, 26 July 2012

Army Science Board (ASB) Study

"The Strategic Direction for Army S&T"

Final Briefing

For
Army Science Board

Presented by:
Dr. James A. Tegnelia
Study Chair

26 July 2012

Study Terms of Reference

- Environment
  - "Our strategic vision is based upon a decisive technological superiority to any potential adversary"
- Army S&T Program Strategic Direction
  - "analyze current RDECOM S&T portfolio and objectives; compare it to other government labs, industrial labs and academic institutions"
- Technology Transition, Innovation and Advanced Concepts
  - Provide findings and recommendations on the following:
    - "Adequacy of the Army technology transition strategies"
- Organization
  - "Army studies suggested a small 'corporate' research center, embedded product development , development and operational test and engineering into the product formation groups and increased reliance on and leverage from other government and commercial activities, similar to the Navy and industrial laboratories."
  - "If the Army decides to pursue this strategy, we need the following:
    - High confidence that we have access to all of the technologies required to build our systems
    - Sufficient technological superiority over our adversaries so that we always have the technical advantage"
- Personnel
  - "We need In-House expertise to be competent buyers of highly technical products"
- Efficiency
  - "at least 10% cut in S&T spending as part of efficiency"

2

Briefing Outline

- Introduction
  - TOR and Study Investigation Process
  - Summary Objectives and Challenges
- Environment
  - Global R&D
  - STEM Educational Situation
- The Army Science and Technology Program Strategy
  - Essential R&D
- The Army Technology Transition Strategy
  - The Need for Prototyping
- Organization and Facilities
  - Organizational Evaluation
  - Facilities Assessments
- Personnel Summary
- Efficiency
- Concluding Remarks

3

2012 Strategic Direction for Army S&T

Summary Objectives and Challenges

Strategic Vision:

- The Army has always possessed technological superiority over its adversaries.
  - Any S&T strategy must assure the preservation of technological superiority. Such a strategy does not now exist.

Challenges:

- This superiority must be maintained in a fiscally constrained environment.
- The sources of technology are globalized and no longer dominated by the US as in the past.
  - The current business model and organization are not suited to the new technology environment (still doing things the old way)
- There is fierce international competition and challenges for S&T talent.
  - Human Resources policy and practice must assure access to top civilian and military S&T personnel – “Hire-the-Best”
  - Army has been successful in hiring excellent people during the economic downturn, the challenge will be to keep them as the economy recovers.

4

2012 Strategic Direction for Army S&T

THE ENVIRONMENT

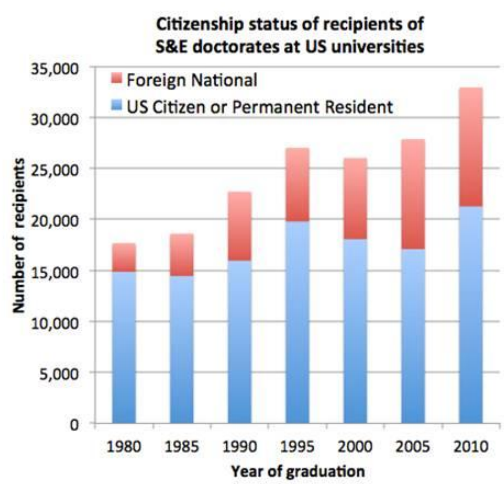
5

2012 Strategic Direction for Army S&T

Change of R&D Environment Over the Last 50 yrs

	Cold War (1965)	End of Cold War (1993)	Today (2009)
US Government	$60B	$75B	$80B
US Commercial	$90B	$200B	$300B
Rest of World	Unk	$300B	$450B

Source: Rand Basic Research Study
DSB 2012 Basic Research Study
Battelle International R&D Summary, Apr 2012



Source: Info Brief NSF 12-303

DoD is no longer a major contributor in technology acceleration

6

2012 Strategic Direction for Army S&T

Finding and Recommendations: The Environment

Findings:

- The technology playing field is changing, important technology breakthroughs are principally driven by commercial and international entities. The Army is still doing business as if it dominates the technology landscape.
- In a world where all have nearly equal access to open technology, innovation is the most important discriminator in assuring technology superiority.
- Time matters. We are not sufficiently agile and lack a technology transition strategy to rapidly prototype and insert technology, regardless of its origins.

Recommendations:

- Look outside. Significantly improve the Army's ability to identify and exploit disruptive technologies initiated by US commercial and international efforts through partnerships with others.
  - Reinvigorate international field office presence
  - Augment Army S&T through partnership technology projects, bilateral agreements, international consortia
  - Consider "Horizon Scanning" strategies employed by OSD

7

2012 Strategic Direction for Army S&T

The Need for Army Science and Technology (S&T) Strategic Plan to Guide Investment

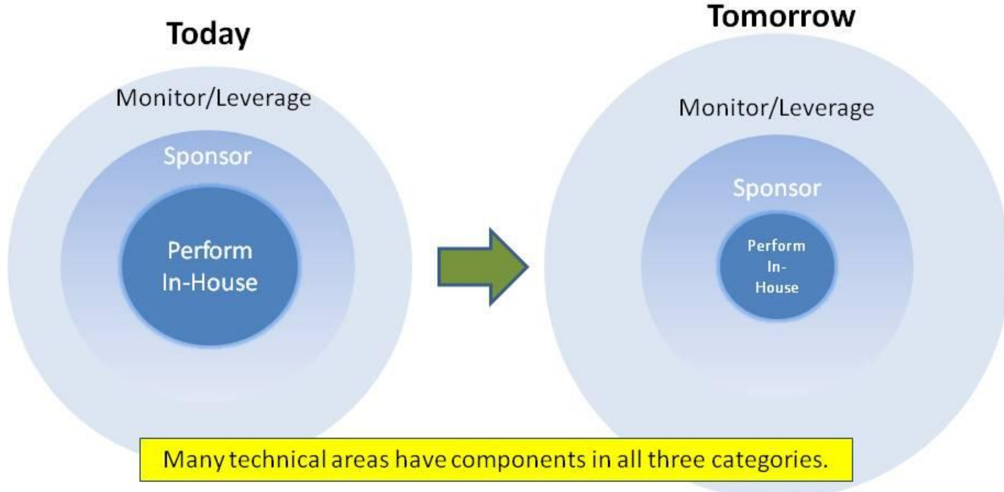
8

2012 Strategic Direction for Army S&T

Focus Army S&T on Core Technologies and Best-In-Class Performers

In times of declining budgets:

- In-House efforts must be best-in-class and focused on Army-unique core competencies.
- For other Army-essential technologies, best-in-class performers are sponsored by the Army.
- Relevant external work by well-funded best-in-class performers should be leveraged.



Many technical areas have components in all three categories.

9

2012 Strategic Direction for Army S&T

ASB S&T Analysis: Proposed Execution for RDECs – Examples

Organization	Must Do In-House	Should Sponsor	Should Monitor/Leverage
AMRDEC – Aviation	Evaluation of critical components (structural, ballistic protection, IR suppressors, ASE equipment) and flight testing.	Rotorcraft drive (gears, tribology, multi-speed) and active rotor technologies.	Alternative fuels, batteries, and energy storage technology. ★
AMRDEC – Missiles	Development of overt, high-bandwidth millimeter-wave/terahertz navigation radar and communication/data links.	Advanced electronic and opto-electronic materials and device fabrication.	Information sciences research relevant to Army missile system needs. ★
ARDEC	Munition systems technologies, including energetics (propellants and explosives), warheads (KE, SC, EFP), and fuzing.	Novel advanced high-performance materials for warheads and gun systems. ★	Hypervelocity impact research and technology developments. ★
CERDEC	Model development and validation for characterization/testing of imaging sensors (EO/IR, countermine, etc.).	Power systems R&D: electro-chemical, power electronics, renewable energy devices. ★	Image and signal processing technology. ★
ECBC	Advanced concepts in chemical and biological sensing and signaling, novel threat agent synthesis and characterization.	Chemical and biochemical computational methods based on processes in nature.	R&D in the areas of nano-technology, microfluidics, aerosols, and metamaterials. ★
NSRDEC	Advanced fiber and textiles, including smart, responsive, or other multifunctional types, for extreme environments.	Power technology for the individual soldier and small units.	Nanomaterials, fiber-reinforced composites, flexible displays. ★
TARDEC	Ground vehicle systems design tools, analysis (M&S); concept development, component integration, testing.	Unmanned ground systems technology, robotics technology. ★	Fuel economy technology (e.g., hybrid drive), water purification. ★

★ reflects change from current state

10

2012 Strategic Direction for Army S&T

Findings and Recommendations: Army S&T Strategy

Findings:

- We did not see a top level S&T strategy or "…a broad technology development 'roadmap' … to better meet the Army's needs." The 2012 S&T Master Plan lacks key elements* of a sound strategy or strategic plan:
  - A vision
  - An assessment of emerging areas of S&T
  - Realistic objectives
  - An approach to achieve the vision and objectives
  - Detailed plans to achieve these objectives
- Progress in portfolio management but S&T portfolio is not integrated or efficient.

Recommendations:

- Develop a strategic plan with the elements above and perform an independent peer-reviewed, thorough, disciplined analysis of the portfolio to identify work that must be performed In-House, should be sponsored by Army, and should be monitored and leveraged.
- More actively interact with industry IR&D projects.

* Report of the DSB Task Force on Basic Research, Jan 2012

11

2012 Strategic Direction for Army S&T

TECHNOLOGY TRANSITION, INNOVATION AND ADVANCED CONCEPTS

12

2012 Strategic Direction for Army S&T

Prototyping Addresses Challenges

- Bridges chasm between S&T and acquisition
- Reduces technical and systems integration risk for programs
- Validates designs and matures manufacturing processes
- Improves basis for cost estimates
- Refines and validates system requirements
- Demonstrates advanced concepts
- Develops and exercises design and development teams
- Exercises core systems engineering teams and skills
- Attracts new generation of scientists and engineers

Weapons System Reform Act of 2009 requires competitive prototyping prior to Milestone B. Requirements may be waived if unaffordable.

13

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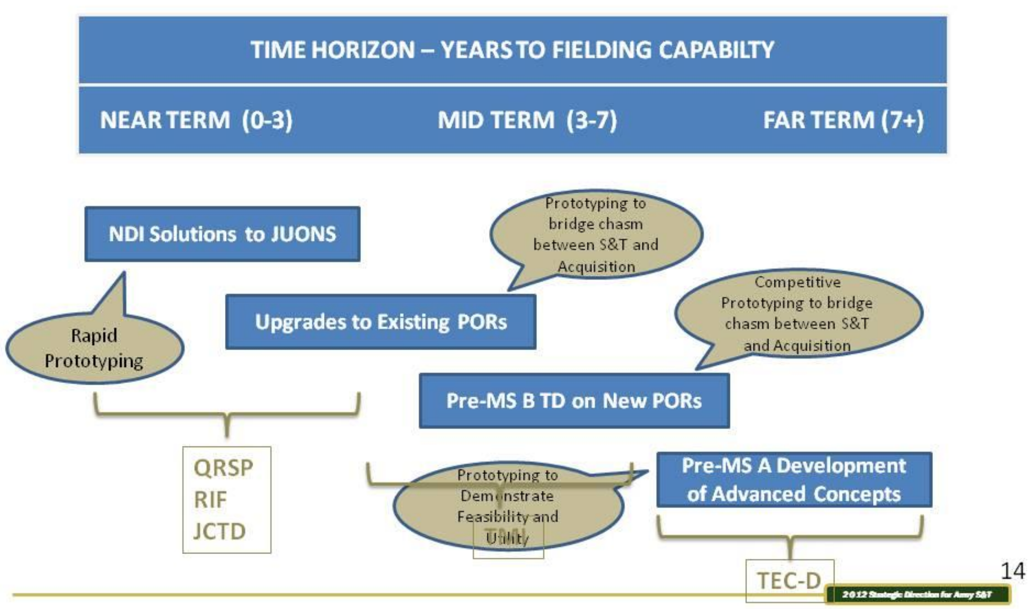
Type of Prototyping Varies Across Time Horizon



14

2012 Strategic Direction for Army S&T

TTIPO Benefits, Funding & Implementation

Charter – Benefits:

- Proactive agent for bridging S&T to acquisition chasm - improves effectiveness and efficiency of technology transition and minimizes chasm-driven POR failures.
- Single point of contact with other DoD transition offices – improves integration and Army competitiveness for OSD initiatives.
- Single point of contact with requirements, S&T and industry - provides a transition champion and path for warfighting experiments and prototyping proposals.
- Conduct prototyping across broad time horizon – avoids overlap/duplication of separate prototyping initiatives and allows consistent application of best practices.
- DARPA-like management office with no dedicated execution infrastructure – minimizes overhead and utilizes existing POR and RDEC system integration facilities.
- Advanced concepts group - fosters development and prototyping of innovative advanced concepts that can lead to disruptive capabilities.
- Competitive selection of projects – ensures competition of ideas and encourages collaboration, timeliness and sponsorship.

Funding and Staffing:

- 6-8% re-allocation of $1,700M BA3/4 portfolio (20 year avg.) for TTIPO initiative.
- DARPA-like staffing billets re-assigned from distributed billets within RDECs.

One Possible Implementation Approach:

- Expand Army BA4 TMI to include full spectrum from rapid prototyping to advanced concepts.

15

2012 Strategic Direction for Army S&T

Findings and Recommendations: Technology Transition, Innovation and Advanced Concepts

Findings:

- No Army technology transition strategy currently exists.
- The principal issue that the strategy needs to address is the chasm between S&T and acquisition.
- Prototyping needs to be a key element of the strategy for bridging the chasm:
  - Successful Programs of Record historically have benefited from prototyping activities.
  - The Weapons Systems Reform Act and OSD policy requires that competitive prototyping be addressed before progressing to Milestone "B".
- Systems engineering and integration skills are critical for effective prototyping.
- Advanced system concepts are important to ensure that prototyping efforts are not all near-term focused in order to achieve game-changing results.
- With few new starts, prototyping provides opportunities for RDECs and industry engineers to hone their skills and experimentation venues for user/PEO/contractor teams to rapidly exploit technology opportunities.
- DASA(R&T) has proactively developed initiatives that address many of the transition issues.

Recommendations:

- Include a technology transition strategy as part of an overarching Army S&T strategy and plan.
- ASA(ALT) establish a Technology Transition, Innovation and Prototyping Office (TTIPO) that champions and integrates prototyping efforts across broad time horizon, from rapid prototyping of NDI to accelerated technology insertion on PORs to demonstration of game-changing concepts. This activity should be a management activity with prototyping efforts executed in the requisite RDECs and PORs. An advanced concepts element should be included in this office to work in partnership with TRADOC to develop and demonstrate game-changing "big ideas".
- Increase the number of exceptional, experienced Chief Engineers and Systems Engineers in the Army labs, RDECs and PEOs.

16

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ORGANIZATION AND FACILITIES

17

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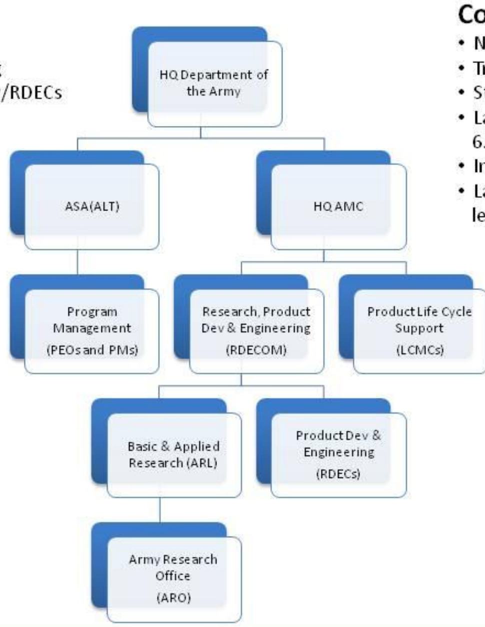
Army Current S&T Organization

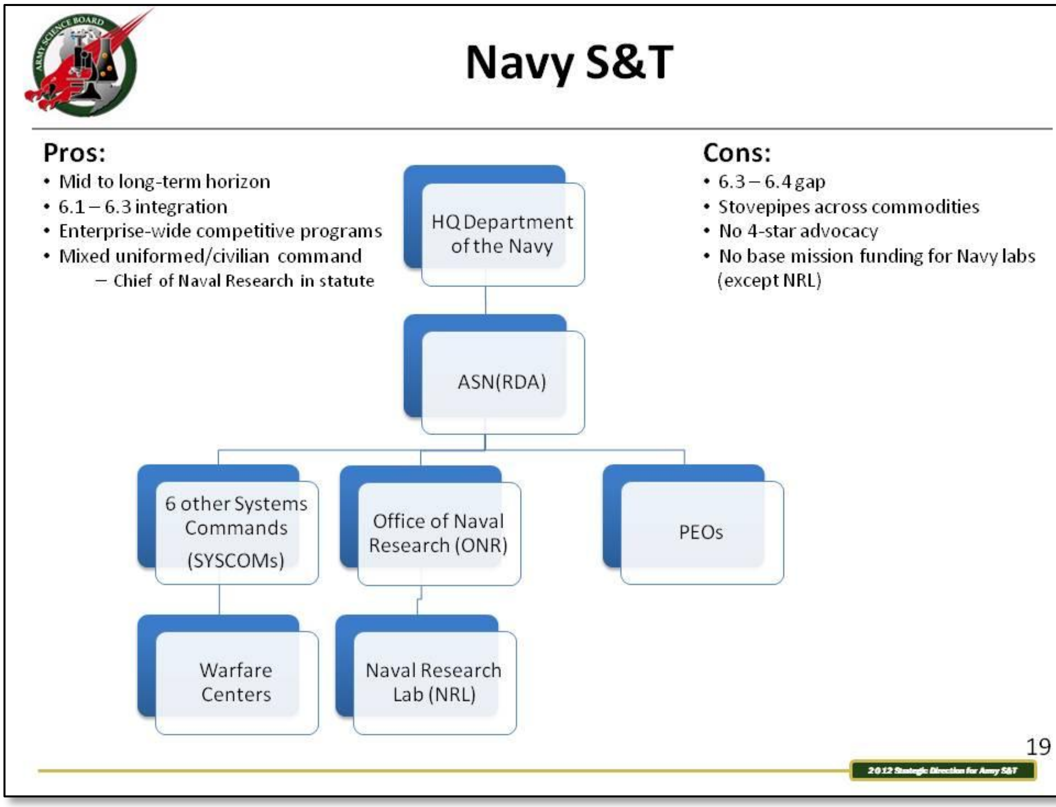
Pros:
- 4-star advocacy
- Base mission S&T funding
- PEOs mostly co-located w/RDECs

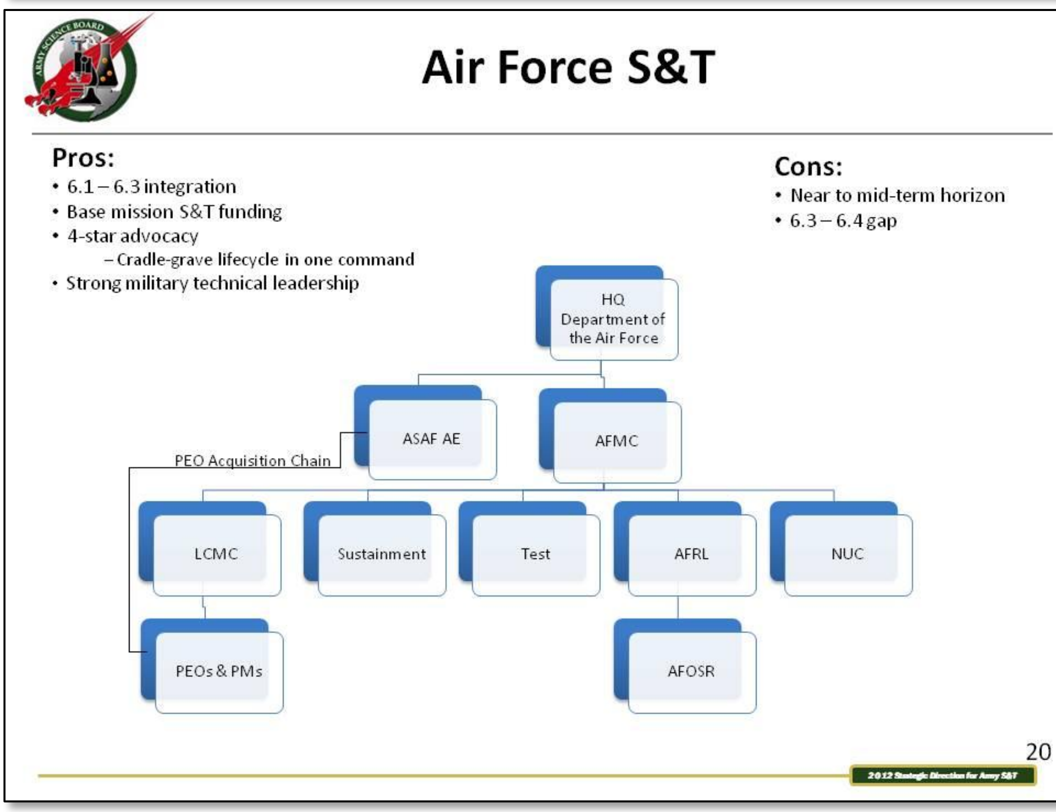


Cons:
- Near to mid-term horizon
- Transition gaps 6.1 – 6.2 – 6.3 – 6.4
- Stovepipes across commodities
- Lack of enterprise-wide 6.1 – 6.3 competition process
- Insufficient global R&D leverage
- Lack of uniformed technical leadership

18

2012 Strategic Direction for Army S&T

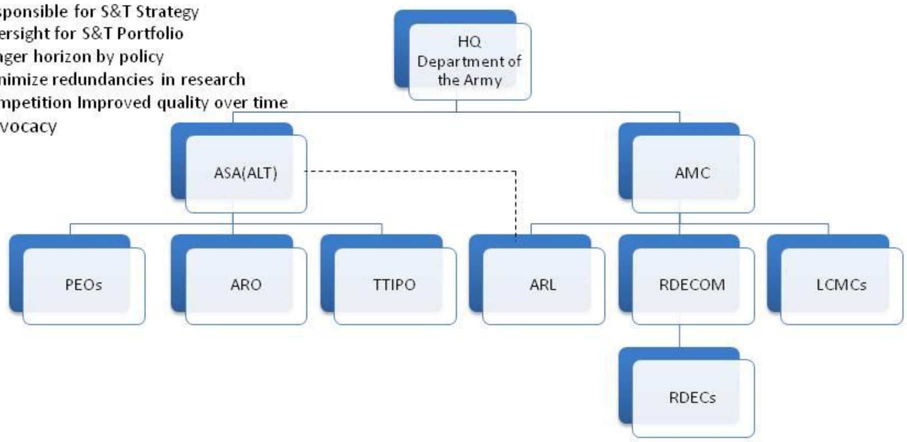

Navy S&T
Pros:
• Mid to long-term horizon
• 6.1 – 6.3 integration
• Enterprise-wide competitive programs
• Mixed uniformed/civilian command
– Chief of Naval Research in statute
Cons:
• 6.3 – 6.4 gap
• Stovepipes across commodities
• No 4-star advocacy
• No base mission funding for Navy labs (except NRL)
HQ Department of the Navy
ASN(RDA)
6 other Systems Commands (SYSCOMs)
Office of Naval Research (ONR)
PEOs
Warfare Centers
Naval Research Lab (NRL)
19
2012 Strategic Direction for Army S&T


Air Force S&T
Pros:
• 6.1 – 6.3 integration
• Base mission S&T funding
• 4-star advocacy
– Cradle-grave lifecycle in one command
• Strong military technical leadership
Cons:
• Near to mid-term horizon
• 6.3 – 6.4 gap
HQ Department of the Air Force
ASAF AE
AFMC
PEO Acquisition Chain
LCMC
Sustainment
Test
AFRL
NUC
PEOs & PMs
AFOSR
20
2012 Strategic Direction for Army S&T

Recommended Army S&T Model

Pros:
- Longer horizon w/ARL focused on critical technologies
- 6.1 to 6.3 integration
- TTIPO improves 6.3 – 6.4 transition
- ARO policy and program oversight
  - Sponsors all AMC 6.1 internal and external
  - Responsible for S&T Strategy
  - Oversight for S&T Portfolio
  - Longer horizon by policy
  - Minimize redundancies in research
  - Competition Improved quality over time
- 4-star advocacy

Cons:
- Stovepipes exist across commodities
- PEOs/PMs outside 4-star Command
- Current lack of uniformed technical expertise



21

2012 Strategic Direction for Army S&T

Findings and Recommendations: Organization

Findings:

- The Army requires an S&T structure that has a long-term horizon, fosters competition, is integrated and avoids redundancies, and provides a robust capability to support basic and applied research on those technologies identified as critical "must-do-In-House".
- After reviewing Industry models we found they are less relevant to Army S&T than peer service S&T organizations, however, in most successful industry models the corporate lab reports to the CEO or CTO.
- The recommended model addresses shortcomings in the current Army S&T organization.

Recommendations:

- Realign ARO as DRU to ASA(ALT):
  - Expand the role to assist ASA(ALT) in development of a strategic plan, programming, policy and prioritization of the 6.1 – 6.3 S&T program
  - Foster enterprise-wide long-term focus, competition via a peer review process, integration and minimization of redundancies in the S&T Program
  - Sponsor competitive execution of the 6.1 AMC-wide program with increasing responsibility for integration of the 6.2 - 6.3 program over time, to increase competition and decrease duplication in the 6.2 - 6.3 program
- Realign ARL as direct report to CG AMC:
  - Divest research and customer-directed workload which is unrelated to Army critical technologies
  - Focus on long-term goals of senior leadership with increased high-risk research on game-changing technologies
  - Improve leverage of global R&D through increased industry, academic and international partnerships
- Establish a Technology Transition, Innovation and Prototyping Office, reporting to the ASA(ALT).

22

2012 Strategic Direction for Army S&T

Findings and Recommendations: Facilities

Findings:

- Army S&T does not compete well for MILCON funding.
- Army laboratories invest significant RDTE dollars in facilities readiness.
- Army has not comprehensively assessed:
  - Facilities and equipment necessary for critical In-House technologies, and those not essential
  - Unnecessary duplications in capabilities and excess capacity
- Army does not have an enterprise-wide strategic modernization and recapitalization plan to:
  - Identify and prioritize gaps and needs
  - Assess duplications and excess
  - Justify resource requirements
- Army does not seek innovative alternative funding and partnership strategies.

Recommendations:

- Create and resource a strategic modernization and recapitalization plan that:
  - Provides periodic assessment and prioritization of facilities
  - Justifies SRM and MILCON requirements
  - Reduces redundant capabilities and excess capacity
  - Enables strategies for innovative use of Army lab facilities, e.g., 3rd party leasing and financing, cooperative use and fee-for-use arrangements
- In lieu of investment, leverage facilities of other federal, academic, industry and international partners.

23

2012 Strategic Direction for Army S&T

PERSONNEL

24

2012 Strategic Direction for Army S&T

Findings and Recommendations: Personnel

Findings:

- Recruitment, retention, development and leadership of scientists and engineers require more attention if the Army is to attract and retain top S&E talent.
- The stature and recognition of ARL in the external research community is considered less than peer Service labs, which is a factor in attracting and retaining high quality staff. The best research laboratories have >50% Ph.D.s - ARL has <40%.
- Military presence in Army S&T is notably low. The Uniformed Army Scientist and Engineer (UAS&E) program was terminated in 2010. There is no legitimate technology career path for Army officers.

Recommendations:

- Recruitment and retention of civilian technical talent must become a SA/CSA priority.
  - Establish a technical career path within a science and engineering "corps," with ASA(ALT) as the functional chief for career management
  - Authorize hiring and retention incentives targeted to increase the ARL S&E Ph.D. population to >50%
  - Implement programs to retain current cohort of S&E talent
  - Extend direct hiring authority for all scientists and engineers
  - Create a personnel process to hire and retain "the best," not just the qualified
- Rebuilding of a uniformed S&T core of technically competent officers should become a SA/CSA priority.
  - Reestablish the Unformed Army Scientist & Engineer program to provide technology-competent officers for critical technology development and leadership roles, with sufficient UAS&E billets to ensure a healthy career progression
  - Assure technical billets and personnel are provided to TRADOC
  - Increase graduate level education opportunities which support critical must-do In-House technologies
  - Increase S&E summer intern opportunities for ROTC and USMA cadets

25

2012 Strategic Direction for Army S&T

CONCLUDING REMARKS

26

2012 Strategic Direction for Army S&T

Findings and Recommendations: Efficiency

Findings:

- Implementation of the S&T Strategy will permit improved, superior S&T program while reducing In-House and sponsored research, leading to a better focused, smaller ARL. Implementing the strategy is pre-requisite to a technologically superior force in today's fiscal environment.
- Creating a TTIPO will allow for efficient, timely modernization of existing hardware in an era of minimum platform new starts. Can be done with existing resources; will assist ASA(ALT) in managing its existing prototyping activity.
- RDECOM HQ has not demonstrated significant value added to the S&T Community and our recommendation includes removal of some of its S&T functions.
- Proposed organizational changes allow for creation of an S&T Strategy within existing resources by employing ARO as office of record. This will permit Improved performance and cost reduction by creating constructive competition, allowing for smaller RDECOM.
- S&T efficiencies require a responsive acquisition community as a receptor. Air Force obtains a responsive interaction by 'dual-hatting' the PEO structure.
- Hiring and retaining best-in-class personnel is best assurance of an effective, efficient S&T program.

Recommendations:

- Implement re-assignment of ARO to create and assist in execution of the S&T Strategy.
- Create and resource TTIPO to assist in effort to efficiently modernize the current platforms.
- Implement a study to consider placing the PMs/PEOs within AMC and 'dual-hatting' them to the AAE for POR acquisition decisions. Study should include assessment of RDECOM contributions to S&T and acquisition activities. Such a study was not within the scope of this study's TOR.
- Army leadership must assure implementation of a human resources strategy to hire and retain best S&T civilian talent and a technically qualified uniformed cadre.

27

2012 Strategic Direction for Army S&T

Conclusion: Implementation of Recommendations

SECARMY

- Sponsor the creation of a scientist and engineer "STEM career field" and supporting management systems

Chief of Staff, Army

- Direct the creation and implementation of the Uniformed Army Scientist and Engineer (UAS&E) program

ASA(ALT):

- Develop and promulgate the Strategic S&T Plan.
- Manage the Army Research Office (ARO).
- Establish a Technology Transition, Innovation and Prototyping Office (TTIPO), including advanced concepts.
- Reinvigorate the International S&T presence/participation.
- Serve as the proponent for "STEM career field".

The Laboratories be given expanded responsibilities:

- To assure execution of a Strategic S&T Plan based on the approach outlined in this presentation.
- For authority to direct hire personnel w/STEM graduate degrees and manage careers in order to assist retention.
- To significantly increase the number of exceptional, experienced Chief Engineers and System-of-Systems Engineers.

AMC and the Commodity Commands be given responsibility for:

- Execution of rapid prototyping in response to the Technology Transition, Innovation and Prototyping Office
- Management of the Army Research Lab.

The Army G-1:

- Reestablish policy for a UAS&E program and develop the UAS&E program (selection, training and career development).

The Army G-3/G-8:

- Develop and promulgate the UAS&E program.

TRADOC:

- Participate in development of advanced concepts and prototype experimentation programs.

28

2012 Strategic Direction for Army S&T

Appendix E – Site Visit and Interview Lines of Inquiry

<u>Fact Finding Questions for the Deputy Assistant Secretary of the Army for Research and Technology (DASA(R&T))</u>

1. What is the current DOD S&T Strategy? Please provide a copy.
2. What is the current Army S&T Plan? Please provide a copy.
3. The TOR asks "What are the technology thrusts that are Army specific and not being addressed elsewhere"? Please provide your answer.
4. How do you know that S&T in the plan is not being done elsewhere?
    a. Why do you think it could not be done elsewhere (e.g., unique facilities only the Army has, etc.)
    b. What is the cost to the Army to maintain this organic capability?
    c. Are researchers fully utilized?
    d. What are facility costs to execute the Army S&T Plan?
5. The TOR requests a "broad technology development 'road map' showing how contributions from all sources ensure open access to better meet the Army's needs. Does one exist and if so please provide a copy.
6. What is the Army technology transition strategy?
    a. What is the process for determining the best technology transition strategy for a program?
    b. What are the most significant tech transition challenges and issues that the strategy addresses?
    c. What are the measures of success for determining whether the strategy is effective?
    d. What does the data over the past two decades show as to how successful the strategy been in terms of these measures?
    e. Has the strategy been benchmarked against Navy and Air Force strategies?
    f. What alternative strategies have been or should be considered?
    g. What are the pros/cons of the current strategy relative to the alternatives?
7. How do you benchmark with NRL, AFRL, FFRDCs, UARCs and selected industry? What have you learned from this benchmarking?
8. Why do you think NRL has earned the reputation as one of the Nation's top research laboratories?
9. Are there meaningful metrics on Army S&T performance/outcomes before and after formation of RDECOM? We are seeking factors/metrics to evaluate/compare alternate S&T organizational and business models per the TOR.
10. Why does the Army not have a funded strategy to re-capitalize equipment and facilities for its laboratories and RDECs? What are the specific barriers? Laws, regulations, directives, 'color of money', policy, etc.?
11. What funding (budget category and program elements) is used to pay all the in-house costs (labor, facilities, etc.) of ARL, ARO and the RDECs each annually, i.e. to keep the doors open? Please provide a break-down by budget category (e.g., 6.1, 6.2, 6.3, 6.4, 6.5, 6.7, OMA, OPA, etc.) for ARL, ARO & each RDEC for FY2011 or FY2010, including overhead/G&A costs, a breakdown of where the money comes from and how it gets spent.
12. What is the person-year (FTE) cost range for researchers? And then how do these numbers compare to other R&D laboratories?
13. What percentage of the FY2012 Army S&T budget is RDECOM? Corps of Engineers? Medical R&D Command? ARI? SMDC?

14. The TOR asks "Why are we funding >80% of our 6.1 and 70% of 6.2 work outside." Are those numbers correct? If not, please provide the correct numbers for Army as a whole and for each of the following: ARO, ARL, each RDEC, ARI, Medical R&D Command labs, Corps of Engineer labs (including WES) & SMDC.
15. Should the Army more actively review, grade, shape and leverage the industry Independent R&D Program to meet Army needs and if so how?
16. There has been little evidence that ILIR at the RDECs produces valuable inventions or innovations. Why not have ILIR at the ARL, not the RDECs who seem to undervalue it?
17. If the Army is directed to take large funding cuts:
    a. Is there a strategy to avoid large reductions in the RDA account (~30% or more as was done in other downturns)?
    b. Should a 'balanced' approach including facility, overhead and personnel cuts be involved even if it takes a long time to implement?
    c. How does the Army determine what facilities to close, what facilities are essential and how they must be "second to none"?
18. If significant RDA cuts are coming, the Army will likely need to increase its reliance on other government labs, industry and academia. What is the Army strategy to accomplish this?
    a. The Army has first rate facilities in the WMD area that are also intergovernmental in their mission. The other Military Services, the DHS, HHS and the FBI rely on them. How will the Army support activities and programs that have requirements from a whole of Government perspective even if they might not be top priority from the Army's perspective?
    b. What are the S&T areas where the Army is the 'lead Service' for DOD and will they be protected?
19. How does the Army R&D community interact with other government labs and the industry to not only understand and participate in what they are doing, but also transition their successful relevant developments into the Army? What are some examples of where, rather than sponsor S&T in a specific area, the Army relies on other government labs and industry?

Fact Finding Questions for the ARL & RDECs

The following is a common set of questions (Lines of Inquiry) distributed prior to ASB Study team site visits to the ARL & RDECs during the months of February and March of 2012. It was hoped that these advance questions would help the visited laboratories and RDECs prepare for briefings and interviews, as well as assist the visiting ASB teams to normalize their own note-taking as small groups engage in multiple interviews. Candid discussions with the lab and RDECs were requested. The ASB sought perspectives from both the technology push side (S&T organizations) as well as the pull side (PEOs/PMs & LCMCs).

For ARL Directorates visited: This should be nominally a 3–4 hour visit per ARL Directorate visited including: Briefings addressing the following questions with ½ of the time allotted to Q&A; a tour of critical, unique S&T facilities/equipment; and a meeting between the visiting ASB team and the Director wherein a candid discussion can take place concerning his/her perspective on the issues contained in the ASB Study TOR. Questions/discussions sought include:

1. Discussion of the Directorate's interaction with the corresponding PEO(s), RDEC(s), and RDECOM in general. Same for industry and academia.
2. What are the Directorate's top 10 accomplishments (transitioned to a Program of Record (POR) or fielded) in past decade?
3. What does the Director think will be top 10 for the next decade?

4. What are your operative technology transition strategies and are they adequate?
5. What are your capabilities and processes for "fast-tracking" unexpected technological developments, and to respond to new needs and opportunities?
6. Regarding your basic and applied research areas, does ARL have, and if so please explain:
    a. A Director's pool of discretionary funding - how much and what is source of that funding?
    b. Peer-reviewed competition for award of discretionary research funds?
    c. Freedom for researchers to pursue new, high risk ideas?
    d. Rigorous accountability for researchers for the quality of their work?
    e. What metrics do you use to evaluate investigators?
    f. In what ways do you recognize superior performance?
    g. Talented technical leadership with the vision and expertise to encourage high risk research, give researchers freedom, and terminate projects when necessary?
    h. What is the career path for technical personnel?
    i. A funded strategy to re-capitalize equipment and facilities for its laboratories? What are the specific barriers, e.g., laws, regulations, directives, 'color of money', policy, etc.?
    j. Broad technology roadmap for organization? How do you track progress relative to roadmap?
7. Can you provide metrics or measures of success on your S&T program over the past five years? Do you foresee any changes to metrics going forward?
8. What are the characteristics of a premier research lab? NRL has the reputation of a premier lab – why do you think that is so?
9. Who are your strategic partners in the S&T domain? Describe the relationship.
10. Can you suggest any changes to the business model, organization or reporting relationships that would enhance the effectiveness of the RDECOM S&T program selection and execution?
11. What are the advantages or benefits of the various RDECs having 6.1 & 6.2 S&T programs in addition to ARL, compared to a fully centralized research program?
12. How do you plan to accommodate future technology, acquisition and military trends? As you look to the future, can you identify new infrastructure and talent/skills needs?

For each RDEC visited: This should be nominally a 3–4 hour visit per RDEC visited including: Briefings addressing the following questions with ½ of the time allotted to Q&A; a tour of critical, unique RDT&E facilities/equipment; and a meeting between the visiting ASB team and the RDEC Executive Director wherein a candid discussion can take place concerning his/her perspective on the issues contained in the ASB Study TOR. Questions/discussions sought include:

1. Discussion of their interaction with the corresponding PEO(s), other RDECs, ARL and RDECOM in general. Same for industry and Academia.
2. What are your operative technology transition strategies and are they adequate?
3. What are top 10 S&T accomplishments (transitioned to POR or fielded) in past decade? What do you think will be your Top 10 S&T accomplishments for the next decade?
4. How do the RDECs interact with TRADOC and the PEOs/PMs to facilitate the development of requirements for technology insertion into Programs of Record (PORs)? How does this process differ for pre-milestone B and post-milestone B programs?
5. What funding is available to the RDEC to engage in pre-ECP/Product Improvement analyses and tradeoffs with the TRADOC to prioritize and select upgrades for ECP/PIP/Block Improvements? Is this funding adequate?

6. What improvements could or should be made to the Army technology transition strategy and process to more effectively capitalize on R&D (Army, Government, academia, industry and international) and upgrade current or new systems?
7. From the RDEC's perspective, are JCTDs and warfighting experiments effective means for evaluating advanced technologies and concepts for development and insertion into PORs?
8. Does your RDEC have, and if so please explain:
    a. A pool of discretionary S&T funding - what is amount and source of that funding?
    b. Peer-reviewed competition for award of discretionary research funds?
    c. Freedom for researchers to pursue new, high risk ideas?
    d. Rigorous accountability for researchers for the quality of their work? What metrics do you use to evaluate investigators? In what ways do you recognize superior performance?
    e. Talented technical leadership with the vision and expertise to encourage high risk research, give researchers freedom, and terminate projects when necessary?
    f. A career path for technical personnel?
    g. A funded strategy to re-capitalize S&T equipment and facilities? What are the specific barriers? Laws, regulations, directives, 'color of money', policy, etc.?
    h. Process for terminating or transitioning projects to new budget category?
    i. Broad technology roadmap for organization? How do you track progress relative to roadmap?
9. How do research problems come to you? How do you prioritize them (portfolio management)? Is there a mix of high & low risk/long & near term?
10. Is there a mechanism for avoiding technological surprise and exploring means to defeat the capabilities developed?
11. What quantifiable outcomes do you have from ILIR work (patents, papers, seminal papers)? How much 6.1 research do you perform?
12. Can you suggest any changes to organization or reporting relationships that would enhance the effectiveness of the RDECOM S&T program execution?
13. What are your capabilities and processes for "fast-tracking" unexpected technological developments, and to respond to new needs and opportunities?
14. How do you plan to accommodate future trends? As you look to the future, can you identify new infrastructure and talent/skills needs?
15. What are the advantages or benefits of the various RDEC 6.1/6.2 S&T programs compared to a fully centralized S&T program?
16. Who are your strategic partners in the S&T domain? Describe the relationship.
17. Can you provide metrics or measures of success on your S&T program over the past five years? Do you foresee any changes to metrics going forward?

For ARL & RDECs visited: At the 15 December 2011 meeting of the ASB Study, the RDECS and ARL identified the four to five most critical research areas in basic (6.1) and applied research (6.2) where the research work:

a. must be performed by the Army in-house
b. can or should be performed outside the Army (i.e. universities, industry, etc.), but require Army sponsorship
c. is important to future Army programs, but work is highly likely to be supported by other sponsors

Note: "In-house" means performed in government facility by government or contractor employees.

For those technologies in group **a** (in-house):

1. What is driver for the research/technology?
2. What is funding level for this area? What are major milestones for this research (and when do you expect to reach them)? How does this link to the organizations overall technology roadmap?
3. What are most compelling reasons for doing the work in-house? What would be risks of not maintaining in-house?
4. What is expected payoff?
5. Is this in-house effort being augmented by sponsored work outside? If so how, what %, and why? What key partnerships are involved (both within the Army and outside the Army)?
6. What topic would you fund with the last available dollar? (in conversation only)

For those technologies in group **b** (sponsored by Army):

1. What is driver for the research/technology? Is it unique to the Army? If so, why? Does it have broader DOD applicability?
2. What is funding level for this area? What are major milestones for this research (and when do you expect to reach them)?
3. What are most compelling reasons for sponsoring the work? What would be the risks of not sponsored?
4. What is expected payoff?
5. What other work is being leveraged? What key partnerships are involved (both within the Army and outside the Army)? UARCs? FFRDCs? National Labs? DARPA?

For those technologies in group **c** (Monitored by Army):

1. What is your established strategy for effectively monitoring such work by others (Industry, Academia, UARCs, FFRDCs, National Labs, Other DOD Agencies)?
2. What is the process by which critical results are effectively leveraged to enhance in-house work or work on sponsored programs?

Fact Finding Questions for LCMCs and PEO/PMs

The following is a common set of questions (Lines of Inquiry) are to be distributed prior to ASB Study team site visits to the LCMCs and PEO/PMs during the months of February and March of 2012. It is intended that these advance questions will help the visited LCMCs and PEO/PMs prepare for briefings and interviews, as well as assist the visiting ASB teams to normalize their own note-taking as small groups engage in multiple interviews. Candid discussions with the LCMCs and PEO/PMs are needed. The ASB is seeking perspectives from both the technology push side (S&T organizations) as well as the pull side (PEOs/PMs & LCMCs).

For each Life Cycle Management Command (LCMC): The ASB requests an office call (NTE 1 hour) by the visiting ASB team with the Commanding General or Executive Director to receive an overview of the

LCMC and discussion of their interaction with the corresponding PEO(s), RDEC(s), ARL and RDECOM Headquarters in general. Answers to the following questions would be appreciated:

1. What are your acquisition, technology and logistics responsibilities/authorities and the LCMC's organizational relationship to the RDECOM, PEOs, Sustainment Command and Army Contracting Command as it pertains to acquisition, logistics and technology?
2. What are your operative technology transition strategies and are they adequate?
3. How does the current RDECOM S&T program meet the needs of your material enterprise for programs of record, urgent needs, and new concepts?

For each Program Executive Officer (PEO) visited: The ASB requests a visit of approximately 2 hours with the PEO and selected PM(s). The ASB requests that the visit include an overview of the PEO (1/2 hour), discussion of the PEO/PMs' interaction with the corresponding LCMC(s), RDEC(s), ARL and RDECOM in general, and a small meeting between the ASB members and the PEO seeking his/her candid opinions on the following:

1. What are your operative technology transition strategies and are they adequate?
2. During the course of your tenure as PEO, what technologies have transitioned successfully from the Army S&T program to one or more of your Programs of Record (PORs) and what was the impact?
3. Have you had a technology product successfully transitioned from DARPA to any of your PORs? How might the Army enhance its leveraging of DARPA to obtain advanced technologies and systems concepts needed by PEO/PMs?
4. How does TRADOC interact with the RDECs the PEOs/PMs to facilitate the development of capability needs and requirements for technology insertion into PORs? How does this process differ for pre-milestone B and post-milestone B programs?
5. What funding is available to the PEO/PM to engage in pre-ECP/Product Improvement analyses and tradeoffs with the ARL, RDEC & TRADOC to prioritize and select upgrades for ECP/PIP/Block Improvements to existing PORs? Is this funding, the requirement process and support from the S&T community adequate? Any suggestions for how to improve it?
6. What improvements could or should be made to the Army technology transition strategy and process to more effectively capitalize on R&D (Army, Government, academia, industry and international) and upgrade current or new systems?
7. From the PEO/PM's perspective, are JCTDs and warfighting experiments effective means for evaluating advanced technologies and concepts for development and insertion into PORs?
8. Describe the extent, quality and responsiveness of technical support received from the RDECOM Headquarters, ARL, and the RDECs? Can this be improved? How?
9. How does the RDECOM S&T program impact your PEO? How could it be improved?

Appendix F – Recent Related Studies

The RAND Arroyo Center and the DSB issued reports in 2012 on the subject of basic research:

- *Improving Army Basic Research, Report of an Expert Panel on the Future of Army Laboratories* (copyright 2012), referenced herein as the "RAND Report"
- *Report of the Defense Science Board Task Force on Basic Research* (January 2012), referenced herein as the "DSB Report"

In 2009, John W. Lyons and Richard Chait performed a study of peer review at the Army Laboratories:

- *Strengthening Technical Peer Review at the Army S&T Laboratories*, Center for Technology and National Security Policy, National Defense University (March 2009), referenced herein as the "NDU Report"

Prior to that, the Office of the Director, Defense Research and Engineering, funded the JASONs to carry out a study in the summer of 2008 on DOD Basic Research:

- *S&T for National Security* (dated May 2009), approved for public release in 2010 in response to a FOIA request, JSR-OB-146, referenced herein as the "JASON Report"

While these studies were conducted under other terms of reference, many of their findings are relevant to this ASB study and consistent with the observations of the Research Panel. This appendix highlights the findings from these four studies that are most relevant to this study.

The DSB report was delivered to the Under Secretary of Defense for Acquisition, Technology, and Logistics under memorandum signed by the Co-Chairs, Dr. Craig Fields and Dr. Lydia Thomas. The DSB:

> was charged in August 2010 to validate the quality of the DOD basic research program and to provide advice on long-term research planning and strategies for the Department of Defense … (and) … soon after (to) advise how the Department should structure its basic research program to incentivize invention, innovation, and the transition of ideas to end-use.

The DSB report asserts that a technology strategy is more than a list of critical technologies, and calls for a technology strategy that "… should have at least five elements:"

- A vision of what DOD's S&T enterprise consists, why it exists, and the rationale for science and technology endeavors.
- An assessment of emerging areas of science and technology, particularly areas of rapid change and substantial promise.
- Realistic objectives prioritized and quantified as much as possible.
- An approach to achieve the vision and objectives. It should include discussion of uncertainties, challenges, and obstacles.
- … detailed plans are needed on how to achieve the objectives, acknowledging that such plans always undergo change.

In terms of organizations, the Army is described as the most complex structure (pp. 14–15) among the three Services. The task force argues against DOD-wide centralization of basic research. Data extraction and analysis struggles during the study prompted the task force to call for action to develop good management information systems for the DOD R&D enterprise.

The RAND report was sponsored by the Director for Research and Laboratory Management, Office of the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (PUIC SAALT08864) and produced by the Force Development and Technology Program of the RAND Arroyo Center, an Army-sponsored FFRDC. . The focal question of the panel was "How can the Army get the best long-term value from its investments in basic research?"

The RAND Report (p. 36) asserts that, "a high-quality research organization should have the following attributes:"

- Clear and substantive mission.
- Critical mass of assigned work.
- Highly competent and dedicated workforce.
- Inspired, empowered, highly qualified leadership.
- State-of-the-art facilities and equipment.
- Effective, two-way relationship with the warfighters.
- Strong foundation in research.
- Management authority and flexibility.
- Strong linkage to universities, industry, and other government labs.[58]

With respect to research budgets, the relevant RAND findings include:

- F8 – The amount of basic and applied research funding available for the ARL Director to invest at his or her discretion, based on his or her local knowledge and capabilities, is far too low—below the 10 percent recommended in Chapter Five and Table 5.1 of this report. The ARL Director's Research, Quick Response, and Strategic Technology Initiatives are budgeted at only $7 million annually, from a core research budget of $174 million for in-house research in 2009. Approximately 75 percent of ARL's core applied research funding is committed to Army technical objectives (ATOs) and technology program agreements (TPAs).

- F9 – The share of the Army's basic research funding allocated to In-house Laboratory Independent Research (ILIR) has been declining since 1997 and has fallen below the 5 percent guidance from the Office of the Secretary of Defense (OSD) and the 5–10 percent goal recommended by the 1983 Packard report.

- R5 – The Army should keep ILIR funding at or above 5 percent of the Army's 6.1 budget and execute it like the Laboratory-Directed Research and Development (LDRD) program at the DOE weapons labs, excluding taxing customers.

- R6 – The Army should increase the amount of discretionary basic and applied research funding allocated to the director of ARL to 5 to 10 percent of its total basic and applied research budget, as recommended in the Packard report. ALR should not have more than 50 percent of its 6.2 mission funding obligated for TPAs and ATOs.

[58] 1991 Federal Advisory Commission on Consolidation and Conversion of Defense Research and Development Laboratories' Report to the Secretary of Defense

Table 3.1 (p. 31) of the RAND report summarizes the Panel's opinions about amounts to be "executed" in-house for budget activities 6.1–6.7*:*

Budget Activity	Execution
6.1	*ARO (<10%)* *ARL (>50%)* *RDEC ILIR (>90%)*
6.2	*ARL (>50%)* *RDEC (<50%)*
6.3	*ARL (<50%)* *RDEC (<25%)*
6.4, 6.5, and 6.7	*PM (<5%)*

Table D.1 – Budget Activity Summary from RAND Report

With respect to the TOR question "**Are we addressing long-term, game-changing ideas"** the relevant RAND findings include:

- F2 – Basic research should expand fundamental scientific knowledge that may lead to future war fighting capabilities. The Army needs a high-quality, inquisitive, agile basic research program with a long-term horizon, in part because geopolitical futures and the needs of the future Army are uncertain.

- F4 – The AMC basic research program is increasingly too near-term in its focus, with declining discovery and invention. In particular, the panel does not find mechanisms that stimulate staff to undertake high-risk but potentially transformational research in areas relevant to the Army.

- F5 – Failure avoidance has grown to the point that research projects are expected to produce a product in addition to providing scientific knowledge. This has created a research, development, and acquisition (RDA) culture that trends toward conservative risk management at the expense of discovery, invention, innovation, and agility.

- F10 – Technical talent and management attention is a finite resource and must be managed accordingly. The panel finds that too much of ARL technical staff time and management attention is devoted to the pursuit of funding from external clients at the expense of mission-funded basic and applied research. While work on applied research (Budget Activity 6.2) and advanced technology development (Budget Activity 6.3) projects is a valid sign of connection to the ultimate customer and of understanding customer needs, the amount of basic research (Budget Activity 6.1) must be balanced accordingly and not neglected.

- F15 – The list provided by ARL of major inventions during the past 25 years originating from ARL basic and applied research (not including ARO-funded research) was uneven, tended to be innovations rather than discoveries or inventions, and dated back beyond the last quarter century. Notable discoveries and inventions are an important output metric for a research organization. ARL's ability to tell its story in and out of government is vital to establishing its reputation, attracting high-quality staff, and demonstrating the value of its basic and applied research at the Army.

Finally, with respect to comparison of the current RDECOM portfolio of S&T projects and objectives with other U.S. Government laboratories, industrial laboratories, and academic institutions, RAND noted

- F6 – The Army S&T resources (funding, people, and facilities and equipment) database does not permit the necessary analysis and insights required by the Army S&T leadership to execute their policy, strategic (sic), planning, oversight and program defense responsibilities.

- F12 – The Army has not expanded its S&E workforce rapidly enough in the fast-changing research area of network and information sciences, where major breakthroughs continue to occur.

The NDU report was undertaken because the Army Science and Technology Executive, Dr. Thomas Killion, requested a study of peer review methods in use at Army laboratories. The paper discusses Army laboratories in terms of generally accepted best practices and compares them with techniques at other DOD laboratories, and at a few other government agencies.

The report recommended establishing a policy and guidelines that would set a minimum performance bar that is to be met or exceeded by all Army S&T laboratories. Specific recommendations are listed below.

- R1 – The policy should require the laboratories to empower outside groups to convene peer review panels and manage the review process.

- R3 – Reviews should be done every 2 or 3 years. To spread out the burden of handling the reviews, the annual review process should be staggered such that any one area is only reviewed every 2 or 3 years.

- R4 – The reviews should cover technical details at the project level.

- R5 – The panels should also assess the quality of the staff, the management environment, the equipment, and the facilities.

- R6 – The panels should provide feedback to the laboratory staff and prepare formal written reports.

The JASON report focuses on how best to structure basic research (BAI or 6.1) within the DOD. The changing national and global context for basic research is reviewed and the rationale for basic research within the DOD is discussed. The present organizational and funding status of DOD research is also reviewed with particular emphasis on the role of DDR&E and observations about the program, personnel, and organization are offered. Recommendations are made aiming at bringing greater visibility and coherence to the BAI/6.1 program, improving the quality and connectivity of the DOD Lab and academic communities, and developing a high-quality S&T workforce.

The report found that the present organization of basic research in the Department can be characterized as program management and execution by the Services, with certification, representation, and a relatively weak review and coordination provided by the DDR&E. While this allows the services to "own" their individual programs, it makes coordination and synergies less likely, and renders the basic research program susceptible to a "drift" away from long-term imperatives to short-term needs. Indeed, the extraordinarily productive DOD tradition of knowledgeable and empowered program managers supporting the very best researchers working on the most fundamental problems has morphed during the past decade into a more tightly managed effort with a shorter-term and more applied character. In the present program, evolutionary advances are the norm, and revolutions are less likely to be fostered than they should be.

Recommendations from the JASON report follow:

- Increase the number of fellowships awarded each year to reach a steady-state community of at least 100.
- Define strategic areas broadly with consideration of the critical mass of researchers within a general area that will be needed to achieve program objectives.
- Change the order of selection criteria to emphasize the quality of the people proposing the work and technical merit of the proposed research.
- Devise a selection process that will be trusted by the target research communities.
- Eliminate the requirement that all awardees obtain and maintain DOD security clearances.

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Appendix G – Army FY2011 S&T Funding

The data used in the analysis below is from FY2011 and includes project-level information provided by ASA(ALT) on funds spent internally, externally, and allocations to specific RDECS (or ARL) within the projects. The portion of ARL funding allocated to ARO was taken from the briefing presented by ARO to the ASB in December of 2011.

It should be noted that while overall Army S&T (BA1 through BA3) funding was $2.0B in FY2011, only $1.5B of that was allocated to organizations under RDECOM (ARL and the RDECs). The remainder was allocated to the Army Research Institute, Space and Missile Defense Command, Engineer Research and Development Center in the Corps of Engineers, and Medical Research and Materiel Command. This analysis focuses on the funding allocated to RDECOM organizations.

G.1 DISTRIBUTION OF S&T AMONG RDECOM ORGANIZATIONS

Within RDECOM, funds are allocated among ARL (including ARO), and the six Research, Development and Engineering Centers (RDECs):

- AMRDEC-Aviation.
- AMRDEC-Missile.
- ARDEC.
- CERDEC.
- ECBC.
- NSRDEC.
- TARDEC.

A small amount is allocated to RDECOM headquarters. Figure F.1 below displays the allocation of funds among these organizations. It should be noted that most funding for ECBC comes through funding lines at DTRA, rather than the Army, and are not included in this discussion.

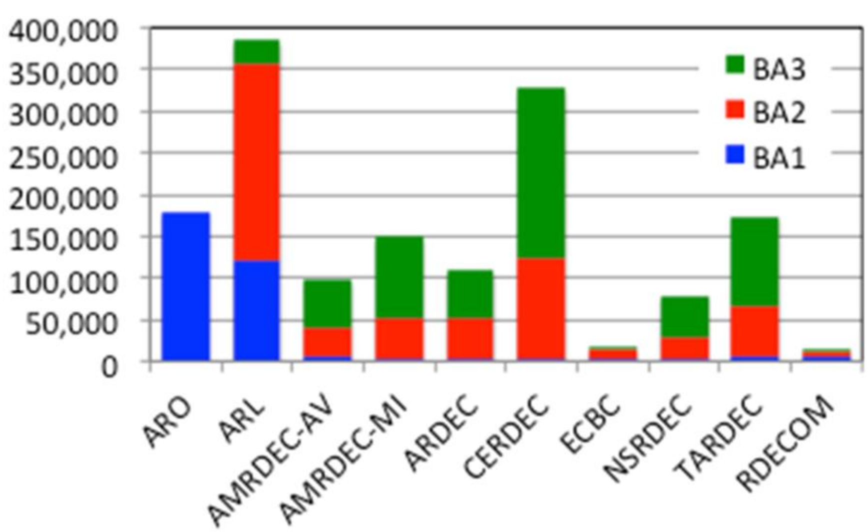

Figure G.1 – Allocation of Funds Among REDCOM Organizations

Approximately 22% of the S&T funding is BA 1; the remainder is split evenly between BA2 and BA3. There is very little BA1 funding allocated to the RDECs; they only receive In-house Laboratory Independent Research (ILIR) funds. The bulk of the BA 1 funding is allocated to ARL and ARO. ARL receives significant BA 2 funds and the RDECS receive most of the BA 3 funds.

AMRDEC funds are divided into aviation and missile efforts following the assignments provided by ASA(ALT). Among the RDECs, CERDEC receives the most funding, followed by AMRDEC if one combines the aviation and missile funding.

G.2 IN-HOUSE VS. EXTERNAL SPENDING

Based on the information provided by ASA(ALT), Figure F.2 below depicts the splits of the funding shown above into in-house and external funding.

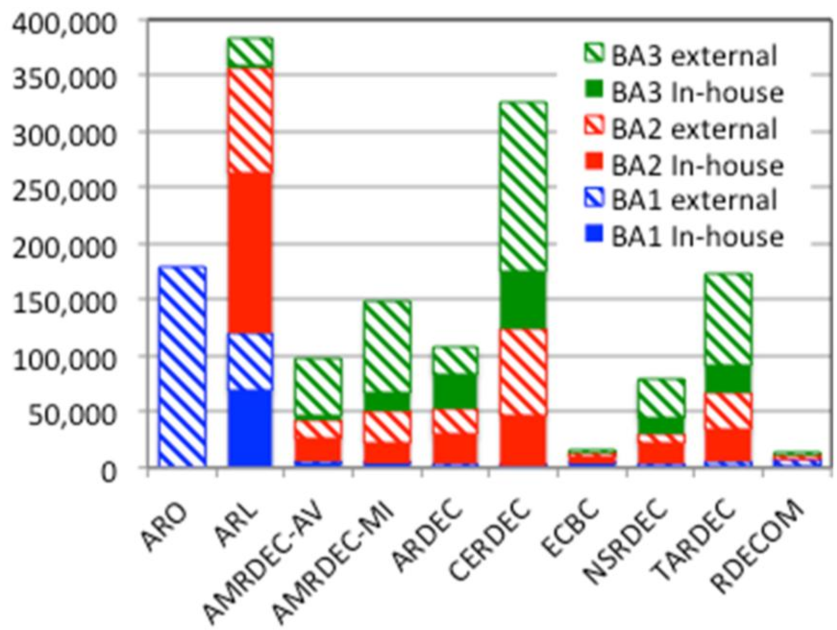

Figure G.2 – In-house and External S&T Funding

Within BA 1, ARO spends most funds externally, primarily within academia. ARL (other than ARO) is divided between Defense Research Sciences (59%) and University and Industry Research Centers (41%). The latter is almost entirely spent externally (96%) while the former is primarily spent in-house (78%). The overall split across BA 1 funds is shown in Figure F.3 below.

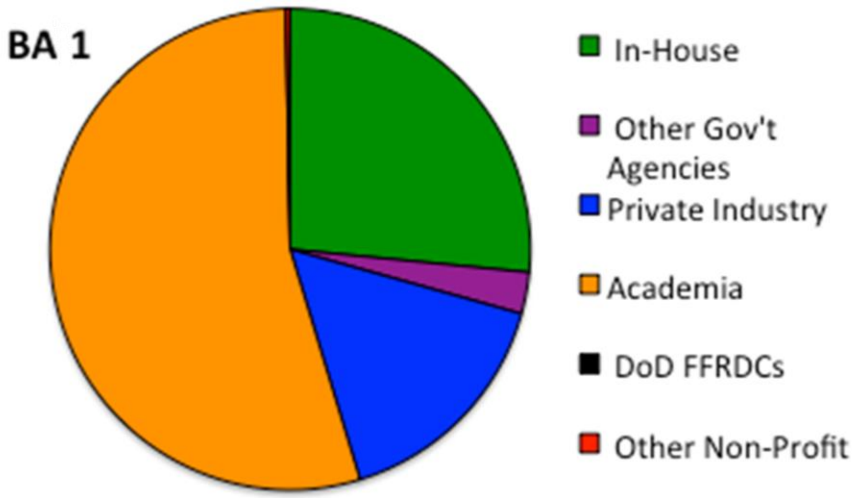

Figure G.3 – BA 1 In-House versus External Funding

The allocations of funds to ARO, ARL and the RDECs, as well as the internal/external splits, vary across the four BA 1 PEs. Note that the relatively small ILIR PE is entirely allocated to the RDECs and is primarily spent in house as is expected. The University Research Initiatives PE is entirely allocated to ARO and is spent externally at the universities. The University and Industry Research Centers includes funding for the Collaborative Technology Alliances, Centers of Excellence, and UARCs and is primarily spent externally. The Defense Research Sciences PE, which funds the single investigators, is a mixture of internal and external funding with the largest components being ARO external and ARL internal spending.

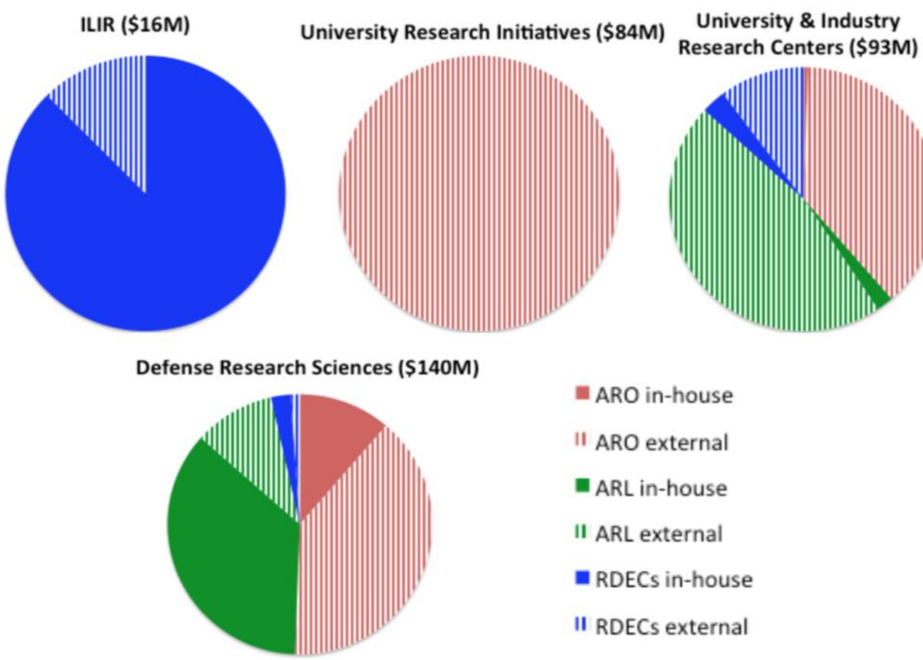

Figure G.4 – BA 1 Funding Disbursement

The in-house/external splits within BA2 and BA3 are usefully considered in terms of percentages as shown in Figure F.5 below. ECBC is not included because most of their funding comes through DTRA rather than the Army.

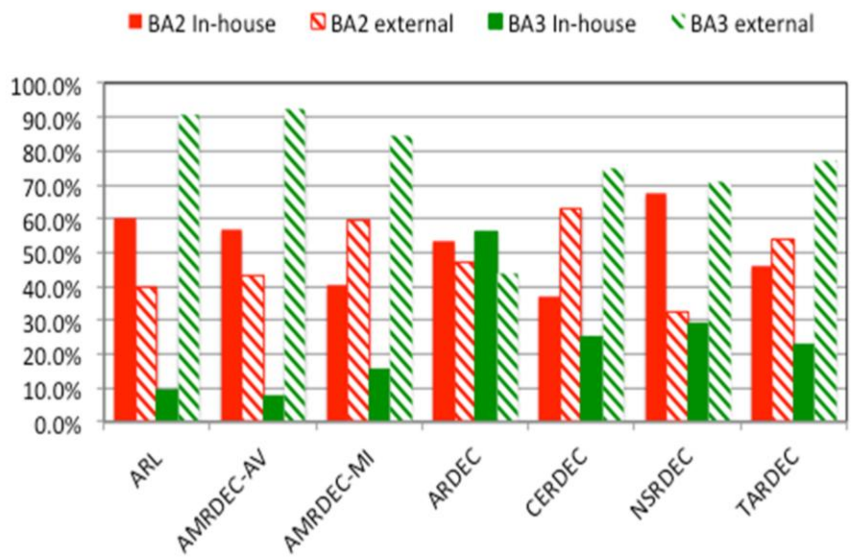

Figure G.5 – BA2 and BA3 In-house and External Funding Percentages

Note that for BA 2, ARL in-house spending is approximately 40%. For the RDECS, BA 2 in-house funds are between 37% (CERDEC) and 68% (NSRDEC). In BA 3, ARL has minimal funding ($27M) and it is primarily spent externally. For the RDECs, BA 3 funds are less than 30% in-house except for ARDEC (57%). This is consistent with the idea that funds should shift to external spending as projects move to BA3 in order to prepare for production.

For BA2, CERDEC spends the smallest fraction in-house, which is consistent with the idea that much of the expertise in communications and networking is external. ARDEC spends the largest fraction of BA 3 in-house, perhaps because some of the production in the armaments area is also performed in-house in Army Ammunition Plants.

The top figure below shows that in BA 2 approximately 52% of the funds are spent in-house and most of the funds spent externally are spend in industry. The bottom figure shows that in BA 3, the majority of the funds is spent externally and is spent in private industry.

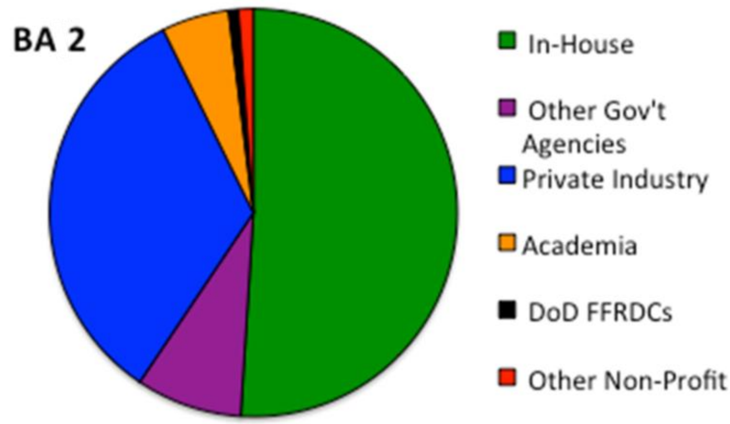

Figure F.6 – BA 2 Funding Disbursement

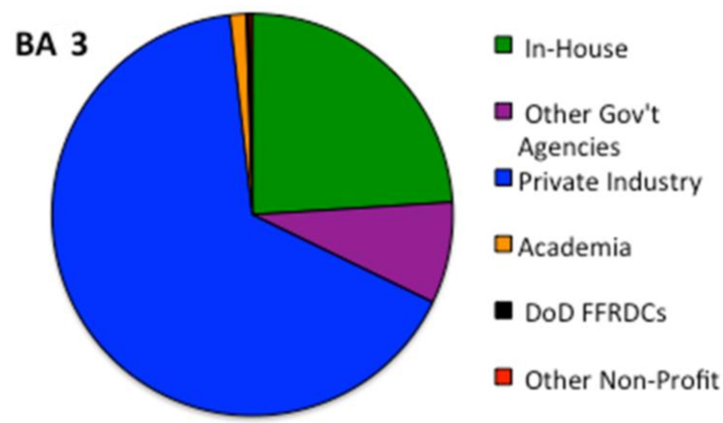

Figure G.7 – BA 3 Funding Disbursement

G.3 SUMMARY

Table F.1 below provides specific data on which the above plots are based.

	FY11 Total			FY11 in-house		
	BA1	BA2	BA3	BA1	BA2	BA3
ARO	191,118			16,304		
ARL (no ARO)	108,906	236,846	26,765	52,108	142,737	2,510
AMRDEC-AV	6,197	35,564	55,892	3,761	20,272	4,364
AMRDEC-MI	3,341	48,162	97,535	2,954	19,461	14,934
ARDEC	2,790	49,956	55,598	1,918	26,535	31,387
CERDEC	1,936	122,249	202,996	1,737	45,040	50,579
ECBC	3,138	10,555	960	2,976	6,329	854
NSRDEC	3,430	26,972	48,249	2,305	18,246	13,967
TARDEC	4,964	61,875	106,889	1,739	28,497	24,244
RDECOM	7,114	4,193	1,233	2,521	335	241
Total	332,934	596,372	596,117	88,323	307,452	143,080
External %				73%	48%	76%
In-House %				27%	52%	24%

Table G.1 – BA 1, BA 2 and BA 3 FY2011 Funding

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Appendix H – Assessment of Army Research

Selected examples of S&T activities of importance to the Army in each of the noted S&T execution categories identified in this ASB analysis are provided below for each of the RDECs and for all of the directorates comprising the Army Research Laboratory. The analyses for the individual organizations were done by ASB study panel members having comprehensive and in-depth relevant knowledge and expertise. The categorization criteria adopted and applied were based on the category descriptions provided above. It is important to note that this compilation is intended to reflect the findings of an ASB analysis based on its broad but not deep review of Army S&T activities. The examples are not offered as specific recommendations but are intended to demonstrate the output that results from an analysis of this kind. Rather, the overall approach and the cited examples are intended to promote the formulation and execution of a more thorough, more detailed analysis of this kind led by Army S&T managers. The ASB study team strongly recommends that such an Army analysis be conducted soon, with particular focus on achieving enhanced efficiencies in the execution of its S&T program and eliminating and avoiding redundant efforts.

Research, Development and Engineering Centers

<u>Aviation and Missile Research, Development and Engineering Center (AMRDEC) – Aviation</u>

Work that must be performed in-house:

- Development of enhanced fundamental understanding of rotary wing flight challenges (rotor wakes, dynamic stall, compressibility, interactional aerodynamics)
- Development and validation of modeling and simulation tools and experimental data important to the design and analysis of rotary wing aircraft (performance predictions, air loads, structural loads, vibration, noise)
- Evaluation of critical components (structural, ballistic protection, infrared suppressors, aircraft survival equipment) and flight testing
- Advanced configuration studies (e.g., to achieve higher speed and operating efficiency to support Joint Multi-Role type objectives)

Work that should be sponsored:

- Research complementary to Army in-house efforts to develop enhanced fundamental understanding of rotary wing flight challenges (rotor wakes, dynamic stall, compressibility, interactional aerodynamics)
- Rotorcraft drive (gears, tribology, multi-speed) and active rotor technologies
- Advanced, lightweight composite materials (for reduced cost, lighter weight, greater damage tolerance, etc.)
- Structural/component health monitoring, condition-based maintenance

Work that should be monitored and leveraged:

- Alternative fuels, batteries, and energy storage technology.
- Information sciences research (processors, data storage, robotics, quantum computing) relevant to Army aviation needs.

<u>Aviation and Missile Research, Development and Engineering Center (AMRDEC) – Missile</u>

Work that must be performed in-house:

- Plasmonics and metamaterials R&D for engineered optical signatures, laser protection, and integrated optical sensors.

- Development of overt, high-bandwidth millimeter-wave/terahertz navigation radar and communication/data links, and controlled chaotic systems for low-cost steerable phased arrays
- Advanced missile guidance, navigation, and control research and technology development.
- Missile system trade studies, system design and integration
- Modeling and simulation important to missile system and component performance

Work that should be supported:

- Fabrication of advanced electronic and optoelectronic materials and devices for high-performance sensors, seekers, and guidance systems
- Advanced, lightweight composite materials (for reduced cost, lighter weight, greater damage tolerance, etc.)
- Missile system electronics
- Missile system and component manufacturing technology

Work that should be monitored and leveraged:

- Information sciences research (processors, data storage, robotics, quantum computing) relevant to Army missile system needs
- Alternative fuels, batteries, and energy storage technology

Armament Research, Development and Engineering Center (ARDEC)

Work that must be performed in-house:

- Munition systems technologies, including energetics (propellants and explosives), warheads (kinetic energy penetrators, shaped charge warheads, explosively formed penetrators), high-g munition guidance and control, and fuzing
- Gun system technologies, including small-, medium-, and large-caliber systems, cannon tube technology, compressive gas flow phenomena
- System trade studies involving the design, integration, and development of advanced armament concept demonstrators

Work that should be supported:

- Modeling and simulation of advanced weapon system and component performance
- Novel and advanced high-performance materials for warhead and gun system applications
- Reserve battery technology for munitions applications
- Scalable non-lethal directed energy armament systems for anti-personnel/materiel applications

Work that should be monitored and leveraged:

- Hypervelocity impact research and technology developments
- Directed energy phenomena and enabling technology for tactical directed energy weapons

Communications - Electronics Research, Development and Engineering Center (CERDEC)

Work that must be performed in-house:

- Model development and validation for characterization/testing of imaging sensors (electro-optical/infrared, countermine, etc.)
- Sensor, electronic warfare, and communication system architecture engineering
- Electronic warfare systems development and evaluation
- Night vision and advanced reconnaissance/surveillance sensors technologies
- Novel electromagnetic materials and fabrication/manufacturing methods for conformal and armor-embedded antennas

- Development of advanced capabilities for coherent transmission and reception of RF signals from multiple fixed and moving systems
- Advanced technologies/capabilities for mine and minefield detection

Work that should be supported:

- Development of affordable, large-format epitaxial infrared focal plane arrays
- Power systems R&D: electrochemical, power electronics, renewable energy devices, grids
- Modeling and simulation of electro-optical/infrared sensors, antennas, radio frequency systems
- Electromagnetic compatibility testing and interference mitigation

Work that should be monitored and leveraged:

- Microelectronics technology
- Image and signal processing technology
- Wireless communications technology

Edgewood Chemical Biological Center (ECBC)

Work that must be performed in-house:

- Novel threat agent synthesis and characterization
- Novel concepts in chemical and biological sensing and signaling; hazardous chemical and threat biological sensing; threat agent spectroscopy; microfluidics; mass transfer/transport; quorum sensing; signal transduction; and modeling
- Mass transport of agents in complex systems, specifically the development of greater understanding of the complex behavior of mass transport in microporous systems with protection and nanotechnological applications

Work that should be supported:

- Rational molecular and nano-system design (abiotic design): rational molecular and nano-system design for the design of abiotic structures, reconfigurable self-organizing systems, novel nanoparticles; or supramolecular self-assembly, functional polymers, quantum dots, novel organic synthesis; SERS materials, etc.
- Chemical and biochemical computational methods modeled after design principles encountered in nature with enhanced robustness, scalability and flexibility

Work that should be monitored:

- Research and technology advances in the areas of nanotechnology, microfluidics, aerosols, and metamaterials
- Advances in synthetic biology (biotic design) – biological nanopores/filters, protein pumps, membranes and liposomes, aerosols, artificial systems, artificial DNA/RNA, chromophores, self-replicating systems, fluorescent proteins, 3-D cellular structures/ tissues, positionally encoded nanostructures, and bio-circuitry

Natick Soldier Research, Development and Engineering Center (NSRDEC)

Work that must be performed in-house:

- Advanced fiber and textile development, including smart, responsive, or other multifunctional types, and materials for extreme environments and to meet requirements for sensing and integration
- Food and water safety, novel food processing methods
- High-rate response of fibrous and soft materials to impact and blast loading; personnel body armor

- Modeling and simulation for assessing the impact of emerging technologies on individual soldiers and small units across a spectrum of missions, environments, and threats

Work that should be supported:

- Power technology for the individual soldier and small units
- Precision air-drop technology
- Soldier cognition in stressful environments

Work that should be monitored and leveraged:

- Nanomaterials research and development
- Fiber-reinforced composites
- Flexible display technology

Tank Automotive Research Development and Engineering Center (TARDEC)

Work that must be performed in-house:

- Ground vehicle systems design tools, analysis (modeling and simulation), and testing; concept development, component integration, testing
- Protection system technology and integration (e.g., active protection systems)
- Vehicle operational safety and survivability
- Suspension technology and electronic stability control for rugged terrain and extreme maneuver
- Concept development, analysis, and hardware associated with man-in-the-loop simulation of ground system performance

Work that should be supported:

- Development of advanced fuels (particularly JP-8 for one-fuel-forward) and lubricants
- Power train and vehicle track technology
- Unmanned ground systems technology, robotics technology
- On-board and export power generation and storage for heavy-duty military applications (e.g., stringent size, weight, power and cost and signature management)
- Development of material models for reliability, safety assessments, and blast effects

Work that should be monitored and leveraged:

- Fuel economy technology (e.g., hybrid drive)
- Water generation, purification and desalination, water quality monitoring, wastewater recycle and reuse

Army Research Laboratory Directorates

Computational & Information Sciences Directorate (CISD)

Work that must be performed in-house:

- Military network security.
- Fast, analyst-controllable network sensors
- Characterization of network dynamics and quality of information important to tactical decision-making

Work that should be supported:

- Electronic, information and network warfare protection, including information assurance and intrusion detection
- Adaptive, self-configuring, secure, robust networks
- Social-cognitive aspects of network and impact on Soldier performance

- Multi-scale modeling of materials under extreme conditions
- Autonomy research: collaborative systems, earning and cognition, robot/human teaming.

Work that should be monitored and leveraged:

- Quantum information and computing basic and applied research

Human Research and Engineering Directorate (HRED)

Work that must be performed in-house:

- Neural indicators of operationally-relevant cognitive and physical performance
- Effects of cognitive-sensory/perception-physical states on soldier performance
- Human system integration: soldier-centered design tools for optimized man-machine performance

Work that should be supported:

- Basic and applied research on translational principles of neuroscience applied to complex operational settings
- Research involving mixed-augmented reality in simulated environments
- Adaptive tutoring for intelligent learning basic and applied research

Work that should be monitored and leveraged:

- Social-cultural behavioral models research and developments
- Social network analysis research and technology development

Sensors and Electron Devices Directorate (SEDD)

Work that must be performed in-house:

- Photonic sensor development and photonic sensor materials/devices
- Advanced electro-optic research for infrared, ultraviolet, and terahertz detectors and devices
- Signature management for soldiers and platforms
- Autonomous sensing and sensor networks

Work that should be supported:

- Micro autonomous vehicles basic and applied research
- Portable power basic and applied research
- Metamaterials basic and applied research

Work that should be monitored and leveraged:

- Battery and fuel cell research and technology development
- Directed energy research and technology development
- Hybrid electric vehicle research and technology development

Survivability/LethalityAnalysis Directorate (SLAD)

Work that must be performed in-house:

- Ballistic vulnerability/lethality modeling and evaluation, soldier survivability modeling
- Electronic warfare applied research, including simulation and analysis tools for electronic warfare technology development, improvised explosive device countermeasures, kill assessment methodologies
- Modeling of active protection system components and overall performance
- Methodologies for analysis of electro-optical system survivability
- System-of-systems survivability simulations

Work that should be supported:

- Modeling and simulation of computer network operations

- Material modeling basic and applied research

Work that should be monitored and leveraged:

- Directed energy research and technology development
- High-performance computing platforms development
- Hypervelocity research and technology development

Vehicle Technology Directorate (VTD)

Work that must be performed in-house:

- Perception and control algorithms for autonomous systems
- Autonomous systems reliability, fault detection and diagnosis, durability and damage tolerance research
- JP-8 engine technology for unmanned systems
- Autonomous systems integration

Work that should be supported:

- Vehicle propulsion, power generation, and power transfer basic and applied research
- Multi-functional structures basic and applied research

Work that should be monitored and leveraged:

- Rotorcraft propulsion research and technology development
- Fuels research and technology development

Weapons and Materials Research Directorate (WMRD)

Work that must be performed in-house:

- Advanced vehicle protection and weapons concepts research and technology development and evaluation, including testing
- Armor materials research and structural integration
- Impact/penetration and lethal mechanism basic and applied research
- Advanced multi-threat armor defeat mechanisms
- Energetic materials and explosive effects basic and applied research
- Blast protection basic and applied research

Work that should be supported:

- High-performance ceramic, transparent, composite, and hybrid materials
- Weapons/munitions guidance basic and applied research
- Coatings, corrosion, and polymers basic and applied research

Work that should be monitored and leveraged:

- Materials manufacturing technology developments
- Macromolecular science research and technology development
- High-performance computing research

Appendix I – ARL/ARO Investments in Game-Changing Technologies

The following write-up, represents the ARL/ARO cited $92M/year of annual investments in promising technologies aimed at transforming Army operations.

1. **MATERIALS AND DEVICES FOR EXTREME ENVIRONMENTS** ($38M/year) focused on 1) improving blast and ballistic protection while decreasing the weight that soldiers carry, 2) creating new methods of detecting and detoxifying chemical and biological threats, and 3) providing physiological monitoring and automated medical intervention. The ultimate goal is to help the Army create an integrated system of nanotechnologies for Soldier protection which are not currently achievable through existing material sets.

   a) ***Nanomaterials*** ($11.4M/year)
      - Graphene nanoelectronics are geared towards demonstrating modeling, design, and fabrication of graphene-based field effect transistors with RF performance up to 3 GHz. This research could potentially impact the Warfighter through compact and high efficiency power electronics and communications systems, transparent and flexible electronics, and wearable electronics.
      - Nano-engineered dielectrics and insulators for capacitors and device packaging are geared towards developing novel dielectric polymer formulations that effectively control charge localization and mobility in the film; initial results have demonstrated substantial improvements in dielectric performance. The program's vision is to provide game-changing technologies for high power electronic and energy storage devices with reduced size, weight, and cost by coupling polymer physics/processing, synthetic chemistry, and computational modeling to engineer new materials. This research should enable critical advances in the protection, lethality, mobility, and reliability of future Army systems, and has the implications in a broad range of military technologies including sensors, electronics, energy storage devices, detectors, actuators, and coatings.
      - Tailored, High-density Nanocomposites focuses on combining polymer nanocomposites with organized polymer matrices and functional, high surface area nanoscopic filler particles in order to create a class of materials that has the potential to generate game-changing technological advances.
      - Heterogeneous Architectures Incorporating Nitride Semiconductors for Enhanced Functionality of Optoelectronic Devices focuses on the physics and engineering of the interface of dissimilar materials. This program investigates the heterogenous integration of III-Nitride semiconductors with materials having dissimilar polarization, band gap, or crystal structure to realize optoelectronic devices that have enhanced capabilities not achievable using either material system individually.

   b) ***Flexible Electronics and Displays*** ($14.2 M/year) focus on the urgent need for ubiquitous electronics to be designed to reliably operate in extreme environments. These technologies are expected to significantly impact the Army as the foundation to develop robust electronic components for a range of platforms and sensors uniquely designed to operate in a tactical environment. Specifically, the Army's program is developing materials and processes for direct view flexible display technologies, addressing the manufacturing challenges to make displays on flexible substrates a viable technology, providing limited quantities of flexible display demonstrators to users, and developing a technology base for flexible electronics to enable novel sensor applications.

c) ***Multiscale Research of Materials*** ($8.3M/year) is focused on developing new capabilities for materials design in the form of computational, experimental, and data tools. This will enable researchers to explore uncharted regions of the design space for new materials and material technologies needed for lightweight Warfighter and vehicle protection against a variety of quickly changing threats and develop high efficiency power and energy and sensor components.
   - Multiscale Modeling of Non-crystilline Ceramics (Glass) is attempting to develop a concurrent multiscale computational finite element code for optimizing or enhancing the performance of various glasses against shaped-charge jets.

d) ***Extreme Energy Science*** ($.9M/year) is focused on unburdening the significant power and energy requirements the Warfighter is challenged across a variety of current Army platforms. Extreme Energy Science is expected to provide dense component technologies from nano- to macroscales that provide power and energy to enhance the mobility, survivability, and lethality of the current and Future Force while reducing logistic burden to the Soldier.
   - Gallium Nitride High Power Electronics devices have the potential to outperform 4H-silicon carbide fabricated high power electronics devices, the current industry standard. The primary objective of this work is to enable routine fabrication of gallium nitride high power electronics devices with low defect density.
   - Understanding Photosystem I as a Biomolecular Reactor for Energy Conversion for developing high efficiency hydrogen fuel cells as an alternative energy source to current technologies. A goal of this work is to mimic photosynthesis through the fabrication of photocatalytic biohybrid system of Photosystem I and inorganic materials to generate hydrogen gas.

2. **AUTONOMOUS SYSTEMS** ($22.9M/year) is focused on extending and enhancing the situational awareness of the dismounted Soldier in complex terrain and confined spaces through teaming with autonomous systems. These include robotic platforms, (aerial and ground), mid-sized to palm-sized and smaller, along with the unique mobility, perception, intelligence, manipulation, and human interface required. Unmanned systems, especially those possessing a significant degree of autonomy, promise to permit the Army to expand its bubble of influence, cover a greater terrain, possess increased situational awareness, move greater amounts of goods, while reducing soldier risks and not requiring increased force structure. The objective of the microscale research is the development of a capability to expand soldier situational awareness using microscale platforms without substantially adding to Warfighter physical burden.

   Research is also focused on expanding the capabilities of larger, more “conventional” unmanned systems, focusing upon bringing a significant level of autonomy to those platforms. This includes research on Human-Robot interaction, *i.e.,* intuitive interfaces for the soldier (especially multi-modal control mechanisms that will minimize loss of self-situational awareness), the development of a “shared mental model” of the environment to aid true soldier-robot teaming, and engender soldier trust in the unmanned system. In concert, these research activities are working towards the overall goal of developing unmanned systems possessing sufficient autonomy to team with soldiers in a set of continually increasing environmental and mission complexity, aiding the small unit in successfully conducting its mission.

3. **ENHANCED TACTICAL NETWORKS** ($21.1M/year) is focused on deriving the fundamental laws of evolution and behaviors of “living” networks, treating them as holistic organisms to enable revolutionary advances in the ability to model, design, analyze, predict and control the joint behavior of secure (tactical) communications, sensing, and command and control (decision making) networks. This fundamental understanding is being leveraged to focus on ways to harness an ever-growing set of computers, from use of large-scale supercomputers to hand-held devices that ultimately put the power of supercomputing in the hands of the soldier for better control of the operational space.

   a) *Trust Management in Networks* is focused on developing methods to characterize the nature of trust (e.g., trust in information, trust in a network node or link), and to take measures to manage the trust (e.g., by changing routing, allocation of resources, isolation of malicious nodes) since trust dynamically changes in the network of devices and Soldiers, especially under the conditions of high-tempo exchange of information, incompleteness and uncertainty, and potential information operations by the adversaries. This research is expected to lead to technologies that autonomously or semi-autonomously manage the network elements and the networked information in a way that explicitly accounts for the need for trust, and maximizes the availability of appropriate trust.

   b) *Networking for Quality of Information* is developing theories, models, and exploratory prototypes of a novel approach to manage and operate networks by optimizing Quality of Information. This technology is expected to ensure that all dynamic networking decisions -- from finding the sources and type of information to routing the information to storage and compression of information to resource and bandwidth allocation -- are made to optimize the quality of information. By contrast, conventional technologies merely focus on the amount of the information delivered, not on its quality from the perspective of the Soldier's mission. These capabilities will dramatically change the extent to which a network acts as an intelligent support to the Soldier, not merely as an information pipe. The impact will be especially dramatic when a capable adversary disrupts or degrades the friendly network, making the quality of the inevitably limited information especially important.

4. Translational neuroscience ($13.1M/year) is focused on exploring advances in soldier cognitive performance by integrating modern neuroscience human factors, psychology and engineering to enhance the understanding of soldier function and behavior in complex operational settings. The Army’s basic research is working on the ability to image the brain and understanding the complexities inherent in the human brain and the real-world environment. In essence, the Army is addressing the translational problem of going from the “bench to the battlefield,” through the creation of a unique research capability that has: 1) deep knowledge of military environments and situations, 2) regular and formal interactions with leading academics and neuroscientists, neurotechnology developers, military system developers, and experienced military personnel, and 3) access to unique, military relevant, and often one-of-a-kind data and data collection opportunities.

   a) *Brain Structure-function Couplings* are using electrochemical modeling, biomechanical structural changes, electrochemical data collection and analysis and time-evolving connectivity in the understanding of the brain’s physical structure, dynamic electrochemical functioning and human behavior. An underlying goal is to understand the individual differences in brain structure that can be leveraged to account, predict or enhance the measurement of brain function at varying time scales. This research will support the development of individualized models that predict soldier neurocognitive performance and armor designed to minimize brain injury.

Appendix J – Technology Transition Initiatives

1. QUICK REACTION SPECIAL PROJECTS

The QRSP supports six separate projects that provide rapid funding to expedite new development and transition of new technologies to the Warfighter. The projects include the Quick Reaction Fund, Technology Transition Initiative, the Rapid Reaction Fund, and the Joint Rapid Acquisition Cell. QRSP provides the flexibility to respond to emergent DOD issues and address technology surprises and needs within the years of execution outside the two-year budget cycle.

QRSP is funded by means of PE 0603826D8Z, using BA 3 funds. It is managed by Office of the USD(AT&L). Within QRSP is the Technology Transition Initiative, which was established by Congress in the FY2003 National Defense Authorization Act to " f**acilitate the rapid transition of new technologies from S&T programs of the DOD into acquisition programs** of the Department for the production of such technologies". The OSD office of Technology Transition subsequently implemented the Technology Transition Initiative "to provide the DOD Warfighter key value added advanced technology systems faster and cheaper in order to maintain our technology superiority; it is a transition bridge between discovered DOD- funded mature technology, the acquisition/procurement process and the Joint Warfighter desired capabilities."

All Technology Transition Initiative projects require a TTA prior to the release of OSD funding, signed by the S&T and acquisition leaders in the executing organization and Director, Office of Technology Transition. A template is provided in the proposal preparation instructions for documents that commit to transition, transition plan details, and resources required, and exit criteria. Funding for this initiative appears to have zeroed in FY2012, but the template has many of the criteria for proposal source selection that would be relevant to the proposed TTIPO.

2. RAPID INNOVATION FUND

Section 1073 of Public Law 111-383, and the 2011 Defense Appropriation Act provide DOD with authorities and funds to facilitate the rapid insertion of innovative technologies into military systems or programs that meet critical national security needs. It directs that SECDEF:

"Shall establish a competitive, merit-based program to **accelerate the fielding of technologies** developed pursuant to phase II Small Business Innovation Research Program projects, technologies developed by the defense laboratories, and other innovative technologies (including dual use technologies). The purpose of this program is to stimulate innovative technologies and reduce acquisition or lifecycle of test and evaluation outcomes, and rapidly insert such products directly in support of primarily major defense acquisition programs, but also other defense acquisition programs that meet critical national security needs."

The DOD goals for use of the Rapid Innovation Fund authority and guidance for its implementation and reporting were provided in USD(AT&L) memo, dated 12 October 2011: " Section 1073 of the National Defense Authorization Act for FY 2011" [5]. Funding was provided through congressional adds in FY2011 ($129M) and FY12 ($200M) in BA 4 program element 0604775D8Z.

3. JOINT CAPABILITY TECHNOLOGY DEMONSTRATIONS

JCTDs (and formerly Advanced Concept Technology Demonstrations - ACTDs) are intended to evaluate the capability of **mature and maturing technologies** to satisfy **near-term capability needs** of Combatant Commanders and to concurrently develop the associated Concept of Operations to permit the technologies to be fully exploited. These capabilities and operational concepts are evaluated in military exercises on a scale large enough to clearly establish operational utility. JCTD proposals are validated by the Joint Requirements Oversight Council and approved by the Under Secretary of Defense for Acquisition, Technology, and Logistics. If a JCTD meets its objectives and the technology is found to be militarily useful, the technology may be transitioned to a formal acquisition program, or the technology may transition directly to theater if only small quantities are needed and the residual hardware does not require modification (or requires only very minor modification). However, in such cases, if an enduring DOTMLPF-supported capability is later desired, the capability must ultimately transition to a POR.

JCTDs are funded jointly by OSD and the military department sponsoring the JCTD. The OSD BA 3 program element 0603648D8Z is funded at approximately $200M/year and now includes the previously separately budgeted BA 4 transition funding program element 0604648D8Z. The military services are expected to put "skin in the game" by contributing a percentage of the funding (normally 30 to 50%) out of the service BA 3 funding.

4. TECHNOLOGY ENABLED CAPABILITY DEMONSTRATIONS

TECDs are a recent initiative out of the DASA(R&T). They serve as a means of bringing normally "stove-pipe" technology solutions together into a more integrated systems environment. Typically, a TECD brings together several new technologies, couples them with existing systems or technologies, and demonstrates integrated near-term technology-based solutions that either enhance the effectiveness of an existing capability or enable a new and necessary capability. TECDs are similar to JCTDs in that their primary focus is evaluation and demonstration of technology capabilities rather than the maturation of a technology that is targeted for insertion into a designated POR.

5. BA 4 TECHNOLOGY MATURATION INITIATIVE

BA 4 Technology Maturation Initiative is a recent initiative by DASA(R&T). It was established to address directly the S&T to acquisition valley of death transition issue. It is intended to **mature promising near-term technologies** and subsystems to TRLs greater than 6 and to **expedite capability transitions** through competitive prototyping, consistent with WSARA. It is funded through a new 6.4 program element 0604115A.

6. WARFIGHTING EXPERIMENTS

While not necessarily an initiative to address technology transition specifically, warfighting experiments, including the Network Integration Evaluation, can contribute to technology maturation. The role of experimentation is to discover, evaluate, and demonstrate new ideas or concepts across the DOTMLPF domains. Experiments are an essential risk mitigation activity from the standpoint of developing a understanding of concepts of operations for exploitation of emerging technology enabled capabilities, but are not intended for technology maturation.

7. THE FOREIGN COMPARATIVE TESTING PROGRAM

Foreign Cooperative Testing is another program that is not necessarily directed toward S&T to acquisition transition, but nonetheless provides a means for the Army to exploit global technology developments. Congress authorized the Foreign Cooperative Testing program in 1989. It is administered by the Director, Test Systems Engineering and Evaluation within the Office of USD(AT&L). The program tests and evaluates foreign NDI developed by U.S. allies and other friendly nations to determine whether the equipment can satisfy capability needs. It is a relatively small program, with annual funding of approximately $30–40M, but has had some notable successes. For example, the program successfully evaluated a South African mine-protected clearance vehicle that protects soldiers from the effects of landmine explosions during route clearance operations. These vehicles have been delivered to the Army, Navy, and Marine Corps. Funding is provided to OSD and does not require expenditures directly out of the TOA of military services.

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Appendix K – Definitions of Technology Readiness Levels

From the Department of Defense Technology Readiness Assessment Deskbook, September 2001.

Table III-1. TRL Definitions, Descriptions, and Supporting Information (Source: *Interim Guidebook*, dated October 30, 2002)

TRL	Definition	Description	Supporting Information
1	Basic principles observed and reported	Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.	Published research that identifies the principles that underlie this technology. References to who, where, when.
2	Technology concept and/or application formulated	Invention begins. Once basic principles are observed, practical applications can be invented. Applications are speculative, and there may be no proof or detailed analysis to support the assumptions. Examples are limited to analytic studies.	Publications or other references that outline the application being considered and that provide analysis to support the concept.
3	Analytical and experimental critical function and/or characteristic proof of concept	Active research and development is initiated. This includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology. Examples include components that are not yet integrated or representative.	Results of laboratory tests performed to measure parameters of interest and comparison to analytical predictions for critical subsystems. References to who, where, and when these tests and comparisons were performed.
4	Component and/or breadboard validation in [a] laboratory environment	Basic technological components are integrated to establish that they will work together. This is relatively "low fidelity" compared to the eventual system. Examples include integration of "ad hoc" hardware in the laboratory.	System concepts that have been considered and results from testing laboratory-scale breadboard(s). References to who did this work and when. Provide an estimate of how breadboard hardware and test results differ from the expected system goals.
5	Component and/or breadboard validation in [a] relevant environment	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so they can be tested in a simulated environment. Examples include "high-fidelity" laboratory integration of components.	Results from testing a laboratory breadboard system that are integrated with other supporting elements in a simulated operational environment. How does the "relevant environment" differ from the expected operational environment? How do the test results compare with expectations? What problems, if any, were encountered? Was the breadboard system refined to match the expected system goals more nearly?

Table III-1. TRL Definitions, Descriptions, and Supporting Information (Source: *Interim Guidebook*, dated October 30, 2002) (Continued)

TRL	Definition	Description	Supporting Information
6	System/subsystem model or prototype demonstration in a relevant environment	Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in [a] simulated operational environment.	Results from laboratory testing of a prototype system that is near the desired configuration in terms of performance, weight, and volume. How did the test environment differ from the operational environment? Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
7	System prototype demonstration in an operational environment	Prototype near, or at, planned operational system. Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment such as an aircraft, vehicle, or space. Examples include testing the prototype in a test bed aircraft.	Results from testing a prototype system in an operational environment. Who performed the tests? How did the test compare with expectations? What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before moving to the next level?
8	Actual system completed and qualified through test and demonstration	Technology has been proven to work in its final form and under expected conditions. In almost all cases, this TRL represents the end of true system development. Examples include developmental test and evaluation of the system in its intended weapon system to determine if it meets design specifications.	Results of testing the system in its final configuration under the expected range of environmental conditions in which it will be expected to operate. Assessment of whether it will meet its operational requirements. What problems, if any, were encountered? What are/were the plans, options, or actions to resolve problems before finalizing the design?
9	Actual system proven through successful mission operations	Actual application of the technology in its final form and under mission conditions, such as those encountered in operational test and evaluation. Examples include using the system under operational mission conditions.	Operational test and evaluation reports.

Appendix L – Bibliography

BIBLIOGRAPHY

1. Air Force Policy Directive 61-1, "Management of Science and Technology," 18 August 2011.
2. Air Force Research Laboratory Mission, Air Force Materiel Command Mission Directive 420, 14 November 2011.
3. Alcatel –Lucent press release, "Bell Labs Receives Its 30,000th Patent; Lucent Technologies' Research and Development Arm Builds on a Rich Heritage as it Continues to Shape the Future of Communications," 10 March 2003.
4. Anderson, R. Joseph, and Oliver R. Butler, "Industrial R&D in Transition," *Physics Today*, July 2009.
5. Army Research Office, *ARO In Review 2008*, 2009.
6. Army Research Laboratory, *ARL Mission and Vision, About ARL, 2009*. Online as of 7 August 2009, http://www.arl.army.mil.
7. Army Research Laboratory, *A History of the Army Research Laboratory, 1992-2003*, ARL, Adelphi MD, August 2003.
8. Ayers, W. M., *MIT: The Impact of Innovation*, Bank Boston, Boston MA, 2002.
9. Berteau, David J., and Ryan Crotty, *FY 2013 Defense Budget and Drawdown Baseline* (briefing), International Security Program, Center for Strategic and International Studies, Washington DC, 2012.
10. Chait, Richard, *Perspectives from Former Executives of the DOD Corporate Research Laboratories*, Defense and Technology paper No. 59, National Defense University Center for Technology and National Security Policy, Fort Lesley J. McNair, Washington, D.C., March 2009.
11. Chait, Richard, John Lyons, Duncan Long, and Albert Sciarretta, *Enhancing Army S&T: Lessons from Project Hindsight Revisited,* Center for Technology and National Security Policy, National Defense University, 2007.
12. Coffey, Dahlburg and Zimet, *Building the S&E Workforce for 2040:Challenges Facing the Department of Defense*, Defense and Technology Paper 49, National Defense University Center for Technology and National Security Policy, Washington, D.C., July 2008.
13. Coffee, Timothy, et.al., *The S&T Innovation Conundrum,* Center for Technology and National Security Policy, National Defense University, August 2005.
14. Decker, Gilbert, et al., *Improving Army Basic Research: Report of the Panel on Future Army Laboratories*, RAND Corporation, Santa Monica CA, 2012.
15. Decker, Gilbert F., Louis C. Wagner, Jr., et al., *Army Strong: Equipped, Trained and Ready*, Final Report of the 2010 Army Acquisition Review, Chartered by the Secretary of the Army, Washington DC, January 2011.
16. Defense Acquisition University, *Glossary of Defense Acquisition Acronyms and Terms, 12th Edition*, Defense Acquisition University Press, Ft. Belvoir VA, July 2005.
17. Defense Science Board, *Report of the Defense Science Board on Basic Research*, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, Washington DC, February 2012.
18. Defense Science Board, *Defense Science Board 2006 Summer Study on 21st Century Strategic Technology Vectors*, Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics, Washington DC, February 2007.
19. Department of the Army, *Army S&T Master Plan*, Office of the DASA(R&T), HQDA, Washington DC, 2012.

20. Department of the Army, *Secretary of the Army's Generating Force Overhead Study —Short Term Phase 1 (FOUO/Limited Distribution), extracts (only) on the materiel enterprise*, 13 January 2011.
21. *Department of Defense Laboratory Civilian S&E Workforce Publication – 2011*, prepared for Dr. John Fischer, Director, Defense Laboratory Enterprise by Diligent Innovations, May 2011.
22. Dickson, D. Bennett, *Minutes and Hours…Not Days and Weeks: U.S. Army Rapid Equipping Force 2002-2007*, Rapid Equipping Force, Ft. Belvoir VA, 2008.
23. Duffner, Robert, *Science and Technology: The Making of the Air Force Research Laboratory*, Air University Press, Maxwell Air Force Base AL, 2000.
24. Federal Advisory Commission on Consolidation and Conversion of Defense Research and Development Laboratories, *Report to the Secretary of Defense*, Department of Defense, Washington DC, 1991.
25. Freeman, Dr. Marilyn, DASA(R&T), *Army Science and Technology Strategic Direction*, briefing to the Association of the United States Army , October 2011.
26. Freeman, Dr. Marilyn, DASA(R&T), Statement before the Senate Armed Services Committee Subcommittee on Emerging Threats and Capabilities, 17 April 2012.
27. Galama, Titus, and James Hosek, *U.S. Competitiveness in Science and Technology,* RAND Corporation, Santa Monica CA, 2008.
28. Gansler, Jacques S., et al*., Urgent Reform Required: Army Expeditionary Contracting*, Report of the Commission on Army Acquisition and Program Management in Expeditionary Operations, 31 October, 2007.
29. Gansler, Jacques S., *Democracy's Arsenal: Creating A Twenty-First-Century Defense Industry*, MIT Press, Cambridge, MA, 2011, ISBN 978-0-262-07299.
30. GAO Report 06-883: *Stronger Practices Needed to Improve Technology Transition Processes*, 1996.
31. Goldwater-Nichols Department of Defense Reorganization Act of 1986, Public Law 99-433, 1 October 1986.
32. Holm-Nielsen, L. B., "Promoting Science and Technology for Development: The World Bank's Millennium Science Initiative," paper delivered to the First International Senior Fellows meeting, The Wellcome Trust, London, UK, 30 April 2002.
33. Jason Program Office, *S&T for National Security*, Report Number JSR-08-146, The Mitre Corporation, McLean VA, May 2009.
34. Kadish, LTG Ronald T., USAF(Ret), Chairman, Defense Acquisition Performance Review Project, House Armed Services Committee hearing on Issues Relating to Defense Acquisition Reform, Washington DC, 29 March 2006.
35. Lawrence Livermore National Laboratory, *Laboratory Directed Research and Development FY 2008 Annual Report*, 2009.
36. Lohr, Steve, "Corporate R&D as a Ringmaster for Innovation," 15 August 2009, www.nytimes.com.
37. Lyons, John W., *Army R&D Collaboration and the Role of Globalization in Research*, Center for Technology and National Security Policy, National Defense University, July 2008.
38. Lyons, John W., et al., *Critical Technology Events in the Development of Selected Army Weapons Systems: A Summary of Project Hindsight Revisited*, Center for Technology and National Security policy, National Defense University, Washington, DC, September 2006.
39. Lyons, John W., and Richard Chait, *Strengthening Technical Peer Review at the Army S&T Laboratories*, Defense & Technology Paper 58, Center for Technology and National Security Policy, National Defense University, March 2009.

40. Lyons, John W., et al., *Strengthening the Army R&D Program*, Center for Technology and National Security Policy, National Defense University, March 2005.
41. Nasr, Susan L., "Top 10 Game-changing Military Technologies," HowStuffWorks, http://www.howstuffworks.com/10-game-changing-technologies.htm.
42. National Academy of Sciences, *Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future*, National Academies Press, Washington DC, 8 March 2007.
43. National Association of Manufacturers, The *Looming Workforce Crisis: Preparing American Workers for 21st Century Competition,* Labor Day Report 2005, Washington DC, September 2005.
44. National Research Council, *1999-2000 Assessment of the Army Research Laboratory*, Army Research Laboratory Technical Assessment Board, Commission on Physical Sciences, Mathematics, and Applications, National Research Council, National Academies Press, Washington DC, 2001.
45. National Research Council, *Assessment of Department of Defense Basic Research*, Committee on Department of Defense Basic Research, Division on Engineering and Physical Sciences, National Research Council, Washington, D.C.: National Academies Press, 2005.
46. National Research Council, *Managing Air Force Basic Research*, Appendix C, National Academies Press, Washington DC, 1993.
47. National Research Council, *The Army Research Laboratory: Alternative Organizational and Management Options*, Committee on Alternative Futures for the Army Research Laboratory, Board on Army Science and Technology, National Academy Press, Washington DC, 1994.
48. Ogg, Erica, “How Apple Gets Away with Lower R&D Spending,” GigaOM Pro, 30 Jan 2012, http://gigaom.com/apple/how-apple-gets-away-with-lower-rd-spending.
49. R&D Editors, "R&D Change in the 1980s," *R&D Magazine*, April 2012(www.rdmag.com).
50. Solow, R. M., “Investment and Technical Progress,” in Arrow, Karlin and Suppes, eds., *Mathematical Models in Social Sciences*, 1960.
51. Sondhi, M. Mohan, “Reflections on My Career at Bell Labs,” IEEE *Signal Processing Magazine,* IEEE, 2006.
52. Stokes, Donald E., *Pasteur’s Quadrant-Basic Science and Technology*, Brookings Institution Press, Washington DC, 1997.
53. Task Force on the Future of American Innovation, *The Knowledge Economy: Is the United States Losing Its Competitive Edge?*, 16 February 2005.
54. Thane, John M., "The Future of the Uniformed Army Scientist and Engineer Program," *Military Review*, November-December 2007.
55. Thomas, Patrick, and Anthony Breitzman, "Apple Has the Most Powerful Patent Portfolio in Consumer Electronics,” *IEEE Spectrum*, November 2011.
56. U.S. Army RDECOM, "Mission," U.S. Army RDECOM homepage, as of 7 August 2009.