Army Science Board
Fiscal Year 2017 Study

Improving Transition of Laboratory Programs into Warfighting Capabilities through Experimentation

Final Report
October 2017

Department of the Army
Office of the Deputy Under Secretary of the Army
Washington, DC 20310-0103

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December 6, 2017

DUSA-ASB

MEMORANDUM FOR SECRETARY OF THE ARMY

SUBJECT: Final Report of the Army Science Board, "Improving Transition of Laboratory Programs into Warfighting Capabilities through Experimentation"

1. I'm pleased to forward the final report of the Army Science Board (ASB) study titled "Improving Transition of Laboratory Programs into Warfighting Capabilities through Experimentation." The purpose of the study was to assess whether and how earlier integration of experimentation into applied and advanced technology development phases could improve the Army's transition process. Specifically, the ASB looked for ways to avoid the so-called "Valley of Death," where innovative technologies languish instead of contributing warfighting capabilities.

2. For this effort, the ASB brought subject matter experts in Physics, Mechanical Engineering, Neuroscience and Cognitive Studies, Electrical Engineering, Medicine, Chemistry, Public Health, and a variety of military operations and technologies, as well as former Army leaders. During its seven months together, the study team conducted over forty visits and interviews among Army and DoD agencies, Federally Funded Research and Development Centers, Academe, and commercial industry.

3. From their work, the study team made several findings around avoiding the "Valley of Death," to include targeted investment strategies. The study team recommended the Army increase its technology maturation budgets and appoint and authority responsible for facilitating coordination and easing transitions between the key organizations in the technology development process. The findings and recommendations were adopted by unanimous vote of the ASB on July 20, 2017.

4. I hereby endorse the findings and recommendations in this report.

Leonard W. Braverman
Chairman

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EXECUTIVE SUMMARY

The Army's current process of transitioning technology from an operational requirement to something useful to Soldiers in the field puts the Army's overmatch capabilities at risk. This study sought to identify methods to improve that process through experimentation, which, for the purposes of this study, was defined as a procedure or operation carried out to investigate a hypothesis and to generate knowledge. That knowledge, in turn, solves problems and helps to answer questions pertaining to the practical, warfighting application of technology.

The main goal of the study was to demonstrate how experimentation should play an integral role in all areas of the Army Materiel Development Process. To illustrate the shortchanging of experimentation in current processes, the study team cited the case of a sensor developed by Night Vision Laboratories (NVL) that mitigated brownout conditions experienced by rotorcraft crews. Brownouts contributed to 496 Soldier fatalities during the wars in Iraq and Afghanistan. Despite the need for the sensor, requirements were written beyond the urgent need (e.g., included whiteouts from snow), and as a result, the sensor that fixed an immediate problem wasn't accepted by program managers because it didn't meet all requirements. Had experimentation been used earlier in the process, and had program managers been given authority to exercise judgment in meeting a critical requirement, the NVL capability could have been fielded and Soldiers' lives could have been spared.

In closely reviewing the current Army Materiel Development Process, the study team noted a lack of overall leadership between functional areas. Currently, requirements comprise a wish list of capabilities which must be met. Such rigid requirements make funding for operational experimentation difficult to obtain. Program managers are unwilling to accept the risk of validating and promoting partial capabilities, thus, it's nearly impossible to validate technology that's "good enough."

The study team also noted that no one owns the materiel development process from start to finish, and there's no accountable authority for results. Thus, it's difficult to make changes to requirements once they're set, and promising new technologies ultimately fall into the "Valley of Death," never making it to warfighter experimentation. Meanwhile, the warfighter must still overcome materiel shortfalls to combat adversaries' strengths.

To identify a more efficient method, the study team examined other organization's processes. For example, the Army Medical Community maintains an integrated process in which a group of interdisciplinary team members and end users are involved from the very beginning of the process, and experimentation is integrated throughout, continually helping to refine requirements and generate solutions

The Navy's Experimentation and Development Process also uses sponsor involvement from the earliest stages by requiring resources to be tied to transition agreements. The Navy gives program managers oversight responsibilities from requirements definition to operational

prototyping, and uses early experimentation for concept validation and forming the basis for S&T funding.

Finally, the study team looked outside the military to the National Science Foundation's I-Corps model, which strives to understand operational needs through early experimentation, thereby reducing investment risks. The model utilizes experimentation to identify end-user needs and then to develop the technology to meet those needs, rather than developing technology that users may or may not find usable.

By incorporating experimentation early in the development process, prior to the traditional S-curve processes, concepts can be validated earlier, and assumptions can be refined throughout the process. Using the I-Corps' model for "evidence-based entrepreneurship," the Army could reduce the risk of writing faulty requirements and losing technologies needed by warfighters to the "Valley of Death" due to lack of ownership and resources.

In summary, the study found that experimentation plays a critical role to validating and expediting capability development for warfighters. It's a key enabler to win wars and save lives. To adequately implement and manage experimentation in the Army, it's essential to provide adequate experimentation budgets for early concept-to-operational validation of technologies, and to establish Army senior leadership accountability, direction, and oversight for technology transitions that can oversee all experimentation activities.

1.0 INTRODUCTION

We're living in an era of rapidly advancing commercial technologies that regularly enable development of a host of new consumer capabilities. Many of these technologies have potential military applications (e.g., autonomous systems, machine learning, robotics, big data mining, 3-D printing, solar power). If the Army is to maintain its overmatch in the future, it must develop methods and processes to adapt these new technologies into military capabilities more quickly and effectively than our adversaries.

1.1 STATEMENT OF THE PROBLEM

Currently, our adversaries are more competent at fielding technology, which places our Soldiers at a significant disadvantage. Congress has been especially vocal on the topic of increasing the speed of military capability development and deployment, pointedly highlighting these concerns to Army Undersecretary Ryan D. McCarthy during his nomination hearing in July 2017.

Congress' increased focus on technology and capability development also motivated the reorganization of the Department of Defense (DoD) Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics (OUSD(AT&L)). In February 2018, AT&L will be divided into two organizations, with an undersecretary for research and engineering, and an undersecretary for acquisition. In the new structure, technology development will hold equal standing with acquisition and sustainment in the DoD.

1.2 TERMS OF REFERENCE (TOR)

The implementation of flexible processes relying on experimentation to rapidly evaluate the military potential of technologies will be key to increasing the rate of new capability development and deployment. Traditional S-curve development that uses structured, linear methodologies will no longer be effective in an environment where we see massive, parallel technology advancements which render technology mired in process obsolete.

"Valley of Death"
When a technology has been demonstrated but falls stagnant and cannot move forward into a program and capability insertion.

As a result, the Secretary of the Army asked the Army Science Board (ASB) to undertake a study investigating how to improve the Army's fielding of technology using experimentation. The study was also to address the question of how emerging technology could avoid falling into the so-called "Valley of Death," a phase occurring when a technology potential has been demonstrated but falls stagnant and cannot move forward into a program and capability insertion.[1] Typically, the "Valley of Death" occurs after Technology Readiness Level (TRL[2]) 6 when the technology has been demonstrated in a simulated operational environment.

The Secretary gave ASB five critical tasks under the TOR:

1. Review past technology development approaches to include: S-curve processes, concurrent engineering practices, past strategies used to develop offset capabilities, and Science Board studies on S&T development.

2. Define the term "experimentation," and compare it to definitions for "demonstration" and "testing."

3. Analyze and validate where and how early experimentation enables advances in Army capabilities.

4. Evaluate processes for S&T experimentation investment strategies.

5. Evaluate the use of capability fielding strategy as a criterion for program investment decisions.

1.3 STUDY TEAM & METHODOLOGY

For this effort, the ASB enlisted members with expertise in physics, mechanical engineering, economics, cognitive studies, electrical engineering, law, medical research, organic chemistry, and business, as well as the military experience of former and retired Army officers (see Appendix B).

The study team gathered data during 40 visits and interviews conducted over seven months with representatives from government, academia and industry. From the data, the study team derived key definitions of terms, established a baseline for the Army's Materiel Development Process, and identified best practices in Government, academia, and commercial industry. The team analyzed the latter and determined which models could best fit the Army in terms of scale and operational requirements. From these, the team distilled a concept for early experimentation that informed both the Material Development Process and the Army's S&T investment strategy. The team concluded by crafting its findings and recommendations to provide an analysis of experimentation within the Army and an investment strategy to promote experimentation within the Army S&T budget.

[1] Davis, Anthony Tom Ballenger, Bridging the "Valley of Death." Defense Acquisition University, Feb 2017

[2] Adopted from NASA, TRLs break down development from basic scientific research (TRL 1) through to the application of a mature technology under operational mission conditions (TRL 9). See Appendix D for a complete listing of TRL definitions.

1.4 FOCUS

The Army materiel development process uses experimentation at every stage to influence and make decisions on critical parameters. For example, U.S. Army Training and Doctrine Command (TRADOC) uses war-game experiments to define critical gaps and needs of the Army, which are then used to influence requirements development. Requirements in turn are influenced by Army Centers of Excellence (COEs) and their capability experiments with industry partners, which evaluate solution sets. This study wasn't intended to look at experimentation through the entire development process. Rather, the study focuses on the question of how experimentation is being used, and how else it might be used, to expedite and influence the transition of technology from laboratory environments into operational capability.

In the "Valley of Death," as defined above, technology lies in limbo, cast aside without the resources to proceed. Typically, this occurs when a technology is demonstrated in a relevant environment and achieves a TRL 6, but then needs additional funds to demonstrate the capability in actual system environment settings to move to TRL 7 (Fig. 1.0).

This study examines that phenomena, why so many technologies fall victim to the "Valley of Death," and what role experimentation plays in transitioning technology into operational capabilities. The study also considers how experimentation can play a role in expediting capability development.

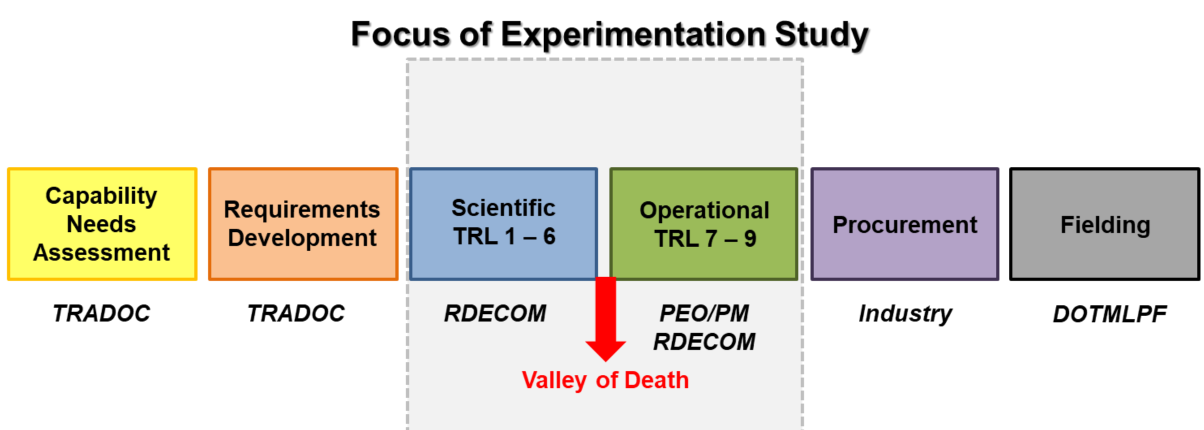

Figure 1.0 Study Focus on the "Valley of Death."

1.5 DEFINITIONS

The panel was specifically asked to define experimentation and to differentiate experimentation from demonstration and testing. Often, the terms are used interchangeably but have different meanings and connotations. The formal definitions that the panel acquired were based on Army sources and Army standard definitions.[3]

- Testing: A defined process or method for assessing if a specification / requirement has been met; ***measures performance*** against set criteria.

Testing for the Army implies a "go / no-go" decision as defined by Army Test and Evaluation Command (ATEC). Requirements and / or criteria are set, and then a process is used to see if those objectives are met. If the requirements cannot be met, presumably the Army will not go ahead with the acquisition. However, testing in a more general sense, such as in laboratory environments, may only provide a measure of overall performance. In that case, the determination is less absolute.

- Demonstration: A version of the end product is used to ***showcase*** new ideas, performance, methods, or features. Demonstrations are externally focused and must be successful to confirm capabilities.

Demonstration has an implication of success, as demonstrations are used to display successful capabilities. In the acquisition development process, demonstrations are used to validate and showcase performance and are used as criteria in moving forward to the next step of the acquisition process.

- Experimentation: A procedure or operation carried out to ***investigate a hypothesis and generate knowledge***. It solves a problem or helps answer questions using structured methodology that measures dependent and independent variable interactions.

Experimentation gains knowledge. It doesn't involve a "go / no-go" decision, nor does it need to have a positive result. Based on the scientific method, it starts with an assumption or hypothesis, then a set of procedures investigates that assumption using structured methodologies to measure the interaction of dependent and independent variables. The resulting observations and conclusions constitute knowledge. There's no such thing as "failure" in experimentation, because an unfavorable set of results produces useful information Knowledge is gained from studying failures as well as successes.

The study team determined one additional definition was necessary to complete the set of commonly used, and sometimes mistakenly, interchanged terms:

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[3] Army Regulation 73-1 - Test and Evaluation; Test and Evaluation Policy; 1 August 2006. USACDEC Experimentation Manual, October 1981; Govt Accession No. AD-A124297. CJCSI 3170.01 Series, "Joint Capabilities Integration and Development System," 12 March 2004

- Prototyping: Use of a technology product (e.g. from an early sample or model to full-scale replica) to assess a concept or process or to act as something that can serve to provide learning or can be replicated.

To perform experiments, prototypes of early releases of concept models are often built for evaluation and to obtain information. These prototypes can yield successful results and then be used as demonstrators for concept showcasing.

2.0 ANALYSIS OF EXPERIMENTATION

The study team analyzed research and development activities in various organizations throughout the DoD and the National Science Foundation. Specifically, the study team focused on methods to expedite the transition of successful technologies into useful capabilities, avoiding the kind of stagnation experienced in the Army's "Valley of Death." The team payed special attention to the role of experimentation in capability development and expedited transitions.

2.1 ARMY'S LINEAR PROCESS

Typically, the Army develops technology and capabilities linearly (i.e., following an S-curve model), going from concepts to scientific development to operational capabilities, (Fig. 2.0). In the current process, there are three stovepipes, but no one owns the process, and little attention gets paid to concurrent engineering, managed transitions, and iterations between these communities. If breakthroughs do occur, they must wait for the next planning cycle.

Figure 2.0 Army Materiel Development Process

The Army's approach to developing technologies is described in detail in "How the Army Runs" and numerous other documents.[4] A key element of technology development is the Army's Science and Technology (S&T) program. The *Army Science and Technology Master Plan (ASTMP),* published biannually, is the strategic plan for the Army's S&T program, which describes the Army's S&T vision, objectives, priorities, and corresponding strategy. It's derived from DoD guidance as well as from other Army organizations, such as TRADOC's Capabilities Needs Assessments. The Army's Research, Development and Engineering Command (RDECOM) carries out the majority of the Army's S&T program, and supplements the ASTMP with its own RDECOM Strategic Plan, which describes how "RDECOM develops the innovative technology that enables the Army's land warfare dominance now and on the battlefield of 2025 and beyond."[5]

The Army's S&T program consists of three parts - basic research (6.1), applied research (6.2), and advanced technology development (6.3).[6] Basic research (6.1) precedes the system-specific work described in the ASTMP and includes all scientific studies and scientific experiments

[4] How the Army Runs: A Senior Leader Reference Handbook, 2015-2016. Army War College, School of Strategic Landpower Carlisle United States. http://www.dtic.mil/get-tr-doc/pdf?AD=AD1001713

[5] RDECOM Strategic Plan: Enabling Battlefield Dominance through Technology FY 2015-2040.

[6] See Appendix E for a complete listing of DoD R&D definitions.

directed toward increasing knowledge and understanding in fields related to long-term Army needs. Applied research (6.2) transitions promising basic research and includes efforts directed to the solution of specific military problems, but not major development projects. Advanced technology development (6.3) includes those efforts directed toward hardware development for operational testing to prove feasibility. From this point, the goal of the S&T program is to support the transition of technologies into operational systems that satisfy approved warfighting capabilities-based materiel requirements. Key to this transition strategy is demonstrations.

In the basic research phase, experimentation occurs at the bench-level with the goal of increasing scientific knowledge. In the applied research phase, most of the effort focuses on applying the scientific knowledge to determine a solution to an Army problem, while in the advanced technology development phase, a prototype might be built for operational testing. The actual warfighter has little to no input into the S&T stages until there's a "widget" that needs to be tested. In fact, in the 2015 RDECOM Strategic Plan, the word "experiment" only appears once, in the caption to a figure.

2.1.1 CASE STUDY: DEGRADED VISUAL ENVIRONMENT (DVE)

The study team cited the following example to illustrate how important, useful technologies can fall into the "Valley of Death," and how experimentation can be used to assess and validate technology potential, as well as to help move the technology forward into programs and capabilities.

Army aviation operations experienced a series of serious accidents, many fatal, in which helicopters were losing stability as they landed in sandy areas of Iraq and Afghanistan. During Operation Enduring Freedom and Operation Iraqi Freedom (OEF / OIF), there were 375 rotorcraft losses with 496 fatalities from October 2001 to September 2009. Mishaps accounted for 81 percent of all losses, with combat losses (i.e., aircraft shot down) accounting for the remaining 19 percent; 73 percent of the fatalities occurred in a combat theater. The combined mishap loss rate (both combat non-hostile and non-combat) was 2.71 losses per 100,000 flight hours, slightly exceeding the loss rate due to combat hostile action. The in-theater mishap loss rate was ten times worse, and the out-of-theater loss rate was four times worse than the Congressional and SECDEF goal of 0.5 mishaps per 100,000 flight hours. Loss of situational awareness and other human factors accounted for more than 79 percent of the losses of airframe and fatalities.[7] The primary causal factors were controlled flight into terrain and brownout, a condition occurring when helicopters generated a large cloud of dust that surrounded the aircraft, virtually blinding the pilot.[8] The pilot would then lose orientation,

[7] Mark Couch (IDA) and Dennis Lindell (Joint Aircraft Survivability Office), "Study on Rotorcraft Safety and Survivability."

[8] Brownout is caused by the downdraft created by a helicopter as it lands over dust-strewn ground. The cloud of dust creates an opaque environment that makes it impossible for the pilot to see beyond one or two feet outside the windshield of the cockpit. At that point, disorientation can occur, causing the pilot to lose sense of the vertical direction.

which caused the helicopter to tilt as it came close to landing, with the rotors striking the ground and resulting in catastrophic failure. The Army identified this condition as Degraded Visual Environment (DVE).

The frequent accidents were so serious that the Army designated the ability to fly helicopters in DVE as one of its top three priorities, and a requirement was written to institute a Program of Record (PoR) to develop a rotorcraft mounted sensor that would allow pilots to be able to see through the clouds of dust whirling around helicopters as they landed.

In response, the Night Vision Laboratory at Fort Belvoir identified a spectral “window” through which electromagnetic radiation can penetrate, and they were able to develop a sensor sensitive to those wavelengths that could display the surrounding terrain onto a screen, much as it would appear in a clear environment. This approach to solving the DVE problem was promising, as there are spectral “windows” in the atmosphere through which light can penetrate, including air containing the fine-grained particles that cause brownout.

Unfortunately, when the sensor requirement was submitted for authorization, it included other environments that can cause a degraded visual environment, such as fog, heavy rain, or “whiteout,” a similar condition occurring in snowy regions. As written in the requirement document, the major categories of DVE included brownout, whiteout, smoke, sand / dust storms, fog, rain, clouds, snow, smog, night, and flat light. The Army’s research and development community, especially AMRDEC, took on the challenge of developing aircraft instruments that could defeat DVE. They identified three key technology components that are part of any comprehensive DVE solution: flight controls, cueing, and sensing. The threshold demonstration goals for the DVE Program thus included rotorcraft piloting capability in all limited visibility environments with all-around situational awareness and the ability for multiple aircraft to cooperatively operate within DVE.

While Night Vision Laboratory successfully developed a sensor that could see through brownout conditions to the point of prototype testing, funding had only been allocated for the basic research to develop the sensor. Funds were then given to a commercial vendor to build a prototype sensor. Once the sensor was developed, additional funding was needed from advanced technology development (6.3) or demonstration and evaluation (6.4) funds to integrate the sensor with the flight operating systems of each of the helicopters being used in Afghanistan. No such allocation was made, because Army 6.3 funds are, in general, very scarce and 6.4 funds are controlled by programs.

The Army’s inability to adjust its DVE requirement statement meant that program managers (PM) for the Blackhawk helicopter were unable to fund a transition for going from the successful sensor prototype to deploying sensors on helicopters, even though solving the brownout problem remained one of the Army’s highest priorities. It remains an open question as to why a program manager didn’t modify the requirement statement to accept the solution for brownout only and drop the requirement for other less urgent environments. That failure of leadership caused more Soldiers to lose their lives.

Once helicopter accidents began to occur in war theaters, commanders reacted in a timely fashion to designate an urgent need for the Army. When a requirement reached the Army's S&T community, in this case the Night Vision Laboratory, it responded rapidly and conducted experiments to achieve a technological solution to the problem. Within a short period of time, Army scientists became aware of a spectroscopic window in a dust cloud that could be leveraged to build a sensor that could see through brownout. They also became aware that other elements, especially water vapor, posed a more serious challenge that did not offer an immediate solution. Thus, while early use of experimentation was commendable, the advantages gained by using early experimentation to identify problems and to suggest a successful course of action to acquire the needed technology was undermined by the requirement process (i.e., the need to develop a 100% versus 80% solution).

The failure to make sensible decisions in R&D can cost Soldiers their lives.

The originators of the requirement statement ultimately compounded the problem by imposing requirements that were too rigid and technically challenging for a specific situation that needed an immediate solution. Because of the way the requirement was written, a partial, 80%, solution wasn't sufficient. Clearly, the requirements developers lacked the insights that experimentation and user feedback could have provided to write a flexible requirement to meet the Army's needs. Furthermore, the requirement was never adjusted based on the insights provided by Night Vision Laboratory. A designated manager would have had the ability to understand the technical issues involved and, therefore, would have been able to make a competent decision and the necessary adjustments.

2.1.2 DVE LESSONS LEARNED

At this point, it's unclear whether a lack of a technical education and training was an underlying factor in the decision-making that prohibited a revision of the requirement statement. Regardless, this case study illustrates the importance of having technically competent leadership that understands the value of experimentation making technical decisions and managing the transition of a technology through the "Valley of Death."

The study team found this example indicative of the Army's linear development process, which lacks overall leadership oversight, accountability, and coordination, making technology transition and capability development difficult (Fig. 2.2).

An Army transition manager could have shepherded the Night Vision Laboratory-developed sensor forward. That same manager could have also steered efforts away from technologies identified by experimentation as being inadequate, and adjusted requirements when experimentation provided useful new information. More specifically, the transition manager could have (1) utilized experimentation to influence early requirements, (2) identified a need for resources for operational experimentation, and (3) stewarded a partial solution in PoRs.

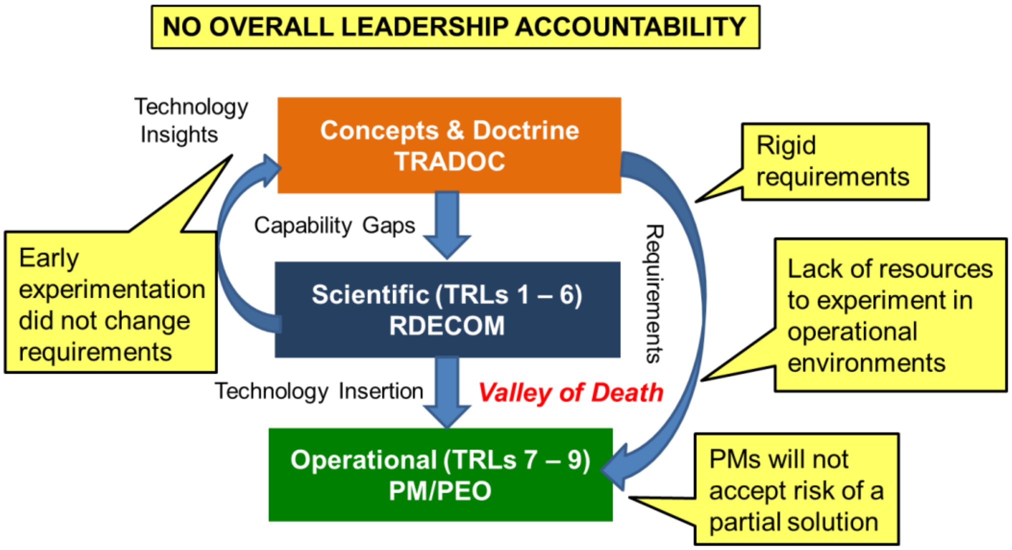

Figure 2.1 Breakdowns in the Army's Development Process

2.2 ALTERNATIVE TECHNOLOGY DEVELOPMENT PROCESSES

With the DVE case study as an example of the breakdowns that can occur in the Army's technology development process, the study team turned to examine three alternative development processes to extract best practices for achieving technology transition.

2.2.1 U.S. ARMY MEDCOM

The U.S. Army Medical Command (MEDCOM) has an integrated requirement generation, research and development (R&D), advanced development, and acquisition process. To execute these functions, MEDCOM has two subordinate commands, the U.S. Army Medical Department Center & School (MDC&S) in San Antonio, TX, and the U.S. Army Medical Research and Materiel Command (MRMC) in Fort Detrick, MD. Both are commanded by a Major General and report to the MEDCOM Commander, a Lieutenant General, providing solid leadership oversight, so that any issues related to requirements, R&D, or acquisition can typically be resolved by the commanders.

The MDC&S is responsible for generating medical concepts, doctrine, and requirements based on a cyclical process informed by the global medical state of the art and science, epidemiological studies, scientific breakthroughs, and development efforts. The MDC&S integrates requirements with all the TRADOC subordinate commands, and the final requirements are approved by the Commander of TRADOC.

The MRMC coordinates its R&D and acquisition efforts with the larger Army R&D community as well as with other Program Executive Offices (PEO) and receives final approval and funding from the Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA(ALT)).

A true cradle-to-grave organization, the MRMC is responsible for the R&D, advanced development, acquisition, and sustainment of the medical force (Fig. 2.2).

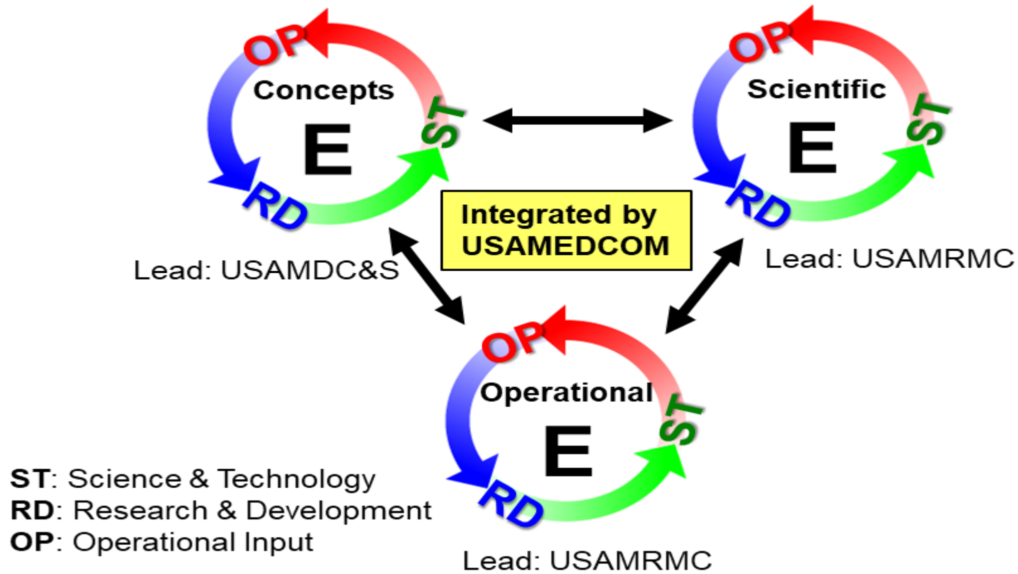

Figure 2.2 MEDCOM's Efficient, Cyclic Integration

Most medical requirements identified by the MDC&S are fulfilled by commercial off-the-shelf (COTS) products, such as pharmaceuticals, vaccines, diagnostics, and medical equipment. A market assessment is made for each product that may need modification or total development. To lower costs and ensure reliable availability, it's preferable to co-develop a product that will have a large market outside DoD in partnership with industry. For example, the miniature ultrasound diagnostic device had a wide market outside the military.

If there are no COTS products, or the available COTS products don't meet all the operational requirements (e.g., security, power, transportation, field sustainment), then an R&D and acquisition strategy is developed with input from MDC&S, MRMC intramural and extramural scientists, and industry. For example, mitigating infectious diseases like malaria or dengue, which present a threat to the force in OCONUS environments, requires MRMC to develop vaccines or treatments. Pre-hospital trauma solutions also required MRMC efforts, given that there are hardly any COTS products addressing these requirements. More notably, the U.S. military was the sole customer for the Anthrax vaccine, an "orphan" medical product that resulted in increased DoD development costs.

When a new product needs development to meet a requirement, a development plan is created by a multidisciplinary team that includes basic scientists, clinicians, and PMs. For highly complex programs, MRMC may recruit the National Academy of Medicine to help with the development plan. After reviewing the state of the science surrounding the requirement and product solution, the command seeks solicitations for research on topics that will lead to product development. This effort is led by a portfolio manager, a staff officer at the headquarters at MRMC charged with the management of R&D programs. The portfolio manager has total visibility and manages all intramural and extramural research efforts in a specific research thrust (e.g., combat trauma, infectious diseases, etc.). All proposed research in the command is peer reviewed to ascertain the scientific merit, experimentation rigor (including protection of animal and human subjects), and programmatic merit (how necessary for product development). As the science progresses from basic research (6.1) to advanced development (6.3), an interdisciplinary team is formed that includes basic scientists, clinicians, manufacturing experts, Food and Drug Administration (FDA) compliance officers, legal officers, and others, as needed, to shepherd the product. Initially, the basic scientist or clinical scientist with the most scientific product knowledge serves as the interdisciplinary team lead. Once the research is completed, the team conducts a review to identify new intellectual property (IP) and to pursue the IP as warranted. Members of the team also begin to seek potential industry partners to help with the development strategy.

As the science matures to demonstration and validation through clinical trials and early product manufacturing (6.4), the lead of the interdisciplinary team transfers to a product manager with acquisition expertise. If an industry partner is engaged, the development plan is revisited with input from the new partner, and the membership of the interdisciplinary team expands to include industry members. The complexity of medical product development, and the typical challenges involved in clinical trials and scaling up manufacturing necessitates utilizing an interdisciplinary team throughout the entire product development process.

The final authority to use medical products on Soldiers resides with the Commissioner of the FDA, which is different from the rest of the DoD R&D and advanced development processes. To obtain FDA approval, it's necessary to abide by all the FDA processes, including the key requirement that experimentation informs all product development, to include basic science, scale up, user acceptance, and operational (clinical) deployment.

FDA regulations force the use of experimentation throughout MRMC's development process.

The presence of uniformed scientists and clinicians during the requirement generation, R&D, acquisition, and sustainment phases of development differentiates the MEDCOM process from the larger Army S&T effort. The incorporation of uniformed scientists and clinicians brings practical, operational input and leadership to all of the organizations and processes responsible for the development of medical solutions. This assures operational user involvement in each step and every organization involved in the effort.

In addition, the MDC&S model is largely threat-based, using epidemiological studies to inform the prevalence of disease is in a given community, the incidence, or number of new cases in a given community, and other risk factors, such as presence of vectors (e.g., mosquitoes) or agents (e.g., particular weapon systems) that may cause injury. These factors determine the risk to the force and drive the prioritization of the R&D and acquisition strategy. The MDC&S then relies on an interdisciplinary team of doctrinal experts, scientists, clinicians (operators), and logisticians to validate the threat and to identify the capabilities required to mitigate the threat. The final product of the process, requirements documents, broadly identify the needs of the Army to mitigate the threat and drive the R&D, acquisition, and the sustainment efforts.

Medical S&T are continuously evolving, requiring the requirement generation system to be nimble.

By writing the requirements in broad terms, MDC&S paves the way for allowing its medical units to resource state-of-the-art equipment. For example, MEDCOM obtains new, advanced x-ray machines because its requirements are generic enough to drive a flexible acquisition strategy. The requirements don't specify types of injuries or body parts, which would narrow the types of machines that could be used. Rather, and in direct contrast to the typical Army requirements development process, they allow for R&D and / or acquisition of the most technologically advanced x-ray machine available.

In sum, MEDCOM provides an example of an efficient, integrated product development cycle. Concept improvement, requirement generation, and product development are concentrated in two subordinate commands (MDC&S and MRMC). The key differentiators of this model from Army S&T include:

- Allows for nimble and flexible requirement generation
- Experimentation informs all steps in the process, from requirements to manufacturing
- Interdisciplinary teams lead all efforts
- Uniformed users (clinicians from medics, nurses, and physicians) are in each interdisciplinary team from beginning to end
- Peer review assures rigorous experimentation and scientific / programmatic merit.
- Centralized research portfolio management improves the R&D process

2.2.2 OFFICE OF NAVAL RESEARCH

The study team visited the Office of Naval Research (ONR) to examine their R&D organization and processes. Previous interviews with leaders in the Office of the Secretary of Defense (OSD) indicated that the Navy achieves high rates of successful technology transitions into capability development (Fig. 2.3). According to the Future Naval Capabilities (FNC) Guidebook, "Sixty percent of all transitioned products are assessed as either deployed or still being further engineered and integrated within an acquisition program of record."[9] The study team wanted to understand the underlying factors that led to these successful transition rates.

Figure 2.3 ONR Technology Transition

The study team's first observation focused on command and authority. The Chief of Naval Research (CNR) is an Echelon 1 command position, meaning the operational commanders have a direct relationship with the CNR and have input into the CNR's research agenda and priorities. This high-level connection between the operational and research functions of the Navy provides opportunities for socializing new research areas and for ensuring buy-in from the operational leadership for new technology transition. There's no analogous position in the Army, meaning Army research efforts don't have high-level representation or connection to the operational commands.

The ONR is a research organization in public law where the leader (the CNR) acts as the sponsor of the research being performed. This is an exception to the Goldwater-Nichols Act that gives both the ONR and the CNR the ability to integrate technical, programmatic, and procurement aspects required for the rapid transition of technology to the field in ways that other Services cannot. Because of that command authority, ONR can rapidly re-allocate funds to meet emerging needs without Congressional approval, creating an agile environment for meeting Navy technology requirements. Army research has a much more cumbersome funding path, with major program procurements taking ten to fifteen years to field due to institutional obstacles prohibiting the rapid altering of PoRs to incorporate novel technologies.

The CNR reports to a board that includes the Vice Chief of the Navy and the Assistant Commandant of the Marine Corp. The board reviews, shapes, and approves funding allocations across the ONR portfolio, kills under-performing programs, and protects funds for research. The

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[9] Future Naval Capabilities Guidebook, 2017.

board also recommends National Academy studies of selected topics and uses the results to shape lines of research. The entire ONR research portfolio and priorities are reviewed annually by the board, and the board provides the long-term vision for ONR research. In this way, the board serves both as the accountability structure for the CNR and ONR, as well as the advocate for naval research programs.

Because of this unique command authority, ONR doesn't have an analog to the Army's Materiel Command (AMC) or the Training and Doctrine Command (TRADOC). ONR generates requirements that are based on the its PMs' relationship with Naval operational units. Similarly, where the Army has separate organizations for internal and external research (Army Research Laboratory (ARL) in Maryland and Army Research Office (ARO) in North Carolina, respectively), ONR has all its internal and external research PMs in the same building. This facilitates communication and collaboration across intramural and extramural research efforts, as well as the maturation of new technologies.

The Army's research efforts (6.1, basic research, to 6.6, research, development, testing and evaluation management) are highly distributed across ARL, ARO, RDECOM, and the COEs. Early research (6.1 to 6.3, advanced technology demonstration) is usually performed at universities, ARL, and RDECOM and transitioned to the field by the COEs and Army PoRs. While most early research ends at a TRL 6 (technology demonstration), most PoRs won't accept new technologies unless they're at TRL 8 (proven technology) or TRL 9 (final application). The disconnect forms the "Valley of Death." The Army's lack of organizational ownership of new technology maturation and requirements development for new technologies exacerbates the gap. On the other hand, within the ONR structure, the stages of research from 6.1 to 6.6 are integrated, allowing for project-based consistency as the novel technology is matured and prepared for fielding. The 6.2 (applied research) and 6.3 PM leads may be the same person, or are highly coordinated teams.

The ONR has approximately 120 Future Naval Capabilities (FNC) program officers overseeing 6.1 and 6.2 research. The goal of an FNC is to rapidly mature and transition new technologies, usually within a two to three-year window. There's a competitive, internal process to secure funding, which focuses on high-risk, high-reward research efforts. Program officers are incentivized to fund transition by developing relationships and trust with the PEOs of Navy PoRs, to include the development of validated requirements for new technologies within a PoR. The ONR accomplishes most of the new technology insertions by engineering change orders to existing PoRs. That contrasts directly with the Army, where it's difficult and time-consuming to change an established PoR. Moreover, to further improve transition from FNC research to PoRs, ONR will not fund 6.4 maturation of new technologies until the PoR allocates their own 6.4 funds that are within the Future Years Defense Program (FYDP). This increases the PoR's commitment to transition the selected technology, and avoids ONR investing in technology that the PoR isn't prioritizing. Transition agreements that are made with the PoRs and are tied to resources within the Program Objective Memorandum (POM) have shown the highest success rates. In addition, ONR is moving toward having fewer FNC projects and limiting the duration of the projects to within the FYDP, also to improve transition to the warfighter.

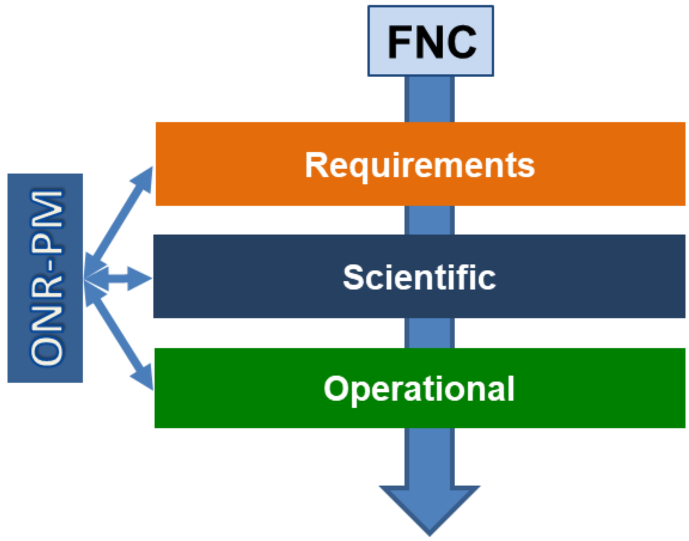


Figure 2.4 Program Manager Oversight in ONR

In another contrast to the Army, the end-state of the PoR's capabilities are clearly defined, but the methodologies used are intentionally not overly specified. This allows ONR to rapidly change the materiel solution for a component of the PoR as technology evolves. The Army procurement process specifies both the materiel solution and the process by which it is developed. This locks the technology solution provider into providing a deliverable that may be obsolete by the time the contract is enacted, and makes the Army technology fielding of new technologies much less agile.

In terms of organizational culture, the identification of new technologies for use in Navy systems is everyone's responsibility, in the sense that ideas for research come to ONR from across the Navy. To vet the research ideas, ONR emphasizes competition within and across the technology portfolios and requires constant PM engagement with Navy PEOs for PoRs. Experimentation is used to validate concepts and to compete for resources. By intentionally integrating technology development, technology maturation, requirement development, and operational feedback, ONR has created a tightly integrated process for technology transition and an organizational culture that collaborates in fielding new technologies.

The PMs at ONR are also seen as the focal points, continually monitoring development, integrated across communities of interest, and adjusting plans to ensure technology is transitioned and capabilities are developed. The Army has no analogous position or person to integrate functions and ensure smooth technology transitions and capability development.

2.2.3 I-CORPS

The National Science Foundation (NSF) works to improve the transition of technology into commercial startup ventures and established companies. Based on its work with Silicon Valley, NSF discovered that most startups fail because they don't understand the customer needs (Fig. 2.5). To address the issue, NSF developed a training program for research called the Innovation Corps (I-Corps). The program uses scientific methods to understand, evaluate, and validate opportunities and needs with the aim of better transitioning laboratory research to the commercial market. In five years, the NSF program has trained and graduated 905 research teams. Of these, 361 have formed companies and have acquired $103M in capital. Although it's still too early to predict the full level of success, Congress feels the NSF training model should be implemented in all Federal agencies where scientist conduct research. OSD is also using this training for scientists receiving DoD funding.[10]

Figure 2.5 Reasons for Startups Failures

The I-Corps model uses early experimentation for validating requirements and needs. Early experimentation, which is called "Customer Discovery," helps transition innovations across the "Valley of Death" between early technology development and customer acceptance. I-Corps

[10] Basic Research: Grants & Agreements; I-Corps @ DoD program, opportunity #W911NF-17-S-0011

leverages best practices culled from the experiences of Silicon Valley investors and entrepreneurs who explored creating business ventures based on new technology.

While NSF has a mission to advance fundamental research at the frontiers of knowledge, embedded within its mission statement is the advancement of the national “prosperity and welfare.” To that end, NSF provides roughly $7B in grants primarily to U.S. colleges and universities, with I-Corps serving as a mechanism to maximize the economic impact of NSF research investments. NSF incorporates I-Corps training into its activities to:

- Foster entrepreneurship leading to the commercialization of technology that’s been previously supported by NSF-funded research

- Prepare scientists and engineers to extend their focus beyond the laboratory and broaden the impact of select, NSF-funded, basic-research projects

The most common mistake made by young technology startups is failure to identify and understand customer needs, i.e., building technology that nobody wants. The lack of awareness underscores the idea that coming up with novel technology isn’t sufficient to ensure commercial impact.

Numerous examples highlight this point. In a well-known case of a company that failed to reach its initial expectation, Segway was launched in 2001, with some fanfare, as a revolutionary personal transportation platform. Its creator, Dean Kaman, predicted that the Segway “would be to the car what the car was to the horse and buggy.”[11] He anticipated that the Segway would have utilization across industries. The company initially targeted corporate and municipal clients but expected that it would also have mass market appeal. The lack of market adoption, however, underscored how little Segway understood about their customers. The early municipal customers, such as postal carriers and police departments, objected to the short battery life and the inability to sort mail and complete other tasks while on the Segway. Money allocated for production and logistics would have been better spent understanding and responding to customer needs. Kaman had predicted that the Segway would sell 50,000 units within its first year and secured nearly $100 million in funding to develop the manufacturing and distribution capacity consistent with that prediction. Despite the large, early investment, Segway sold only 23,500 units total during its first 4 years of operation. Today, the Segway is relegated primarily to the niche market of city tours. If there had been a better understanding of customer needs, the money could have been better utilized to support Segway or perhaps another startup.

To avoid similar mistakes. I-Corps training, initiated in 2011, invites university researchers to participate in an intense, 7-week course during which they’re required to engage customers, partners, and competitors in order to understand the needs of the marketplace. The I-Corps environment is fast-paced and relentlessly direct. Teams that participate are challenged to

[11] Wall Street Journal, “From Hype to Disaster: Segway’s Timeline” 27 Sep 2010.

learn quickly whether there is a core idea worth pursuing further. They do this by applying Customer Discovery, which is a variant of Concept Evaluation and User Analysis.

At the heart of the I-Corps process lies early experimentation in advance of technology development. Although teams come into the program with viable basic research or more, the focus of early experimentation is not overcoming technical challenges. Rather, the process focuses on exposing stakeholder needs and pain points and using that data to identify issues that will raise barriers to user adoption or partner acceptance. It should be noted that in the context of early experimentation, the broad term “stakeholders” includes end users of the innovation as well as buyers, decision makers, influencers, recommenders, and potential saboteurs. In the context of the Army, this implies that the warfighter should be engaged early, as should potential PMs, to bridge the “Valley of Death.”

The I-Corps program also requires participating teams to test the underlying hypotheses that inform their innovation. To address the start-ups’ lack of understanding of market needs, hypothesis testing in I-Corps begins with exploring who the target stakeholders are and what they need. After confirming a “problem-solution fit,” teams have a ranking of specific problems that exist in their stakeholder ecosystem. These are used to inform requirements for initial prototyping, such that testing “product-market fit” can commence.

Following this process, the full set of product requirements the team envisioned upon entering the program generally gets reduced, and that reduction saves development time and capital expenditures. It also motivates early prototyping, which drives continued experimentation. Prototypes can be used to test hypotheses on product viability, product usability, and other key assumptions, with the goal of obtaining user feedback. Within the I-Corps program, the early experimentation prototypes need not even be fully functional. For example, medical teams have used non-working prototypes to understand the form and function of medical devices in advance of full product development. Teams working on web or mobile application will use wireframes to represent the application. These substitutes serve as viable methods for obtaining getting critical stakeholder feedback, which is used to make incremental improvements to the prototype in a cyclical design process.

The outcome of the standard, 7-week I-Corps boot camp is a “Go / No-go” rating. During the course, teams present lessons learned each week as they investigate all aspects of the business model. These lessons touch on understanding the customer and the value the customer needs, determining how the innovation will be adopted and how to best socialize it for wide acceptance, deciding which activities need to be accomplished in-house and which need to be outsourced, and identifying the key elements needed to drive partnerships. A “Go” rating represents clear evidence of product-market fit; a “No-Go” represents anything less. Each team announces its own decision, and the instructors also provide an evaluation of each team based on their presentations.

The I-Corps program also provides a path for additional funding opportunities, as the NSF effectively established a series of gates for its grant process. For example, after a researcher secures a grant for basic research that forms the basis for an innovation, the I-Corps program would be introduced to help to guide additional investment in the form of follow-up research grants. The researcher would re-accomplish separate proposals for additional funding at each progressive level, i.e., advanced research, prototype development, and small business innovative research (SBIR). The NSF organizes a panel of subject matter experts to rate each proposal, with key criteria including intellectual merit and broader impact. Data collected from participation in the I-Corps program, particularly stakeholder feedback, helps participants enhance broader impacts. Not surprisingly, participants in I-Corps enjoy greater historical success rates for securing SBIR grants.

> **"I-Corps is at the leading edge of a strong, lasting foundation for an American innovation ecosystem."**
>
> **American Innovation and Competitiveness Act**

In addition to increasing commercialization activity, I-Corps also influences the research culture at commercial and educational institutions that participate in the program. Both Entrepreneurial Leads (ELs), who tend to be graduate students, and principal investigators (PIs), who are generally university professors, credit the program with changing their approach to research (Fig. 2.6). Participants often leave the program with a more entrepreneurial mindset, even if they intend to remain at the university.

Figure 2.6 I-Corps Post-Participation Survey

Due to its success, the I-Corps program has been recognized by Congress as a successful model to be replicated across other government agencies. Congress explicitly stated in the American Innovation and Competitiveness Act that, "The I-Corps program model has a strong record of success that should be replicated at all Federal science agencies."[12] The I-Corps program continues to expand and has been adopted at the National Institutes of Health (NIH) for its SBIR

[12] See https://www.congress.gov/bill/114th-congress/senate-bill/3084/text; p. 130.

awardees. Likewise, through the Hacking 4 Defense (H4D) program, I-Corps has begun to reach into the DoD.[13]

2.5 VALUE OF EARLY EXPERIMENTATION

The NSF I-Corps model proves that a focus on early, efficient experiments helps to mitigate risk and increases overall development efficiency. These are important factors considering the constrained research budgets throughout the DoD.

Stefan Thomke, a long-term researcher on experimentation at Harvard and MIT and author of of "Experimentation Matters," believes the significant upfront investments required for early experimentation efforts are rewarded by the long-term financial gains. Microsoft, for example, has invested extensively in test beds to run about 10,000 early experiments per year. One third of these experiments have no effect on Key Performance Indicators (KPIs), while one third have a negative effect, and about one third have a positive effect and move on to full project funding. From a narrow perspective, only a third of the tests are successful. However, from a learning and financial perspective, 100% of the experiments are successful, because they help limit the resource and opportunity costs that would have been incurred if all 10,000 developments were pursued. In the end, Microsoft is more efficient and effective in developing successful product launches.

For the Army, prototyping and experimentation allow early investigation of doctrine and tactics, accomplish mature hardware specifications for future development, and discard bad ideas before moving forward. This speeds up development and increases the probability of success. Experimentation with the user, in the field with troops, is a major determinant in establishing TRL and speeding up development.

The nuclear and automotive industries have also developed simulation and modeling tools to reduce costly testing.[14] While it's often the case that scientists and engineers will be skeptical of models and simulations, and the ensuing validation of results drives costs higher, early experimentation still provides overall cost reductions as well as improved success rates.

According to Thomke, there's a need for developing highly credible individuals with a background in experimentation to drive cultures that support iterative testing as early and as often as possible. Unfortunately, there are few courses on experimental design, and where courses are offered, they're taught sporadically, and participants forget the content because it's not reinforced throughout the curriculum. As a result, the role of controls, a topic in experimental design courses, is too often neglected by researchers.

[13] The H4D program recruits graduate students to work on Defense programs.
[14] Study team interview with Stefan Thomke on 17 July 2017.

3.0 INVESTMENT STRATEGIES

The TOR tasked the study team to evaluate processes and proponents for the Army's investment strategies and execution. Although the team didn't look at specific technology investments, it did consider strategies that could yield better-informed investments decisions by the Army.

3.1 CURRENT EXPERIMENTATION INVESTMENTS

Experimentation plays a major role in crossing the "Valley of Death," first with the validation of technology concepts in laboratory environments, and then with the validation of capabilities after technology has been implemented into systems. Thus, when it comes to technology transitions, the Army has two specific budgets that deal with funding experimentation activities: (1) an S&T Technology Maturation Budget controlled by ASA(ALT) DASA R&T, and (2) the Army 6.4 Program Budget, controlled by program offices.

Funding for the S&T Technology Maturation Budget comes from an Army S&T portfolio of approximately $2B. In 2017, the Technology Maturation Budget was $61M, and in 2018, it was increased to $115M. It's important to point out, however, that the funding increase for 2018 was due primarily to an increase in high-energy laser work mandated by Congress. Essentially, the 2018 budget remains around $60M. Furthermore, the Technology Maturation Budget often becomes a bill payer for other activities.

Experimentation represents less than 3% of the Army's overall S&T maturation budget.

Upon further examination of the Army S&T Technology Maturation Budgets, the study team noted that the funding level for S&T experimentation represents less than 3% of the overall S&T funding. Consistently, several lab PMs reported (as noted in the DVE example) that technology experimentation funding was not available to help transition their research into systems. Thus, it can be concluded that these transition budgets are inadequate and are facilitating the "Valley of Death."

On the other hand, the 6.4 Program Budget is significantly higher at approximately $909M in 2018, which is quite substantial, but technology needs to be validated in the laboratory before programs are willing to use 6.4 funds. Currently, programs and PMs appear unwilling to risk their experimentation budgets to perform further testing in operational settings unless they have sufficient evidence of technology performance.

3.2 INVESTMENTS AND BIG BETS

Experimentation can also play a significant role in taking on more risk with less consequence. George Day, a professor at the University of Pennsylvania's Wharton School, has developed a risk matrix analysis of corporate investments (Fig. 3.1) where he addresses investments in technologies that are new to a company or represent a new market or different way of doing business. Dr. Day explains that the further a project is from the norm (in terms of technology or application area), the higher the risk and the less likely that companies will fund the work. Pressures from the existing customers, internal developers, and financial managers cause companies to invest most of their available funds in evolutionary capabilities that fall below the 40% risk level.

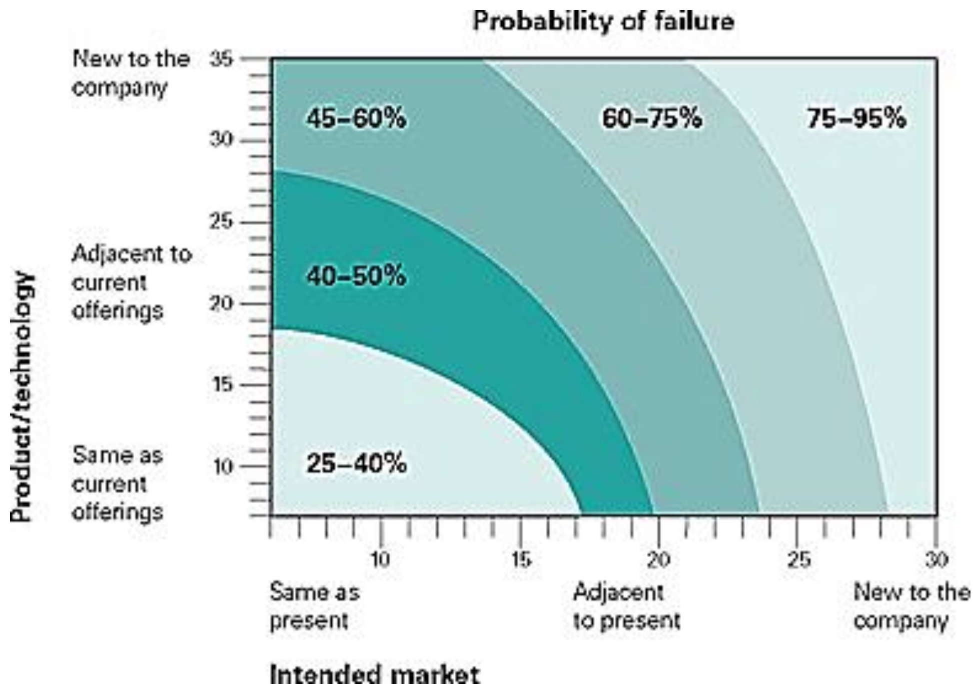


Figure 3.0 The G. Day Risk Matrix

Day's matrix shows that investment in low risk projects yields safe, profitable returns, but at far lower levels than potentially could be achieved by the higher risk projects, or Big Bets. One way to manage the risk associated with these projects is to do early experimentation (i.e., "fail often, fail fast") to validate concepts before making risky investments. As noted in the I-Corps process, validating certain early parameters through experimentation can significantly increase the chances of success as well as limit costly, immature investments.

In the case of the Army, investment in Big Bets has the potential to produce significant new Army capabilities, and these types of projects need to be adopted as portions of the investment portfolio. Early Experimentation helps lower the cost of investment in these Big Bet projects. (Fig. 3.1).

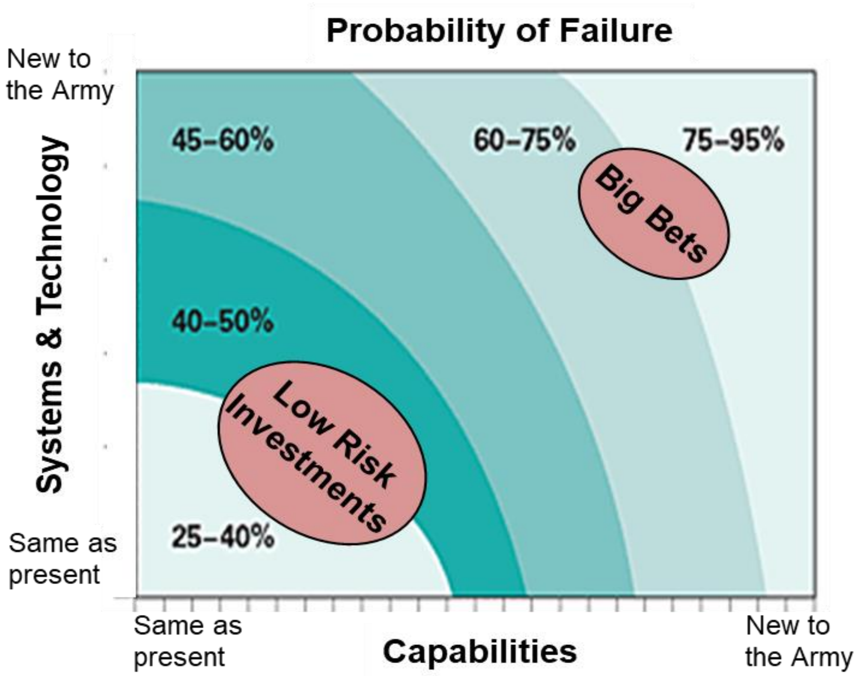


Figure 3.1 The G. Day Risk Matrix Applied to Army Big Bets

The Army investment portfolio experiences significant pressures to upgrade equipment, maintain capabilities, and produce systems without failures. As a result, the Army, as industry, is prone to make most of its S&T portfolio investment in areas that are lower risk with assured positive returns. However, adversaries are investing in non-traditional areas and are continually trying to maneuver in asymmetric spaces to counter the American military's strengths. If the Army is to achieve overmatch capabilities, a certain portion of the S&T portfolio needs to target investment in Big Bets. By using early experiment as a screening tool, Big Bet concepts can be validated without taking on significant costs. Federal grant-awarding agencies, such as the NIH[15] and NSF[16] dedicate a percentage of their budgets to nonconventional projects that show promise in transforming the sciences. Although a climate of risk aversion exists, sufficient resources should always be dedicated to "high-risk, high-reward" projects.

3.3 EARLY EXPERIMENTATION AS A CRITERION FOR INVESTMENT

Army technology and capabilities development normally follows a traditional S-curve process. Once concepts or ideas are identified and the science is proven, there's a focus on prototype development, then CONOPS, and finally deployment. The process doesn't include significant user analysis or concept evaluation prior to the prototype development, which leads to inefficiencies and higher incurred costs overall. In contrast, the I-Corps process advocates for early concept validation and engagement with users in operational settings before investments

[15] See https://commonfund.nih.gov/highrisk
[16] See https://www.nsf.gov/about/transformative_research/faq.jsp

in any prototype activities. Though I-Corps was developed for assisting in transiting technologies into profitable businesses, the notion of early experimentation for concept validation can be applied as a criterion for investment when selecting Army projects, as well (Fig 3.2).

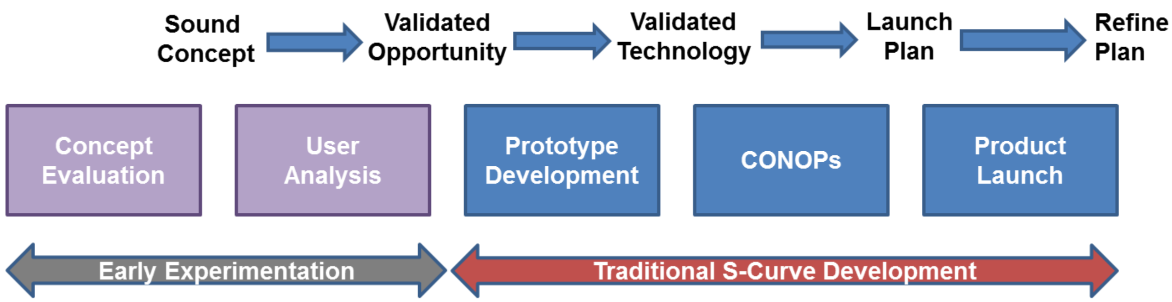


Figure 3.2 S-Curve + Early Experimentation

The panel felt that requiring early validation of concepts by laboratory scientists using an I-Corps-type model could serve as a basis for funding and a criterion for selection of projects. This could help bridge the “Valley of Death” by ensuring that there are valid user inputs and CONOPS before any investments are made. It could also serve to rank investment projects by the quality of early experimentation inputs.

3.4 INVESTMENT PROCESSES

The Acting Secretary of the Army signed off on an S&T investment planning process (Fig. 3.3) in July, and the study team interviewed MG James Richardson, the Special Advisor for Program Integration, Office of the Vice Chief of Staff of the Army, about some of the details.

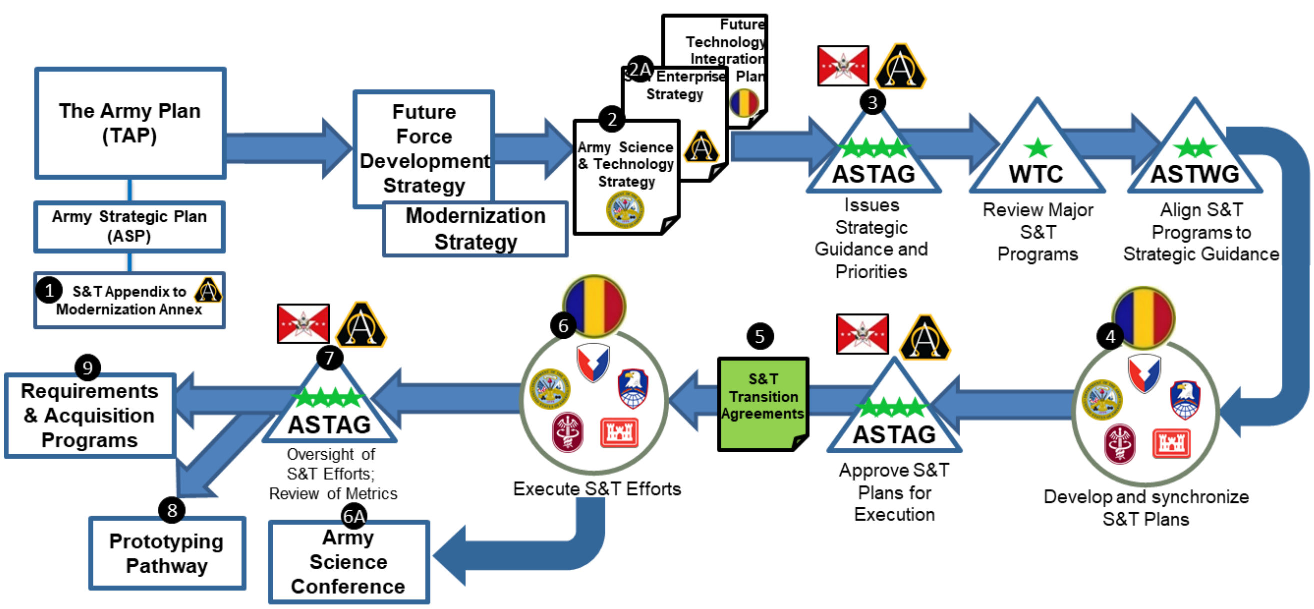


Figure 3.3 Army S&T Investment Process

Based on that discussion, the study team made the following observations regarding the investment process and the role of experimentation in the process:

- Early engagement between some key stakeholders (Steps 1-2b) – The new planning process advocates early stakeholder engagement to help drive useful requirements, however, it's essential to understand that stakeholders want perfection. If requirements are too stringent, the program may be stopped, and no one wins, so agility in the Operational Requirements Document is essential. The panel felt that this type of early engagement was critical to ensuring future success. The Navy's use of Technology Transition Agreements (TTA) ensures early intellectual exchanges between the S&T community and the end-user, as well as agility in the requirements. This allows for the incorporation of vital information in requirements and helps with anticipating future needs. The I-Corps process engages end-users early in product conception to avoid developing products that buyers aren't interested in purchasing, thereby mitigating investment risk. Receiving early feedback from the end-user is essential when investing in S&T. The current process falls short in this area.

- Use of transition agreements to ensure fit with Army strategy (Step 5) - Transition agreements can play critical roles in development processes (as noted with Navy TTAs), but they must be structured properly. If financial commitments and current plan funding isn't attached to the Army's TTAs, it can leave the S&T community and the PMs with little incentive to commit to the agreements. Army TTAs should have an assessment, a vision for acquisition, and a technology path forward as well as resources tied to each of these development areas. Currently, these agreements are merely a written indication of who has interest and nothing more. Going forward, a closer relationship between TRADOC and the community of stakeholders will ensure that the agreed outcomes are met. The new Army S&T strategy enables a closer relationship between the end-user and Army S&T community. The panel would advocate that FYDP resources also be committed and identified through these transition agreements.

- Enhanced use of prototyping & experimentation to reduce risk / cost (Step 8) – Experimentation plays a significant role in the planning process, but the panel felt it should start earlier, i.e., at the very beginning of the planning process and not at the end stages. The results of experimentation should influence decisions, investments, and requirements. It's critical that senior management have knowledge of experimentation results early in the process so they can be incorporated via iterative decision-making. Experimentation could also be used to investigate ideas that offer high payoff but with some risk, i.e., Big-Bets.

- Use of S&T to inform requirements and acquisition (Step 9) – The character of war will change by 2030, and expertise is needed to anticipate future requirements and concurrent investments to ensure future capabilities. Unfortunately, funding hasn't always been available to send Army engineers and scientists to conferences in their respective fields to remain current with the latest scientific and technological advances. That kind of expertise is highly valued in the commercial sector. For example, Google has a Center of Excellence dedicated to ensuring domain expertise. Although Army scientists and engineers currently possess the acumen needed to protect the nation, scientific knowledge more than doubles about every ten years. From a talent management perspective, it's critical that the Army makes funding available for scientists and engineers to ensure they maintain domain expertise through attending conferences, taking classes, participating in webinars, etc. The goal is to ensure that Soldiers aren't at a disadvantage on the battlefield because of a lack of current knowledge. The Army needs well informed scientists who closely collaborate with the requirements and engineering communities to make certain the latest technology advancements are incorporated into Army Systems. Army scientists need rotational assignments in requirements organizations to make certain the knowledge transfer loop remains closed.

- Linear process – The study team found the overall process not conducive to changing requirements. The process is too linear, with a multitude of steps, and an issue with any one of them may torpedo the entire program. As such, changing requirements triggers a complete restart.

In summary, the study team made the following observations regarding the current Army S&T investment process:

- Big Bets need to be considered in the Strategic Plan.
- Experimentation should start earlier in this process to influence investment decisions.
- Transition Agreements need to be tied to resources.
- Prototyping and modeling & simulation must occur earlier in the process.

Other items to consider include:

- At the time of transition, immature technology can significantly increase program risk.
- The role of industry cannot be underestimated, since industry integrates the system.
- At transition, the user may need to change the team dramatically as the phase of development changes.
- Coordination with other Army and DoD customers is necessary to pick the best technology and to receive the biggest payoff.
- The Big Bet approach appears to be a good idea; somewhat more risk but higher payoffs are likely.

- Most individual systems become part of a system of systems, thus the transition of technology may not be as simple as it appears.

- Development programs like the Navy's demonstrate a better focused, single decisionmaker management approach.

4.0 SUMMARY

The study team developed findings and recommendations in two major areas: experimentation and investment strategies.

4.1 EXPERIMENTATION

Rapid fielding and crossing the “Valley of Death” requires the Army to develop a new concept. The study team believes Army leadership should take a new, bold approach patterned after the Army's Competition Advocate Office formed in the mid-1980s, where the Secretary of the Army (SA) and the Chief of Staff of the Army (CSA) directed a senior military officer to organize, develop, and lead the effort to increase competition in Army procurements.

Findings:

Rapid fielding and crossing the “Valley of Death” requires:

- Joint ownership between the program (PEO), TRADOC, and S&T (AMC) throughout materiel development and the acquisition process.

- Formal Agreements with all stakeholders bound by resource agreements for experimentation.

- Consistent leadership oversight for directing operations, prioritizing issues, and facilitating tasks, providing decision authority and circumventing issues throughout the development process.

- Early experimentation for informing requirements. Scientists and capability managers must be trained in evidence based requirements development and analysis.

Recommendations:

ASA(ALT) adds a MilDep or Principal Deputy with directive authority, responsible for facilitating coordination and easing transitions between the key organizations: ASA(ALT), S&T, the PMs/PEOs, TRADOC, AMC, and the warfighter. This individual will direct, fund, coordinate, and integrate the entire process. ASA(ALT) should provide a quarterly report to SA and the CSA on transitions.

- Institute I-Corps training for Army scientists and capability managers to help mitigate risks and refine concept development through early experimentation (i.e., "Bench to Battlefield” training).

– Increase scientists' access to warfighters; Army S&T Enterprise should have more Soldiers and career paths for military in S&T; increase capability managers' access to scientists.

– Establish Formal Agreements with all stakeholders bound by resources within the current POM

The study team advocates senior Army leadership form an office within ASA(ALT) to lead and coordinate the experimentation efforts geared toward more rapidly bringing new technology to the warfighter. This requires the involvement of an individual high enough in the organization with the authority to move funds, prioritize requirements, and decide which projects can compete among near-term projects to get the "green light." This individual will also be charged with following and directing overall execution, fast-tracking the experimentation project from lab to warfighter.

Shared ownership among key stakeholders is imperative. TRADOC, AMC (S&T), as well as other financial management activities of ASA(ALT) must cooperate and cohesively prioritize to move new technology to the warfighter. The study team found most of the personnel in the S&T / acquisition system perform true to their organizational purpose, but the the focus of the proposed new position will lie in the ability to cross functional lines, direct performance, and terminate a project when required. Shared ownership between key Army stakeholders should be outlined in formal agreements that are executable within current POM cycles. When these elements are in place, the Army S&T / acquisition team, led by this newly designated individual, will be able to focus efforts on early experimentation and ensure that managers and scientists receive additional training in their respective subjects, allowing for more robust execution of requirements development and analysis.

Preferentially, the new position would be a Military Deputy to effectively interface between civilian and military, or a Principal Deputy with directive authority, responsible for facilitating, coordination, and easing the transitions between key organization such as ASA(ALT) S&T, the PM's / PEO, TRADOC, AMC, and the warfighter. This position is so critical to the Army and its ability to move new technology from the "bench to the battlefield" within a reasonable timeframe that the SA and the CSA should put their full and constant support behind it and have the ASA(ALT) periodically report to each of them on program progress. The focus must remain on streamlining efforts and improving processes to transition new technology from the laboratory to a product that the warfighter can use to maintain superiority on the battlefield.

4.2. INVESTMENT STRATEGIES

While the overall Army 6.4 maturation budget has grown, funding earmarked for S&T experimentation needs to be reviewed and increased. The DVE case study demonstrates an inadequate 6.4 budget caused the failure to transition from a successful sensor prototype in brownout conditions to deployment sensors on helicopters. Had increased S&T experimentation funds been available, the "Valley of Death" could have been avoided. Without additional S&T experimentation budgeting, programs and PMs will resist risking their experimentation budgets to perform testing in operational settings unless they have sufficient evidence of technology performance. This reluctance slows the rapid fielding of effective and operationally useful S&T necessary to maintain Army overmatch.

Findings:

The 6.4 S&T experimentation budgets are inadequate as a percentage of the overall Army S&T Budget, impeding the transition of S&T.

- There is a lack of designated funding for early validation of concepts and disruptive (Big Bet) experimentation.

Recommendations:

ASA(ALT) should:

- Increase the Army 6.4 tech maturation budgets for S&T experimentation.
- Identify funding and processes which support early concept validation and Big Bet analysis through experimentation.
- Make early concept validation a process-gate to acquiring S&T project funding (I-Corps Model).

Big Bets – high risk, high reward projects – need to be supported financially. This requires a better understanding and appreciation for failure as a stepping stone to innovation. An integration of Big Bets into the low risk, near-term portfolio will require a shift in culture, beyond one that only rewards and values testing and demonstrations. Incremental advancements are important for upgrading equipment, maintaining current capabilities, and producing systems without failures. However, incremental advancements won't maintain Army overmatch when our adversaries are budgeting for big risk, high return projects. Several nonconventional, high-return projects should be budgeted annually with accompanying guidelines that require early experimentation / prototyping to gauge viability before more significant funding is made available. This is the "fail fast, fail often" culture of innovation, and while it works well in Silicon Valley with certain kinds of technology-supported business models, it may not align as well with innovation in hardware and warfighting capabilities. Nevertheless, early experimentation with low fidelity prototypes for hypothesis testing meets Army needs for rapid technological advancement. Following the I-Corp model, this would mean that a Minimum Viable Product (MVP) would need to be developed and "tested" with warfighters much earlier in the usual design and development cycle. The early concept validation could then serve as the gateway for earning S&T project funding.

5.0 CONCLUSION

Tasked to explore the value of experimentation in transitioning new technology from the laboratory to warfighting capabilities, the study team identified a two-fold problem:

1. Adversaries' rapid fielding of effective, operationally-useful, advanced S&T capabilities puts Army overmatch at risk.

2. The Army's fielding of effective, operationally-useful, advanced S&T capabilities isn't particularly rapid or cost-effective, to the detriment of Soldiers.

The challenges are well documented. During Ryan D. McCarthy's confirmation hearing as Under Secretary for the Army, the Army Times reported that Senators encouraged the nominee to provide new technology to Soldiers more expeditiously.[17] Senator McCain, Chairman of the Senate Armed Services Committee, and his colleagues stressed the need to "overhaul the Army's procurement style."

The study team found the Army's current use of experimentation could be expanded to improve the procurement process and to increase the rate of technology transition to the warfighter. In addition, various approaches demonstrated that earlier experimentation in the S&T procurement process would be highly beneficial, serving the Army as a key enabler to win wars and save Soldiers' lives.

[17] "Senators call on Army undersecretary nominee to get new tech to soldiers faster;" Army Times, 12 July 2017. https://www.armytimes.com/news/your-army/2017/07/12/senators-call-on-army-undersecretary-nominee-to-get-new-tech-to-soldiers-faster/

APPENDIX A: TERMS OF REFERENCE

SECRETARY OF THE ARMY
WASHINGTON

FEB 2 2 2017

Dr. James Tegnelia
Chairman, Army Science Board
2530 Crystal Drive, Suite 7098
Arlington, VA 22202

Dear Dr. Tegnelia,

I request that the Army Science Board (ASB) conduct a study entitled "Improving Transition of Laboratory Programs into Warfighting Capabilities through Experimentation." The objective of the study is to assess if early integration of concept experimentation (BA 6.4) with Applied (BA 6.2) and Advanced (BA 6.3) Development helps avoid the "valley of death" for emerging, innovative technologies and capabilities.

While DoD's and the Army's Science and Technology Enterprise is large (more than $30B at DoD level) and has been studied extensively, most of the investigations have concentrated on optimizing individual investments to achieve challenging technical objectives. They have not examined if early experimentation would provide additional guidance on the direction and goals for these developmental programs. In particular, past studies have not explored if greater emphasis on early experimentation, demonstration and validation of integrated capabilities would increase the number of technologies that successfully transition out of research and development (R&D).

This study is intended to look at the Army's broader science and technology effort, including early experimentation (6.2-6.4), with the focus on rapidly developing and exploiting innovative capabilities. It should consider, at a minimum, the literature mentioned in task a below, and build upon the 2016 Army Science Board studies that analyzed innovative operational concepts to counter near-peer adversary integrated air defenses, long-range precisions fires, and armor/anti-armor capabilities and identified key enablers. The analysis should include a comprehensive look at differing developmental approaches, technology maturation models, and potential disruptions including:

a. Set-based concurrent and resilient engineering.

b. The possibility that capabilities could be fielded so quickly that it creates an inflection point relative to the character of warfighting, similar to the changes seen in hypercompetitive commercial sectors.

c. If S-Curve technology-readiness level or other technology maturity analyses, when viewed from the end-product perspective, could help provide insight into the investment program.

d. Best practices in areas where the Army and other R&D centers are more successful in transitioning S&T into fielded programs.

e. Potential incentives for defense contracts to accept and transition Army S&T.

The study team's tasks shall include, but not be limited to, the following:

a. Review the first and second offset strategies and previous studies of the Army's and DoD's S&T enterprise including, but not limited to, the 2013 and 2014 ASB studies on Strategic Direction and Core Competencies, the RAND Study on technology S curves based upon patent disclosures, the ASD(R&E) study on return on investment for the Defense Laboratories, DoD's current Third Offset Strategy, and the most recent long-range research and development strategy for ground combat.

b. Clearly define experimentation as compared to demonstration and testing to highlight the role and distinction of hypotheses, analysis, and iteration as a result of lessons learned in experimentation.

c. Analyze and validate where early experimentation with potential innovative/disruptive or proposed technologies might enable advances within the land domain and suggest a proposed course of action.

d. Evaluate the processes and proponents for the investment strategies and execution, suggesting where further integration might increase effectiveness and reduce the bureaucratic barriers to the program.

e. Given the Army's budget constraints, the Board will suggest if viewing individual programs as a portion of a larger rapid capabilities fielding strategy (rather than on individual merit) would provide an additional lens by which to view innovation creating activities versus thrusts that should be curtailed.

The Assistant Secretary of the Army for Acquisition, Logistics, and Technology (ASA(ALT)), is the sponsor of this effort. The ASA(ALT) will assist the study team in accessing classified information up to Top Secret and including Sensitive Compartmented Information and Special Access Programs.

To the extent possible, the study team's recommendations should not require changes in either Title 10 or the Goldwater Nichols Act, and they should recognize

-3-

that the Army's S&T budget is unlikely to dramatically increase over the next 10 years.

A briefing and report with findings and recommendations will be provided by September 30, 2017 to the Secretary of the Army and Army Chief of Staff. The study will operate in accordance with the Federal Advisory Committee Act and Department of Defense Directive 5105.4, DoD Federal Advisory Committee Management Program. It is not anticipated that this study will need to go into any particular matters regarding the meaning of United States Code, nor will it cause any member of the study team to be placed in the position of acting as a procurement official that may constitute a conflict of interest.

Sincerely,

Robert M. Speer
Acting

APPENDIX B: STUDY TEAM MEMBERS

Ms. Teresa Smith
Study Chair

Dr. Grant Warner
Study Vice Chair

Study Members

Ms. Vivian Baylor
MG (R) Charles R. Henry
Dr. Jill Harp
Dr. Jasper Lupo
MG (R) Lester Martinez-Lopez, M.D.
Dr. Wendy Newstetter
LTG (R) Malcom O'Neill, Ph.D.
Mr. Tom Ramos
Dr. Marcus Shute
Dr. Bruce Swett
Dr. Alan Willner

Study Mentors / Red Team

Dr. Leonard Braverman
GEN (R) Paul Kern
Dr. Jim Tegnelia
GEN (R) David Maddox

Dr. Ellen Holthoff
Study Manager

Ms. Constance Srader
Tech Writer / Editor

APPENDIX C: VISITATIONS

Agency	Contact	Meeting Date
Army Research, Development, & Engineering Command (RDECOM)	MG Cedric Wins	8 MAR 2017
Naval Research Laboratory (NRL)	Dr. Bruce Danly	23 MAR 2017
Defense Advanced Research Projects Agency (DARPA)	Dr. Stephen Walker	19 APR 2017
Joint Improvised-Threat Defeat Organization (JIDO)	Ms. Lisa Swan	6 APR 2017
Army Research Laboratory (ARL)	Dr. Philip Perconti	7 APR 2017
Night Vision & Electronic Sensors Directorate (NVESD)	Dr. Donald Reago	24 MAR 2017
Quantico Marine Corps Warfighting Laboratory/Futures Directorate	LTC Donald Wright	25 MAY 2017
Missile Defense Agency (MDA)	Dr. Doug Deason	19 APR 2017
National Geospatial-Intelligence Agency (NGA)	Dr. Peter Highnam	23 MAR 2017
DASA (R&T), ASA(ALT)	Dr. Thomas Russell	7 MAR 2017
Rapid Equipping Force (REF)	COL John Ward, Mr. Todd Wendt	24 MAR 2017
Deputy Chief of Staff, TRADOC G9	Mr. Rickey Smith	6 APR 2017
Communications-Electronics RDEC (CERDEC)	Mr. William Hoppe	8 MAR 2017
Communications-Electronics Command (CECOM)	Mr. Larry Muzzelo	8 MAR 2017
Army Test and Evaluation Command (ATEC)	Mr. Raymond Fontaine	8 MAR 2017
(Acting) Assistant Secretary of Defense for Research and Engineering [ASD(R&E)]	Ms. Mary Miller	24 MAY 2017
Test Resource Management Center (TRMC)	Mr. Derrick Hinton	7 MAR 2017
ASD(R&E), Principal Director, Research	Mr. Dale Ormond	7 MAR 2017
ASD(R&E), Principal Deputy for Emerging Capability & Prototyping	Dr. Charles Perkins	7 MAR 2017
ERDC	Mr. Nicholas Boone	25 MAY 2017
ASA(FM&C)	Mr. Cameron Keys	24 MAY 2017
Office of Naval Research (ONR)	Rear Admiral David Hahn	20 JUN 2017
Rapid Reaction Technology Office	Mr. Jon Lazar, Mr. Glenn Fogg	18 MAY 2017
OSD ATL, Emerging Capability and Prototyping	Mrs. Ellen Purdy	24 MAY 2017
Air Force Research Laboratory	Mr. Richard Hencke	25 APR 2017
National Defense University (NDU)	Mr. Albert Sciarretta, Dr. Steve Ramberg	18 APR 2017
Vice Chief of Staff of the Army's (VCSA) Special Advisor for Program Integration	MG Jim Richardson	24 MAY 2017

Director of Strategy, Plans & Policy, Deputy Chief of Staff G-3/5/7	MG William Hix	23 JUN 2017
PEO Aviation	Mr. Bob Sheibley	15 JUN 2017
Novak Biddle Venture Partners	Mr. Roger Novak, Mr. Jack Biddle	15 JUN 2017
National Science Foundation (NSF)	Mr. Steve Konsek	22 JUN 2017
ASA (ALT)/ DASA R&T Director for Business and Operations	Ms. Sheri Briggs	6 JUL 2017
Medical Research & Material Command (MRMC)	Dr. George Ludwig	18 APR 2017
Georgia Tech Research Institute (GTRI)	Mr. Ben Riley	2 MAY 2017
Air Force Science Advisory Board (SAB)	Mr. Steve Butler	1 MAY 2017
TRADOC Army Capabilities Integration Center (ARCIC)	Mr. Timothy Drake	28 JUN 2017
PEO Ground Combat Systems (PM Armored Fighting Vehicles)	COL James Schirmer	23 JUN 2017
Stefan Thomke (Experimentation Matters Author, Harvard Business School)	Mr. Stefan Thomke	17 JUL 2017

APPENDIX D: TECHNOLOGY READINESS LEVELS

Technology Readiness Level	Description
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.
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.
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.
4. Component and/or breadboard validation in 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.
5. Component and/or breadboard validation in relevant environment.	Fidelity of breadboard technology increases significantly. The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
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 simulated operational environment.
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.
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.
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.

APPENDIX E: DOD DEFINITIONS OF R&D

Definition of R&D					
Government-Wide			DOD-Unique*		
OMB Circular No. A-11 (1998)			DOD Financial Management Regulation (Volume 2B, Chapter 5)		
Conduct of R&D**	Basic Research	Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications toward processes or products in mind.	**S&T Activities*****	Basic Research (6.1)	Systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and/or observable facts without specific applications toward processes or products in mind.
	Applied Research	Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.		Applied Research (6.2)	Systematic study to gain knowledge or understanding necessary to determine the means by which a recognized and specific need may be met.
	Development	Systematic application of knowledge toward the production of useful materials, devices, and systems or methods, including design, development, and improvement of prototypes and new processes to meet specific requirements.		Advanced Technology Development (6.3)	Includes all efforts that have moved into the development and integration of hardware for field experiments and tests.
				Demonstration and Validation (6.4)	Includes all efforts necessary to evaluate integrated technologies in as realistic an operating environment as possible to assess the performance or cost reduction potential of advanced technology.
				Engineering and Manufacturing Development (6.5)	Includes those projects in engineering and manufacturing development for Service use but which have not received approval for full rate production.
				RDT&E Management Support (6.6)	Includes R&D efforts directed toward support of installation or operations required for general R&D use. Included would be test ranges, military construction, maintenance support of laboratories, operations and maintenance of test aircraft and ships, and studies and analyses in support of R&D program.
				Operational System Development (6.7)	Includes those development projects in support of development acquisition programs or upgrades still in engineering and manufacturing development, but which have received Defense Acquisition Board (DAB) or other approval for production, or for which production funds have been included in the DoD budget submission for the budget or subsequent fiscal year.
				Developmental Test and Evaluation	Efforts associated with engineering or support activities to determine the acceptability of a system, subsystem, or component.
				Operational Test and Evaluation	Efforts associated with engineering or support activities to determine the acceptability of a system, subsystem, or component.
R&D Equipment	The acquisition of major equipment for R&D. Includes expendable or movable equipment (e.g., spectrometers, microscopes) and office furniture and equipment. Routine purchases of ordinary office equipment or furniture and fixtures are normally excluded.		No separate definition	Major equipment dollars are mixed with the dollars for the "Conduct of R&D" and carried in the RDT&E accounts (i.e., 6.1 through 6.7) listed above. In FY 1998, DOD requested a total of $68M for major R&D equipment.	
R&D Facilities	The construction and rehabilitation of R&D facilities. Includes the acquisition, design, and construction of, or major repairs or alterations to, all physical facilities for use in R&D activities. Facilities include land, buildings, and fixed capital equipment, regardless of whether the facilities are to be used by the government or by a private organization, and regardless of where title to the property may rest. Includes such fixed facilities as reactors, wind tunnels, and particle reactors. Excludes movable R&D equipment.		No separate definition	In FY 1998, close to 90% of the $67M requested by DOD for R&D Facilities was carried separately in Military Construction accounts. The rest were included in the costs of major development programs and are mixed with the dollars for the "Conduct of R&D" carried in the RDT&E accounts (i.e., 6.1 through 6.7) listed above.	

* Does not pertain to the Corps of Engineers.

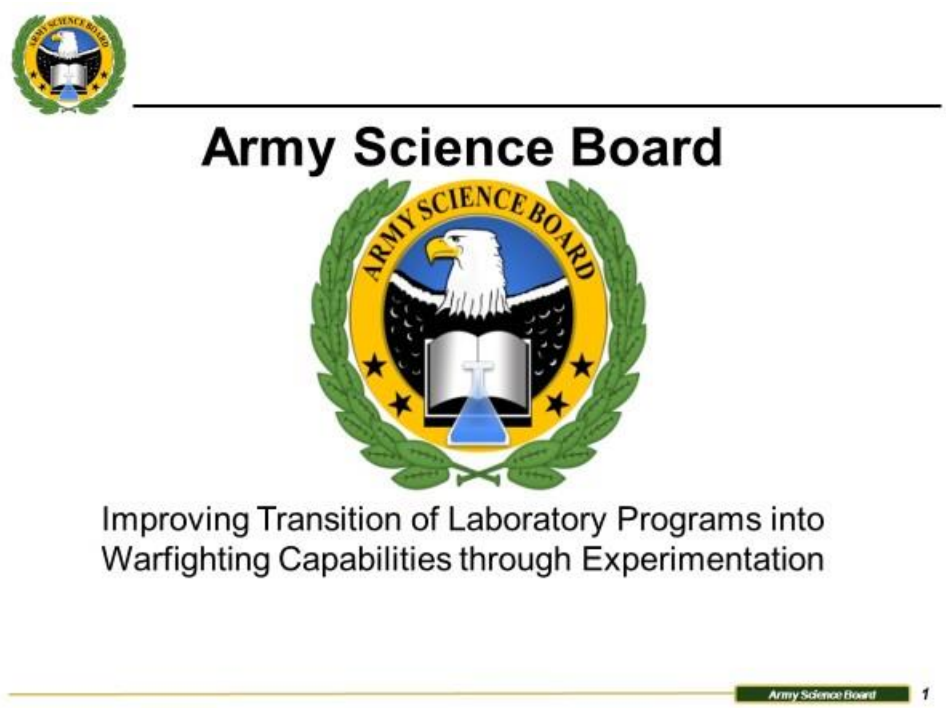
** Includes administrative expenses. Excludes routine product testing, quality control, mapping, collection of general-purpose statistics, experimental production, routine monitoring and evaluation of an operational program, and the training of scientific and technical personnel.

*** Includes costs of laboratory personnel, either in-house or contractor operated.

F. ASB APPROVED BRIEFING WITH FINDINGS AND RECOMMENDATIONS

The following briefing was presented by Teresa Smith, Study Chair, to the Army Science Board in plenary session at the Arnold and Mabel Beckman Center of the National Academies of Sciences and Engineering on 20 July 2017.

By unanimous vote, the ASB approved and adopted the findings and recommendations made by the study team.



Outline

- **Introduction**
  - The Problem Statement
  - Study Overview & TOR
  - The Team & Data Collection
  - Definitions
  - Army Materiel Development Process
- **Analysis of Experimentation**
  - Findings & Recommendations
- **Investment Strategies for S&T Experimentation**
  - Findings & Recommendations
- **Conclusions**

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The Problem

Context: *Rapid fielding of effective, operationally-useful S&T by adversaries puts Army overmatch at risk.*

How can the Army increase the rate of technology transition to the Warfighter using experimentation?

Senators call on Army Undersecretary nominee to get new tech to soldiers faster

Army Times, July 12, 2017

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Study Overview & TOR

Terms of Reference (TOR)

Sponsor: DASA R&T

Purpose: The objective of this study is to investigate how to improve the Army's transition of technology through ***experimentation***, and to help avoid the "Valley of Death"* for emerging technologies.

Critical Tasks:

A. Review technology development approaches, S-curve, concurrent engineering, offset development strategies, and other science board studies.
B. Define experimentation as compared to demonstration and testing.
C. Analyze and validate where / how early experimentation enables advances in Army capabilities.
D. Evaluate processes for S&T experimentation investment strategies.
E. Evaluate using capability fielding strategy as a criterion for program investment decisions.

*Inability to transition from advanced development into Warfighter operational capabilities

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Experimentation Team & Data Collection

ASB Members

Chair – Ms. Teresa Smith
Vice Chair – Dr. Grant Warner
Red Team – Dr. Leonard Braverman, GEN (R) Paul Kern, Dr. Jim Tegnelia, GEN (R) David Maddox

- Ms. Vivian Baylor
- MG (R) Charles R. Henry
- Dr. Jill Harp
- Dr. Jasper Lupo
- MG (R) Lester Martinez-Lopez, M.D.
- Dr. Wendy Newstetter
- LTG (R) Malcom O'Neill, Ph.D.
- Mr. Tom Ramos
- Dr. Marcus Shute
- Dr. Bruce Swett
- Dr. Alan Willner

Study Manager – Dr. Ellen Holthoff
Technical Writer – Ms. Constance Srader

Over 40 Sources:

Government/Public Sector

- ASA(ALT) – Dr. Thomas Russil (DASA R&T)
- ASD(R&E) – Mr. Dale Ormond (Principal Director, Research)
- EC&P – Dr. Chuck Perkins (Acting DASD EC&P)
- TRMC – Mr. Derrick Hinton (Acting Director)
- ATEC – Mr. Raymond Fontaine (Test Management)
- RDECOM – MG Cedric Wins (CG)
- CECOM – Mr. Larry Muzzelo (Deputy to CG)
- CERDEC
- National Geospatial Agency (NGA)
- NRL
- NVESD
- Army REF – COL John Ward (Director), Mr. Todd Wendt (Program Manager)
- JIDO
- TRADOC G-9 – Mr. Rickey Smith
- ARL
- MRMC
- NDU – Mr. Albert Sciarretta, Dr. Steve Ramberg
- DARPA
- MDA – Dr. Douglas Deason
- AFRL – Mr. Richard Hencke

Government/Public Sector (continued)

- AF SAB (T&E Study) – Mr. Steve Butler, Chair
- RRTO/JCTD
- ASD R&E – Mary Miller (Acting)
- DUSA T&E – Mr. David Jimenez
- OUSD AT&L – Ms. Ellen Purdy
- MG Richardson – Army G-4
- ASA(FM&C)
- ERDC
- Marine Corps Warfighting Lab (MCWL)
- MG Hix – Army G-3/5/7
- Office of Naval Research (ONR)
- TRADOC ARCIC
- PEO Aviation
- National Science Foundation (NSF)
- PEO Ground Combat Systems
- Ms. Sheri Briggs, DASA (R&T) Director for Business and Operations

Corporate/Private Sector

- Novak Biddle Venture Partners
- ASB Subject Matter Experts

Academia

- Mr. Ben Riley – GTRI
- George Day – Harvard Business School
- Mr. Stefan Thomke – MIT/Harvard Business School

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Army Definitions – Testing, Demonstration, Experimentation, and Prototyping

- ***Testing:*** A defined process or method for assessing if a specification / requirement has been met; *measures performance* against set criteria.
- ***Demonstration:*** A version of the end product used to *showcase* new ideas, performance, methods, or features. Externally focused and must be successful to demonstrate capabilities.
- ***Experimentation:*** A procedure or operation carried out to *investigate a hypothesis and generate knowledge*. It solves a problem or helps answer questions using structured methodology that measures dependent and independent variable interactions.
- ***Prototyping:*** An *early sample, model, or release* to assess a concept or process or to act as something that can serve to provide learning or can be replicated.

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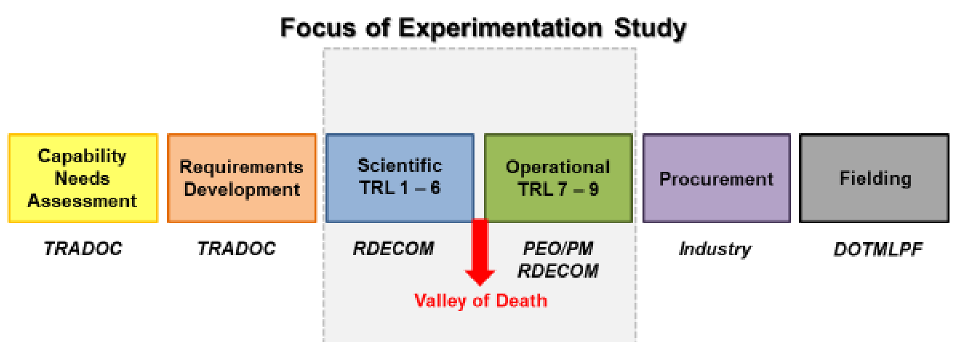
Army Materiel Development Process



Experimentation is integral to all areas

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Outline

- Introduction
  - The Problem Statement
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- Investment Strategies for S&T Experimentation
  - Findings & Recommendations
- Conclusions

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Analysis of Experimentation

Example: Army Experimentation

Degraded Visual Environment (DVE)

- During OEF/OIF, there were 375 rotorcraft losses with 496 fatalities, with brownout identified as cause for almost 81 percent of all aircraft crashes.*
- The Army designated the ability to fly in DVE as one of three highest priority needs.
- Requirement was written such that additional degraded visual environments became "must haves" instead of "nice to haves."
- Army's Night Vision Laboratory developed a solution for brownout (only) that the PM could not accept.

Night Vision Lab's solution has been adopted by some units; however, Big Army has yet to implement the technology

A directed, coordinated transition process facilitated by experimentation would have:

- Saved lives and assets.
- Ensured early on that the requirement was realistic, flexible, and achievable.
- Enabled Army to re-structure the requirement to ensure a solution could be phased into PORs.
- Prevented at least 3 to 4 years of lost time in fielding a solution.

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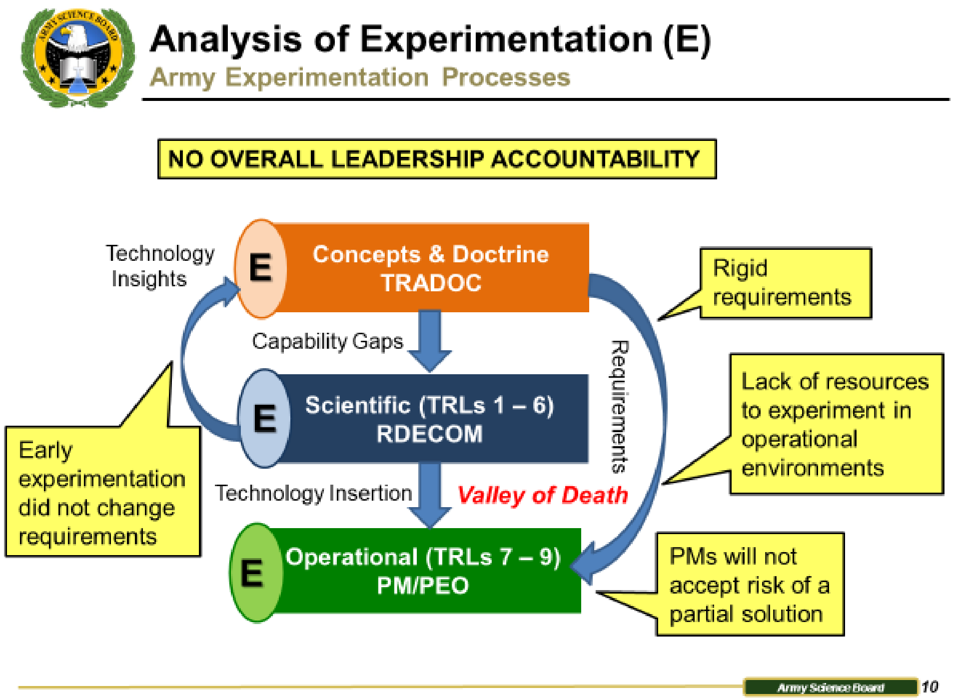
Study on Rotorcraft Safety and Survivability, 2014



Analysis of Experimentation (E)
Army Experimentation Processes
NO OVERALL LEADERSHIP ACCOUNTABILITY
Technology Insights
E Concepts & Doctrine TRADOC
Capability Gaps
E Scientific (TRLs 1 – 6) RDECOM
Technology Insertion
Valley of Death
E Operational (TRLs 7 – 9) PM/PEO
Requirements
Rigid requirements
Lack of resources to experiment in operational environments
PMs will not accept risk of a partial solution
Early experimentation did not change requirements
Army Science Board
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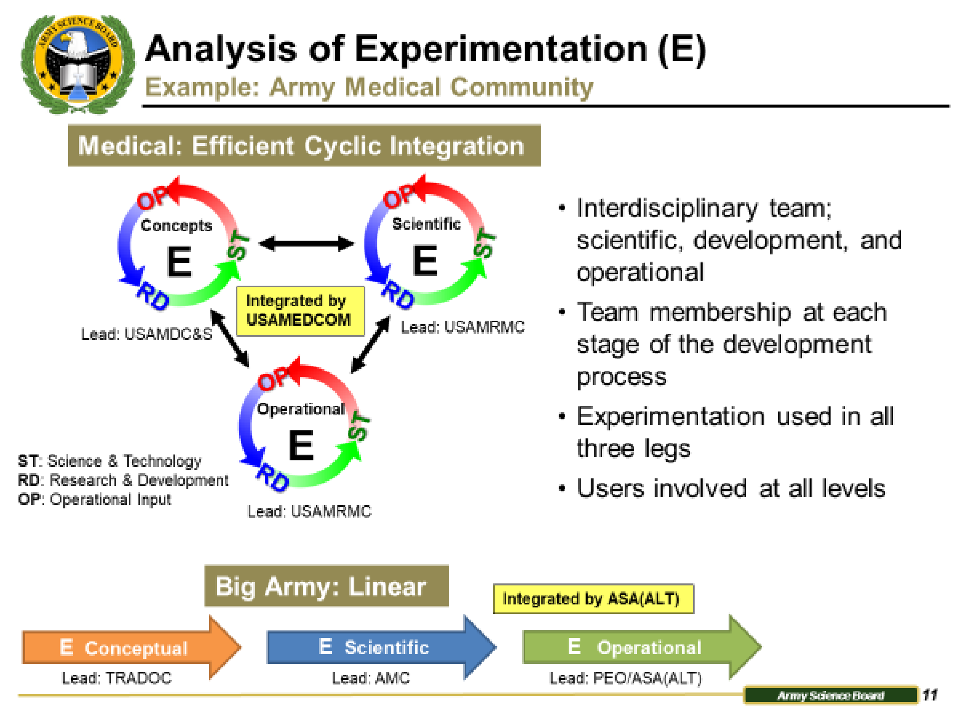

Analysis of Experimentation (E)
Example: Army Medical Community
Medical: Efficient Cyclic Integration
OP Concepts E ST RD
Lead: USAMDC&S
OP Scientific E ST RD
Lead: USAMRMC
Integrated by USAMEDCOM
OP Operational E ST RD
Lead: USAMRMC
ST: Science & Technology
RD: Research & Development
OP: Operational Input
• Interdisciplinary team; scientific, development, and operational
• Team membership at each stage of the development process
• Experimentation used in all three legs
• Users involved at all levels
Big Army: Linear
Integrated by ASA(ALT)
E Conceptual
Lead: TRADOC
E Scientific
Lead: AMC
E Operational
Lead: PEO/ASA(ALT)
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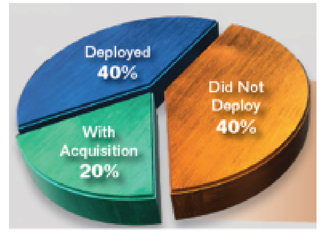
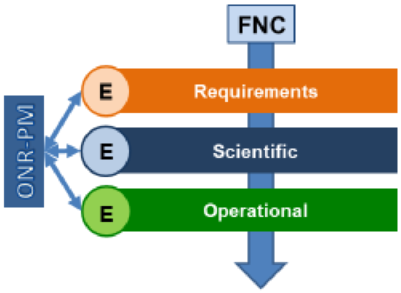
Analysis of Experimentation (E)

Example: Navy Experimentation and Development

Future Naval Capabilities (FNC)

"60 percent of all transitioned products are assessed as either deployed or still being further engineered and integrated within an acquisition program of record." - *2017 FNC Guidebook*





- ONR PMs have oversight from requirements definition to operational prototyping.
- PMs use Transition Agreements to coordinate activities among stakeholders.
- Transition Agreements that are tied to resources within the POM have shown the highest success rates.
- Early experimentation and concept validation is used to compete for S&T resources within ONR.

Admiral Hahn: **"Transition Agreements do not work unless there is skin in the game."**

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Analysis of Experimentation

Example: NSF Innovation Corps (I-Corps)

- Most start-ups fail because they do not understand customer need.
- NSF I-Corps is a training program using the scientific method to understand operational needs through early experimentation, which helps reduce risk.
- In 5 years, 905 teams graduated, and of these, 361 formed companies, resulting in a total of $103M in investment capital.
- "The I-Corps model has a strong record of success and should be replicated at all Federal science agencies"…US Congress.

Example: Segway could have saved $10s of millions of lost investment with the I-Corps training.

Top Reasons Start-Ups Fail

"If we build it, they will buy it."

I-Corps analysis helps validate investments

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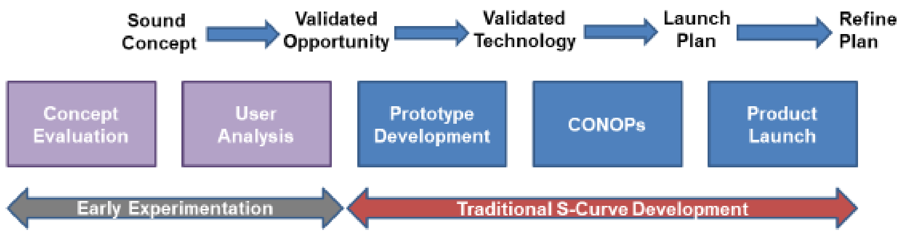
Analysis of Experimentation

Early Experimentation Could Reduce Risk



- **Early experimentation** starts before the traditional S-curve processes and prototype development, enabling concepts to be validated and refined.
- Each step in the development process should apply **concurrent / iterative practices** to continually refine assumptions.
- NSF I-Corps is developing training for scientist in "**evidence based entrepreneurship**" for early validation of concepts.

"Knowledge, not intuition, needs to guide decisions." – Stefan Thomke

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Analysis of Experimentation

Findings & Recommendations

KEY FINDINGS:

Rapid fielding and crossing the "Valley of Death" requires:

- **Joint ownership** between the program (PEO), TRADOC, and S&T (AMC) throughout materiel development and the acquisition process.
- **Formal Agreements** with all stakeholders bound by resource agreements for experimentation.
- **Consistent leadership oversight** for directing operations, prioritizing issues, and facilitating tasks, providing decision authority and circumventing issues throughout the development process.
- **Early experimentation** for informing requirements. Scientists and capability managers must be trained in evidence based requirements development and analysis.

RECOMMENDATIONS:

ASA(ALT) adds a MilDep or Principal Deputy with directive authority, responsible for facilitating coordination and easing transitions between the key organizations: ASA(ALT), S&T, the PMs/PEOs, TRADOC, AMC, and the Warfighter. This individual will direct, fund, coordinate, and integrate the entire process. ASA(ALT) should provide a quarterly report to SECARMY and the CSA on transitions.

- **Institute I-Corps training** for Army scientists and capability managers to help mitigate risks and refine concept development through early experimentation (i.e., "Bench to Battlefield" training).
- **Increase scientists' access to Warfighters**; Army S&T Enterprise should have more Soldiers and career paths for military in S&T; **increase capability managers' access to scientists**.
- Establish **Formal Agreements** with all stakeholders bound by resources within the current POM.

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Outline

- Introduction
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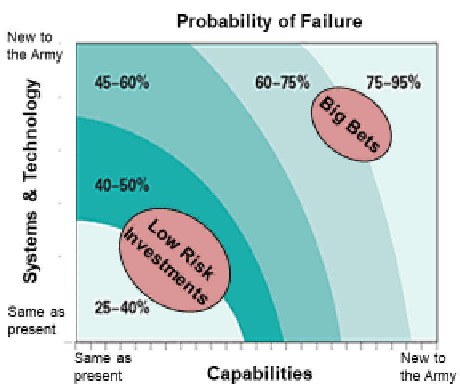
Investment Strategies for S&T Experimentation

High Risk, High Payoff – Big Bets

Army Investment Portfolio



- There is a natural aversion to make significant investments in riskier projects.
- Army has not had an S&T strategy which targets Big Bet investments.
- A **small percentage** investment could produce significant technological advancements.
- **Enemy is making this investment now!**

> - **Senior Army leadership must advocate for investment in Big Bets**
> - **Experimentation can be used to draw down risk on high-potential, disruptive concepts**

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Investment Strategies for S&T Experimentation

Current Army Experimentation Investment

- Army lacks dedicated dollars for experimentation in:
  - Early concept validation
  - Disruptive innovations (Big Bets)
  - Operational experimentation (6.4)
- Army S&T 6.4 Tech Maturation Budgets: 2017 = $61M; 2018 = $115M
  - Increase in 2018 driven by high energy laser plus-ups.
  - Historically, tech maturation has been targeted as a bill payer; 2016 budget reduced to $34M.
- Overall Army 6.4 Funding for 2018 = $909M.

6.4 S&T experimentation represents less than 3% of the Army's $2B S&T budget; lack of 6.4 S&T funds is impeding fielding capabilities

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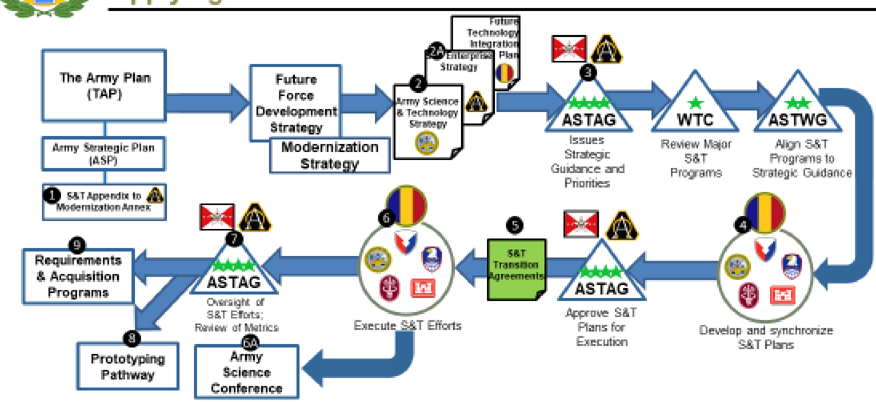
Investment Strategies for S&T Experimentation

Applying Recommendations to New S&T Governance Process*



Comments on the Process:

- Big Bets need to be considered in the Strategic Plan.
- Experimentation should start earlier in this process to influence investment decisions.
- Transition Agreements need to be tied to resources.
- Prototyping and modeling & simulation must occur earlier in the process.

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*Office of Process Innovation and Integration

Investment Strategies for S&T Experimentation
Findings & Recommendations

KEY FINDINGS:

- **6.4 S&T experimentation budgets are inadequate** as a percentage of the overall Army S&T Budget, impeding the transition of S&T.
- **There is a lack of designated funding** for early validation of concepts and disruptive (Big Bet) experimentation.

RECOMMENDATIONS:

ASA(ALT) should:

- Increase the **Army 6.4 tech maturation budgets** for S&T experimentation.
- Identify funding and processes which support **early concept validation and Big Bet analysis through experimentation.**
- Make **early concept validation a process-gate** to acquiring S&T project funding (I-Corps Model).

Conclusions

The Problem

Context: *Rapid fielding of effective, operationally-useful S&T by adversaries puts Army overmatch at risk.*

How can the Army increase the rate of technology transition to the Warfighter using experimentation?

Senators call on Army Undersecretary nominee to get new tech to soldiers faster

Army Times, July 12, 2017

1. **Provide adequate experimentation budgets for early concept through operational validation.**
2. **Establish senior leadership accountability, direction, and oversight for technology transitions.**

Experimentation is a key enabler to win wars and save lives