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An Analysis of Technology Transition Within the Department of Defense

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Appropriate methods and the proper execution thereof are critical to the success of technology transition. A significant hurdle in this process is the phase in which the Science & Technology community is prepared to hand-off a technology, which has not achieved a sufficiently high enough Technology Readiness Level (TRL), Manufacturing Readiness Level (MRL), or System Readiness Level (SRL) for the Engineering and Manufacturing community. This analysis concentrated on three technology transition factors: Organization, Policy, and Metrics (OPM.

Organizational transformation encompasses the recent expansion of technology transition groups and initiatives within DoD. Additionally, the overall mindset of cooperative development and open communication are detailed within the Organizational focal area. The Policy focal area delves into the various DoD technology transition governing principles included in the DoD 5000, the Defense Acquisition Guidebook, and other governing documents. Lastly, the Technology Metrics focal area concentrates on the importance of technology maturation and how to qualitatively and objectively assess technologies. Thorough research was conducted on these areas to demonstrate DoD's recent efforts to bridge the gap and provide innovative solutions to the Warfighter within a reduced timeframe.

Additionally, a case study analysis was conducted on a Defense Advanced Research Projects Agency (DARPA) Program, Boomerang, to highlight attributes of a successful technology transition.

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AN ANALYSIS OF TECHNOLOGY TRANSITION WITHIN THE DEPARTMENT OF DEFENSE

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

ACTD	Advanced Concept Technology Demonstration
ARPA	Advanced Research Projects Agency
AT	Advanced Technology
CDD	Capability Development Document
COCOM	Combatant Command
COTS	Commercial Off the Shelf
CPP	Commercialization Pilot Program
CR	Concept Refinement
CRADA	Cooperative Research & Development Agreement
CTE	Critical Technology Element
DAC	Defense Acquisition Challenge
DAG	Defense Acquisition Guidebook
DARPA	Defense Advanced Research Projects Agency
DAS	Defense Acquisition System
DAU	Defense Acquisition University
DDP	Design Dependent Parameter
DoD	Department of Defense
DoDI	Department of Defense Instruction
DPA	Defense Production Act
DRR	Design Readiness Review
DTC	Developmental Test Command
EMD	Engineering & Manufacturing Development
EMI	Electromagnetic Interference
FCB	Functional Capabilities Board
FCT	Foreign Comparative Testing
FNC	Future Naval Capabilities
FRP	Full Rate Production
GAO	Government Accountability Office
HMMWV	High-Mobility Multipurpose Wheeled Vehicle
ICD	Initial Capabilities Document

IPPD	Integrated Product and Process Development
IPT	Integrated Product Team
IRL	Integration Readiness Level
IRT	Independent Review Team
ITP	Integrated Technology Plan
JAST	Joint Advanced Strike Technology
JCIDS	Joint Capabilities Integration and Development System
JCTD	Joint Concept and Technology Demonstration
JROC	Joint Requirements Oversight Counsel
JSF	Joint Strike Fighter
JWP	Joint Warfighting Program
KPP	Key Performance Parameter
LRIP	Low Rate Initial Production
ManTech	Manufacturing Technology
MDA	Milestone Decision Authority
MDAP	Major Defense Acquisition Program
MOE	Measures of Effectiveness
MRA	Manufacturing Readiness Assessment
MRL	Manufacturing Readiness Level
MS	Milestone
NASA	National Aeronautical and Space Administration
NDE	Nondestructive Evaluation
OAST	Office of Aeronautics and Space Technology
OSD	Office of the Secretary of Defense
PIF	Prototype Integration Facility
PM	Program Manager
POR	Program of Record
R&T	Research & Technology
RDC	Rapid Deployment Capability
REF	Rapid Equipping Force
RTT	Rapid Technology Transition
S&T	Science & Technology

SBIR	Small Business Innovation Research
SME	Subject Matter Expert
SOCOM	Special Operations Command
SPO	Special Projects Office
SRL	System Readiness Level
ST/STE	Science & Technology/Special Test Equipment
STO	Strategic Technology Office
TD	Technology Development
TDS	Technology Development Strategy
TIPS	Technology Insertion for Savings Program
TPM	Technical Performance Measure
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
TTI	Technology Transition Initiative
TTO	Tactical Technology Office
USC	United States Code
USD(AT&L)	Under Secretary of Defense (Acquisition, Technology, & Logistics)
WMD	Weapon of Mass Destruction

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I. INTRODUCTION

A. BACKGROUND

Technology transition has become an area of extensive focus within the Department of Defense (DoD) over the last several years.

> (DoD) is in the process of transforming the U.S. armed forces from a Cold War-era fighting force to one that is lighter, more flexible, and more reliant on technology. This fighting force will be able to respond to a wide range of asymmetric threats with speed and efficiency. Accelerating the transition of new technologies into defense systems will be crucial to achieving this military transformation. However, the typical time required for moving new materials and processing technologies from research to applications is at least 10 years, and many times even longer. Historical precedents for the transition of new technologies into defense systems have been neither fast nor efficient. (www.nap.edu, p. 1)

To understand the motivation behind a shift in the manner DoD transitions technologies, one may simply examine the statistics of major systems that have faltered during development due to the inability to successfully accelerate the incorporation of advanced technology.

> Faster incorporation of new technologies into complex products and systems holds the possibility of ever-increasing advantages in cost, performance, durability, and new functionalities. (www.nap.edu, p. vii)

More efficient and effective management of technology is critical to ensuring the Warfighter receives timely, innovative solutions within cost and schedule constraints while maintaining mission effectiveness. A Memorandum from the Under Secretary of Defense (Acquisition, Technology, and Logistics) (USD(AT&L)) to the Secretary of Defense, Subject: Top 5 Priorities for AT&L, August 5, 2002, clearly stated,

> Accelerating the flow of technology to the Warfighter is one of the top priorities of the [USD(AT&L)], as well as the Services, defense agencies, and other key defense organizations that help transition technology. (DoD-DAU, p. xv)

As a result, new organizational structures, policies, and metrics have evolved.

The Valley of Death occurs around the Milestone B decision at the time the system is progressing from the Technology Development (TD) phase into the Engineering & Manufacturing (EMD) phase (as seen in Figure 1).

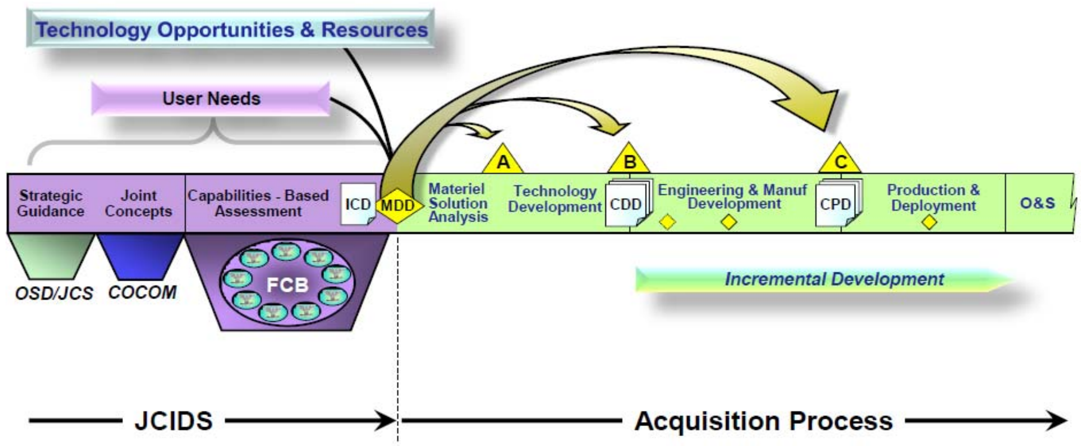

Figure 1. Defense Acquisition Management System (From: Matthews, p. 40)

Milestone B is the critical point in the Acquisition Management when the technology enters the Systems Acquisition Phase. At that time,

> The project shall exit the Technology Development Phase when an affordable program or increment of militarily useful capability has been identified; the technology and manufacturing processes for that program or increment have been assessed and demonstrated in a relevant environment; manufacturing risks have been identified; a system or increment can be developed for production within a short timeframe (normally less than 5 years for weapon systems); or, when the MDA decides to terminate the effort. During Technology Development, the user shall prepare the Capability Development Document (CDD) to support initiation of the acquisition program or evolutionary increment, refine the integrated architecture, and clarify how the program will lead to joint warfighting capability. The CDD builds on the ICD and provides the detailed operational performance parameters necessary to complete design of the proposed system. A Milestone B decision follows the completion of Technology Development. (AT&L, p. 19)

The period of time between TD and EMD also correlates with a Technology Readiness Level (TRL) 6, as defined by the Defense Acquisition University and shown in Figure 2, as "System/subsystem model or prototype demonstration in a relevant environment." Historically, the S&T community has developed technologies through TRL 5, yet, acquisition programs focus on more mature technologies at the TRL 7.

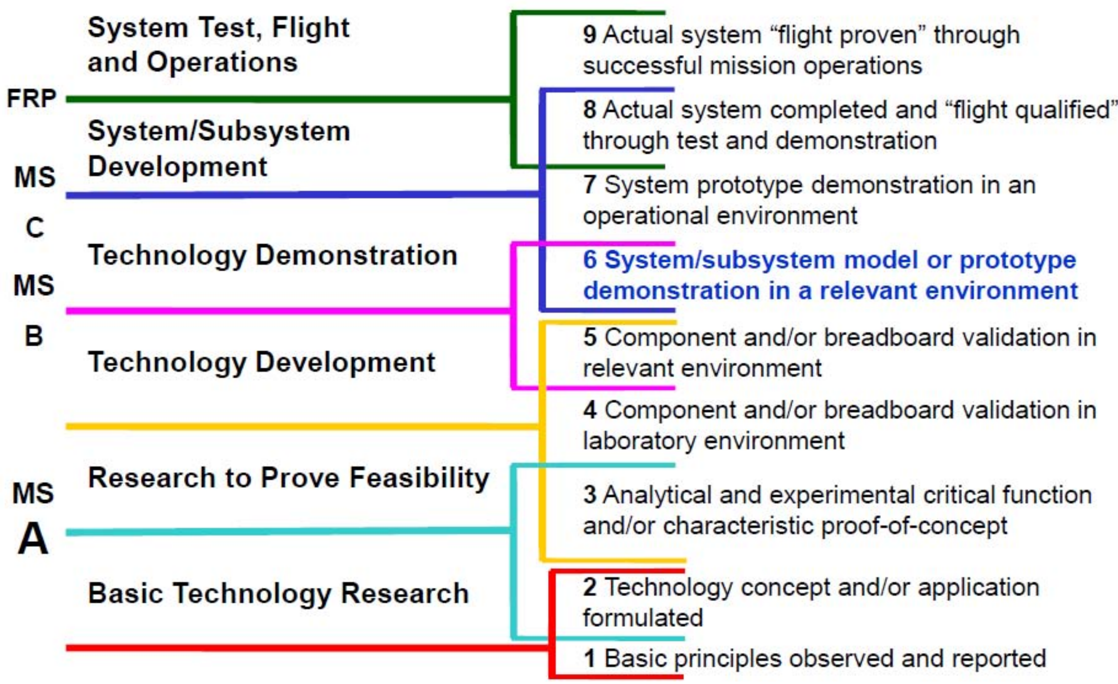

Figure 2. Acquisition Cycle and Technology Readiness Levels

B. DEFINITION

A vital step in the authors' research was to define technology transition. Contrary to the common wisdom, technology transition and technology transfer are significantly different. The Defense Acquisition University defines technology transition in the following manner:

> The process of applying critical technology in military systems to provide an effective weapons and support system—in the quantity and quality needed by the Warfighter to carry out assigned missions and at the "best value" as measured by the Warfighter.

The authors suggest that the concept of time be included in the definition. In today's geopolitical instability and in the face of relentless adversaries, it is essential that the DoD performs technology transition in a practical yet expedient manner. Time is a critical factor in technology transition.

On the other hand,

> Technology Transfer is the transfer or licensing of technology developed in Federal Laboratories to domestic partners, including industry, state and local governments, and academia. Key mechanism for the transfer are Cooperative Research and Development Agreements (CRADAs), Patent License Agreements, Educational Partnership Agreements, and DoD-wide Partnership Intermediaries. (acc.dau.mil, n.p.)

Technology transfer, although a critical component of technology development, shall not be discussed in this document.

C. CHALLENGES

All programs and initiatives will face expected and unexpected challenges. Historical evidence shows DoD's difficulties overcoming these challenges in transitioning technologies from S&T to EMD.

> DOD relies on its research laboratories and test facilities as well as industry and academia to develop new technologies and systems that improve and enhance military operations and ensure technological superiority over adversaries. Yet, historically, DOD has experienced problems in bringing technologies out of the lab environment and into real use. At times, technologies do not leave the lab because their potential has not been adequately demonstrated or recognized. In other cases, acquisition programs—which receive the bulk of DOD's funding in research, development, testing and evaluation of technology—are simply unwilling to fund final stages of development of a promising technology, preferring to invest in other aspects of the program that are viewed as more vital to success. Other times, they choose to develop the technologies themselves, rather than rely on DOD labs to do so—a practice that brings cost and schedule risk since programs may well find themselves addressing problems related to technology immaturity that hamper other aspects of the acquisition process. And often, DOD's budgeting process, which requires investments to be targeted at least 2 years in advance of their activation, makes it difficult for DOD to seize opportunities to introduce technological advances into acquisition programs. In addition, it is challenging just to identify and pursue

> technologies that could be used to enhance military operations given the very wide range of organizations inside and outside of DOD that are focused on technology development and the wide range of capabilities that DOD is interested in advancing. (GAO, p. 4)

Along with the aforementioned challenges, three other contributory factors have constrained technology transition.

- Lack of policy guiding and/or enforcing the implementation of technology transition processes
- Lack of organizational initiatives and structure that encourage and foster a strong technology transition environment
- Lack of a standardized metrics-based system to measure the maturity of a technology and the ability to correlate that information with the acquisition framework

Addressing the challenges with a systematic approach has allowed for a gradual shift in mindset within DoD; the changes are being embraced.

D. NOTIONAL CONSTRUCT

Transitioning technology, or ”bridging the gap” as organizations such as DARPA refer to it, is a complicated task requiring a tremendous cooperative effort amongst those shown in Figure 3. The combination of organizational transformation, policy adjustments, and a metric-based recognition of technology maturation provides a DoD a path forward to cross the dreaded valley of death.

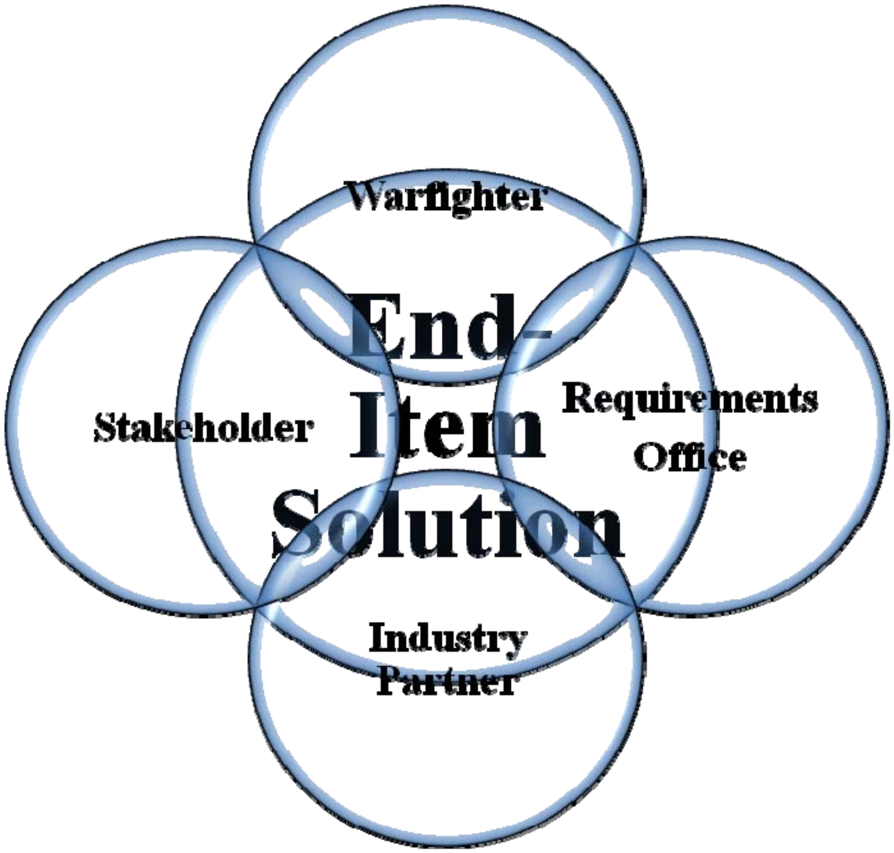

Figure 3. Collaborative Influences

As indicated in Figure 3, there is a close-knit interdependence between the Warfighter, the Requirements Office, the Industry Partner, and the Stakeholder, which influences the resultant end-item solution. This tight interaction is critical throughout the technology transition phase to ensure the appropriate solution is delivered to the Warfighter. Unfortunately, this arrangement has historically delayed the rapid insertion of technology due predominantly to the requirements portion. DoD programs are highly requirements-driven programs; the requirements take lengthy periods of time to derive. Therefore, DoD made a strategic decision per the 2001 Quadrennial Defense Review in which the Joint Capabilities Integration and Development System (JCIDS) was stood up to replace DoD's legacy Requirements Generation System (GAO, p. 4)

> The JCIDS process requires that gaps in military capabilities be identified and potential materiel and nonmateriel solutions for filling those gaps be developed based on formal capability assessments. The results of these capability assessments are formally submitted as initial capabilities documents (ICD)—a capability proposal—by a military service, defense agency, COCOM, FCB, or other sponsor. ICDs are intended to document a specific capability gap or set of gaps that exist in joint warfighting functions and propose a prioritized list of various solutions to address the gap(s). (GAO, p. 5)

The GAO study continues to state:

> The JCIDS process may lack the efficiency and agility needed to respond to warfighter needs—especially those that are near term—because the review and validation of capability proposals can take a significant amount of time. A proposal submitted to JCIDS can go through several review and comment resolution phases before consensus is reached on the proposal, and through several levels of approval before the JROC [Joint Requirements Oversight Council] validates the proposal. Our review of capability proposals submitted to JCIDS from fiscal years 2003 through 2008 found that review and validation takes on average 8 to 10 months (see fig. 5). JCIDS and service officials also indicated that prior to submitting a JCIDS proposal, the sponsor can take a year or more to complete a capabilities-based assessment and get a proposal approved. In other words, 2 years or more can elapse from the time a capability need is identified by a sponsor to the time the capability is validated by the JROC. (GAO, p. 13)

What if a requirement does not exist, but a technology or prototype developed in the S&T community has the potential to be of great benefit to the Warfighter? Unfortunately, in most if not all cases this transition will not occur due to the inability to acquire funding. This lack of appropriated funding to support non-JROC sanctioned efforts is disruptive to the technology development process and detrimental to mission effectiveness. An organizational shift to include funding set-asides and a bubble-up or technology push approach would more effectively address the immediate needs of the Warfighter. The men and women engaged in the daily activities of the battlespace can offer a tremendous amount of insight into what is needed. As opposed to waiting for vetted requirements to drive technology development, allow concepts and prototypes to bubble-up through the ranks, consequently utilizing the buy-in of the operator community to address a capability gap with a specific technology. This improved organizational process would increase the probability of meeting or exceeding the performance expectations of the Warfighter and reduce the time necessary to hand-off the end-item solution.

E. HISTORICAL BACKGROUND

The attention given to technology transition is a fairly new initiative as compared to the lengthy history of DoD. Official legislation introducing the Technology Transition Initiative (TTI) was established by Congress in the FY2003 National Defense Authorization Act. TTI, enacted by the 107th Congress of the United States of America, was detailed as follows in H.R.4546:

> (a) Initiative Required – The Secretary of Defense, acting through the Under Secretary of Defense for Acquisition, Technology, and Logistics, shall carry out an initiative, to be known as the Technology Transition Initiative (hereinafter in this section referred to as the "Initiative"), to facilitate the rapid transition of new technologies from science and technology programs of the Department of Defense into acquisition programs of the Department for the production of such technologies.
>
> (b) Objectives – The objectives of the Initiative are as follows:
>
> (1) To accelerate the introduction of new technologies into operational capabilities for the armed forces.
>
> (2) To successfully demonstrate new technologies in relevant environment. (107th Congress, p. 37)

Prior to the enactment of H.R.4546, limited activity occurred within DoD to improve upon the past performance of technology transition. One example of such an initiative is the Advanced Concept and Technology Demonstration (ACTD) Program.

> The Department of Defense's traditional approach to developing and building weapon and information systems has been criticized for taking too long, costing too much, and not adequately involving those who ultimately use the equipment. To address those problems, the Department of Defense (DoD) initiated the Advanced Concept Technology Demonstration (ACTD) program in 1994. (Joseph, n.p.)

The ACTD process, as seen in Figure 4, addresses the technology maturity and insertion issues abating technology transition from the TD Phase to the EMD Phase. However, process alone was not enough to ensure a successful transition.

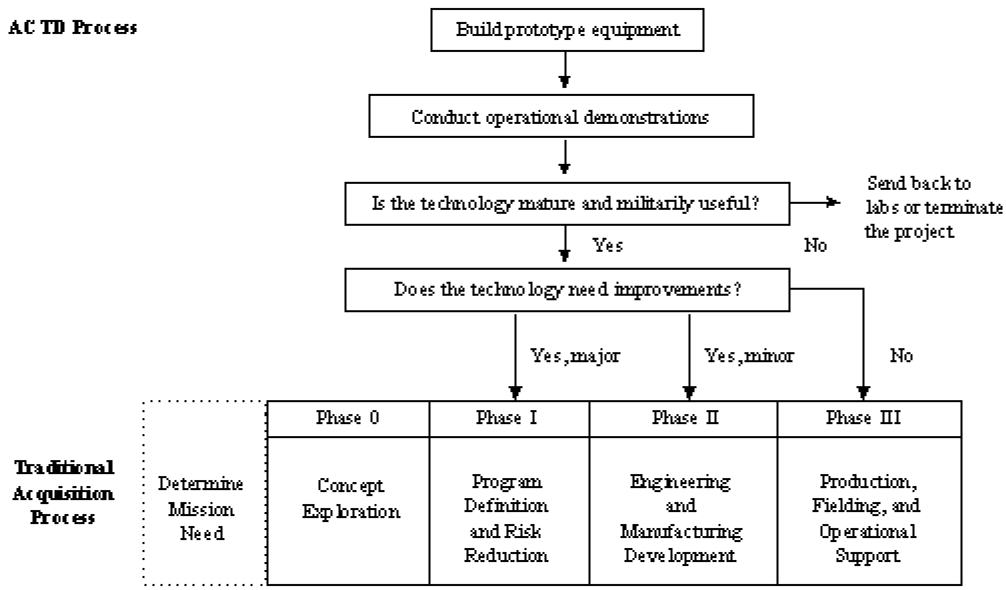

Figure 4. ACTD Process (From: Joseph, n.p.).

> When DoD established the ACTD program in 1994, it did not include a formal approach to address any concerns that might arise about the transition stage of the projects….For ACTDs that began in and after 1996, the AT Office (Office of the Deputy Under Secretary of Defense for Advanced Technology) made one important change by requiring project managers to establish transition integrated product teams (IPTs) where applicable. Transition IPTs examine whether a program will be affordable, what the requirements for operating and supporting the residual capability will be, what strategies are needed for testing and evaluation, and whether there is adequate documentation for maintenance, training, or moving a system into procurement. (Joseph, n.p.)

The ACTD Program has gradually transitioned to the Joint Concept and Technology Demonstration Program or JCTD; it "was first introduced into the President's Budget in 2006" (Peterson, p. 9).

> The new Joint Capability Technology Demonstration Program (JCTD) furthers this [the ACTD] concept by developing and maturing technologies to support the unique needs of the joint community in an even more adaptive and responsive process. (Krieg, p. 7)

The JCTD program falls within the structure of the Rapid Fielding Directorate, OSD. The Rapid Fielding mission is, "Rapidly transition innovative concepts into critical capabilities that counter unconventional and time-sensitive threats" (www.acq.osd.mil/rfd/, n.p.).

Since the inception of the ACTD/JCTD process, several additional initiatives and organizations have emerged. (The authors address these in Chapter III.) Yet one prominent organization evolved well before ACTDs and other technology transition initiatives—the Defense Advanced Research Projects Agency (DARPA).

> DARPA was created in 1958 as the Advanced Research Projects Agency (ARPA). The political and defense communities recognized the need for a high-level defense organization to formulate and execute R&D projects that would expand the frontiers of technology beyond the immediate and specific requirements of the Military Services and their laboratories. (www.darpa.mil, History)

Since DARPA's inception, the organization has proven to be very successful maturing technologies and establishing technology transition strategies. A study conducted by the Potomac Institute for Policy Studies in 2001 presented the following regarding the success of DARPA's technology transition initiatives.

> The principal finding of the study is that DARPA's transition performance has been excellent over the past forty years, inserting over 120 products or technologies into fielded systems (about 3 per year). During the past decade, the Agency's record has been even better, about 5 per year. Finally, where data was available, we calculated transition rates and found them to be at a level exceptionally high according to industry's standards. Considering DARPA's other missions and its responsibility to foster high-risk/high-payoff ideas, the Institute's team considers these statistics quite impressive. (Richardson, n.p.)

II. TECHNOLOGY TRANSITION POLICY

A. INTRODUCTION

This section discusses the technology transition policies within the DoD. The major polices governing technology transition within the DoD are found in DoD Directive 5000.01, DoD Instruction 5000.02, and in the Defense Acquisition Guidebook. The major policies related to technology transition are explored below.

B. DOD DIRECTIVE 5000.01

DoD Directive 5000.01 outlines the Defense Acquisition System. It is applicable to all acquisition programs within DoD. This Directive defines the Defense Acquisition System (DAS) as "the management process by which the Department of Defense provides effective, affordable, and timely systems to the users" (p. 4). It defines an Acquisition Program as a "directed, funded effort that provides a new, improved, or continuing materiel, weapon or information system, or service capability in response to an approved need" (p. 4).

The purpose of the DAS is to:

> Manage the nation's investments in technologies, programs, and product support necessary to achieve the National Security Strategy and support the United States Armed Forces. The investment strategy of the Department of Defense shall be postured to support not only today's force, but also the next force, and future forces beyond that. (DoD Directive 5000.01, p. 3)

It further states that

> the primary objective of Defense acquisition is to acquire quality products that satisfy user needs with measurable improvements to mission capability and operational support, in a timely manner, and at a fair and reasonable price. (DoD Directive 5000.01, p. 3)

In order to ensure the continued technological superiority of U.S. forces over our adversaries' successful technology transition is a key component in the DAS. DoD Directive 5000.01 specifically addresses technology development and transition.

It requires that a program:

> Address user needs; maintain a broad-based program spanning all Defense-relevant sciences and technologies to anticipate future needs and those not being pursued by civil or commercial communities; preserve long-range research; and enable rapid, successful transition from the S&T base to useful military products. (DoD Directive 5000.01, pp. 9–10)

C. DOD INSTRUCTION 5000.02

DoD Instruction 5000.02 implements DoD Directive 5000.01 and lays out the operation of the DAS. It is applicable to all acquisition programs within DoD. The Defense Acquisition Management System prescribed in the DoD Instruction 5000.02 is illustrated in Figure 5.

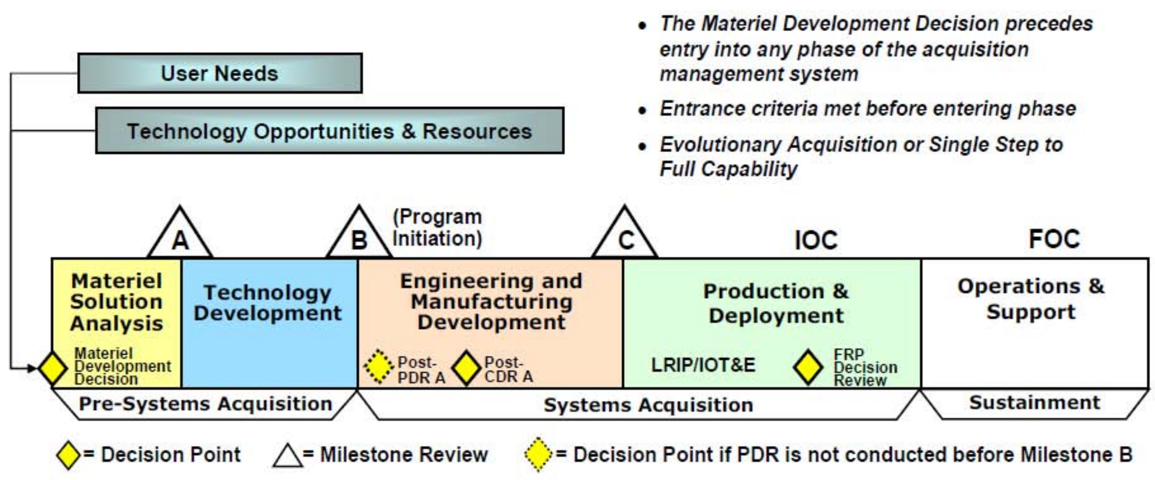

Figure 5. Acquisition Cycle

Concerning technology transition, the technology development phase of this management system is of key importance. During this phase, promising new technologies must be matured to a sufficient state allowing them to bridge the Valley of Death occurring around the Milestone B decision and be successfully transitioned into an acquisition program.

The purpose the technology development phase is to:

> Reduce technology risk, determine and mature the appropriate set of technologies to be integrated into a full system, and to demonstrate CTEs

> [Critical Technology Elements] on prototypes. Technology Development is a continuous technology discovery and development process reflecting close collaboration between the S&T community, the user, and the system developer. It is an iterative process designed to assess the viability of technologies while simultaneously refining user requirements. (DoD Instruction 5000.02, p. 16)

In order to enter the technology development phase the Milestone Decision Authority (MDA) must approve the material solution and the Technology Development Strategy (TDS). The TDS must explain the proposed acquisition approach, either single step to full capability, or evolutionary, which is the preferred approach. When an evolutionary strategy is being used, the TDS must explain the increments that the material solution will be divided into given the maturity of the technology involved in the system.

DoD Instruction 5000.02 further states:

> If an evolutionary strategy is used, the initial capability represents only partial fulfillment of the overall capability described in the ICD, and successive technology development efforts continue until all capabilities have been achieved. In an evolutionary acquisition, the identification and development of the technologies necessary for follow-on increments continue in parallel with the acquisition of preceding increments, allowing the mature technologies to more rapidly proceed into the Engineering and Manufacturing Development (EMD) Phase. Each increment of an evolutionary acquisition program that includes a Milestone A shall have a Milestone Decision Authority (MDA)-approved TDS. (p. 18)

DoDI 5000.02 requires that technology risk be managed and mitigated in order to help ensure the program meets its cost and schedule goals. To this end, DoDI 5000.02 requires routine objective assessments of technology maturity and risk. DoDI 5000.02 states that

> Technology developed in S&T or procured from industry or other sources shall have been demonstrated in a relevant environment or, preferably, in an operational environment to be considered mature enough to use for product development. (p. 19).

This corresponds to at least TRL 6. DoDI 5000.02 requires that Technology Readiness Assessments be conducted and if the technology is determined not to meet the minimum maturity level then an alternative technology meeting the minimum maturity level and satisfying the users' requirements must be used. If that is not possible, then modifying the users' requirements is discussed with the user.

The DoD Technology Readiness Assessment (TRA) Deskbook (2009) defines a TRA as

> a formal, systematic, metrics-based process and accompanying report that assesses the maturity of technologies called Critical Technology Elements (CTEs) to be used in systems. (p. 1–1).

> CTEs are defined as

> A technology element is "critical" if the system being acquired depends on this technology element to meet operational requirements (within acceptable cost and schedule limits) and if the technology element or its application is either new or novel or in an area that poses major technological risk during detailed design or demonstration. (DoD, 2009, p. 1–1)

In order to help clarify this definition, the DoD TRA Deskbook further states that "If the technology represents a major risk, it should be identified as a CTE so that the TRA will include technical information that can be used to mitigate the risk" (p. 1–1). TRAs are conducted by an independent review team (IRT) composed of the necessary subject matter experts (SMEs). DoD acquisition programs must prepare a TRA at Milestone B and C. In accordance with 10 USC 2366b on Major Defense Acquisition Programs (MDAPs) the MDA must certify that the CTEs are at least at TRL 6. The law allows the MDA to waive this certification; however, this is only in extraordinary circumstances.

In summary, the DoDI 5000.02 requires that CTEs be at least at TRL 6 in order to be used in the system past Milestone B. So, before and during the technology demonstration phase technology elements identified as critical must be managed so that they are matured to at least TRL 6 or else they will not be usable in that increment of the program. These technologies could be slated for further maturation and potential insertion into a future increment of the program once they have reached TRL 6 or they could be shelved with no plan for future use.

D. DEFENSE ACQUISITION GUIDEBOOK

The Defense Acquisition Guidebook (DAG) is meant to complement DoDD 5000.01 and DoDI 5000.02 and provides additional guidance to the Acquisition Community on implementing these policies. Relative to technology transition the DAG provides additional information concerning the content of the TDS. The DAG specifies that the TDS should include a technology maturation section. It states,

> The Technology Maturation section of the TDS should include discussion of the identified preliminary critical technology elements (CTEs) and the respective strategies for attaining at least Technology Readiness Level (TRL) 6 prior to Milestone B. (p. 2.2.8)

The goals for the maturation of each of the CTEs should be laid out including any reviews, tests, and/or demonstrations of how the CTEs are maturing. As previously discussed for CTEs, a TRL level of at least 6 must be reached prior to Milestone B. A TRL 6 indicates the CTE has been demonstrated in a relevant environment. Therefore, in order to make this assessment, the relevant environment must be defined in the context of the specific system being developed.

The Defense Acquisition Guidebook states that the:

> Technology Development Strategy should identify the relevant environment including potential threats against the capabilities desired and the physical environment (altitude, temperature, vibration, electro-magnetic, etc…), within which the materiel solution needs to operate. The characteristics of the environment should also be related to testing efforts in the Test and Evaluation Strategy. (p. 2.2.8.1)

DoDI 5000.02 requires competitive prototyping involving at least two competing teams prior to Milestone B approval. The DAG provides additional guidance to DoD acquisition professionals regarding competitive prototyping. The DAG states that the TDS "should include a description of the prototyping purpose and the prototyping strategy at the system and subsystem levels" (p. 2.2.8.2).

It further states,

> The prototyping strategy should be competitive and provide for prototypes of the system or, if a system prototype is not feasible, for prototypes of critical subsystems before Milestone (MS) B approval. (p. 2.2.8.2)

The use of competitive prototyping at the system or subsystem level is a valuable tool to help mature technology, reduce risk, provide the government with a better understanding of the technology, and increase contractor motivation (DoD, 2010).

DoDI 5000.02 requires Program Managers (PMs) to consider the use of Small Business Research Innovation (SBIR) program technologies and "…give favorable consideration to successful SBIR technologies" (p. 14). The DAG provides further implementing guidance stating that the PM should

> …prepare a Technology Development Strategy (TDS) that appropriately uses the SBIR program to develop needed technologies, includes the use of technologies developed under the SBIR program, and gives fair consideration to successful SBIR technologies. (p. 2.2.10.1)

The PM must examine available SBIR technologies for inclusion in the system, either in the current increment or for possible inclusion in a subsequent increment and plan accordingly to develop those technologies to the appropriate maturation level and transition them into the program.

III. ORGANIZATION

A. PROGRAMS

In the post-Cold War era, a change was necessary to remain the most technologically superior military in the world. At that point, DoD began to implement organizational transformations to account for a leaner, rapid response military with a global perspective. The DoD Acquisition System, up to the early '90s, was prohibitive to rapid, cooperative technology development and insertion. In order to address this predicament, DoD established several organizations that utilized non-traditional, industry practices to abate the difficulties bringing technologies to a suitable maturation state. Albeit these organizations may not remedy the technology transition difficulties, their intent was a paradigm shift in DoD acquisition. The following chart describes a portion of the DoD organizational initiatives.

Program	Management	Characteristics that Facilitate Transition
Advanced Concept/Joint Capabilities Technology Demonstration (AC/JCTD)	Program direction and oversight by OSD Projects managed and executed by Military Departments, Defense Agencies and SOCOM	Focuses on Joint Warfighter Functional Capabilities which are often under-resourced and with no one organization tasked to meet these needs Allows warfighters to evaluate a technology for its potential
Agile Integration and Development	Army	Funds acceleration for selected high-payoff emerging technologies Improves technology readiness by accelerating the tech development schedule and/or performing detailed safety & validation tests in field/operational environment

Collaborative Technology Alliances	Army	Collaboration among Government-Industry-University researchers to achieve affordable transition of innovative technologies
Defense Acquisition Challenge Program (DAC)	OSD oversight Military Department/ Defense Agency management and execution	Provides an "on-ramp" for industry and government to propose innovative new technology and equipment solutions for acquisition programs
Foreign Comparative Testing (FCT)	OSD oversight Military Department/ Defense Agency management and execution	Helps find developed technologies in allied nations and funds their testing for potential procurement
Future Naval Capabilities (FNC)	Navy	Involves near-term S&T efforts that deliver maturing technologies for more timely incorporation
Rapid Deployment Capability (RDC)	Navy	Provides the ability to reach immediately to a newly discovered threat or to respond to significant and urgent safety situations
Rapid Technology Transition Program (RTT)	Navy	Has a charter to rapidly transition technology from any source, including those not traditionally associated with defense technology, into PORs
SBIR Commercialization Pilot Program (CPP)	Army, Navy, Air Force OSD Oversight, Direction, and Coordination	Identifies projects with potential to meet high priority military needs Provides assistance to affect rapid transition
Technology Insertion for Savings Program (TIPS)	Navy	Concentrates on existing and/or COTS technology that can be formed quickly into the solution and has a high return on investment after insertion

Technology Transition Initiative (TTI)	Program direction and oversight by OSD Projects managed and executed by Military Departments, Defense Agencies and SOCOM	Accelerate the introduction of new technologies into operational capabilities for the armed forces
Warfighter Rapid Acquisition Process	Air Force	Provides transition funding for development & fielding of successful experiments, demonstrations, & innovative approaches Complete, approved acquisition plan Budget Activity 7

Table 1. Technology Transition Organizational Initiatives

(Source: Department of Defense Report to Congress on Technology Transition, p. 12)

All of these organizations foster a strong, open-communicative architecture, beginning with the user (the Warfighter) progressing through the S&T and EMD arenas. They were formed to fulfill a common goal—rapidly transition mature technologies to the Warfighter. Whether the organization is supplying the funding to bridge the S&T and EMD appropriation gap or providing over-arching management or actually developing and maturing the technology, they have impacted the Warfighter with highly functional, relevant solutions. Yet, much larger strides in organizational reform are needed to overcome DoD's historically slow development cycle. Even after Mr. David Packer of the Blue Ribbon Commission on Defense Management lamented over the "unreasonably long acquisition life cycle of 10–15 years" (Packer, p. 47) in 1986 DoD still lacks the ability to reduce the acquisition cycle of a major system. This unfortunately

> leads to obsolete technology in our fielded equipment [and] we forfeit our five-year technological lead by the time it takes us to get our technology from the laboratory into the field. Packer, p. 47)

In addition to addressing a broad technology base, the various organizations and initiatives listed in Table 1 span across the joint services, a critical attribute in the modern-day military environment where a large portion of programs are jointly represented. This joint approach is intended to leverage the knowledge, skills, and abilities across the services and maintain commonality to more rapidly mature a technology. Solutions may have their slight differences between the services; however, they have a common goal to transition useful technologies such as the F-35 Joint Strike Fighter (JSF) Program. The JSF Program, originally referred to as the Joint Advanced Strike Technology (JAST) Program, was a joint effort between the Navy, Air Force, Marines, and the UK.

> The goal of the JAST program was not to have developed a new aircraft, but instead it was to mature the technologies that a new series of tactical aircraft could use. (www.jsf.mil, History/JAST)

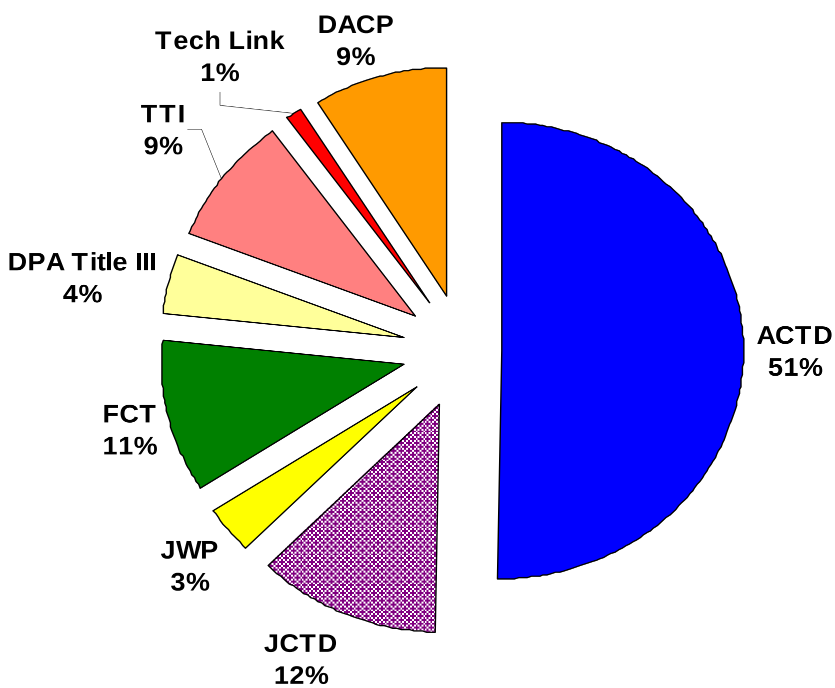

Figure 6. Technology Transition Initiative Funding Break-out
(Source: Payton, Slide 9)

Program	$M
Advanced Concept Technology Demonstration (ACTD) (BA-3)	$164
Joint Capability Technology Demonstration (JCTD) (BA-3/4/5 & Procure)	$40
Joint Warfighting Program (JWP)-BA-3	$10
Foreign Comparative Testing (FCT)-BA-6	$36
Defense Production Act (DPA) Title III	$13
Technology Transition Initiative (TTI)-BA-3	$30
TechLink (BA-3)	$3
Defense Acquisition Challenge Pgm (DACP)-BA-5	$29

Table 2. Technology Transition Initiative Funding ($)
(Source: Payton, Slide 9)

As demonstrated in Figure 1 and Table 2, a sufficient amount of funding has been injected into these new programs. Based upon these amounts and the number of new initiatives, it is clear the need for a more efficient technology transition process has been recognized within DoD. DoD must maintain vigilant oversight to ensure efforts that all within these and forthcoming programs do not become victims of traditional 10–15 year programs.

B. COOPERATIVE INITIATIVES

Reform of the acquisition process is now a driving force in the Department of Defense. A number of specific acquisition reform initiatives have been conceived, some borrowed from industry, and briefed at the highest levels of Government. Many have been mandated by the Secretary of Defense, Dr. William Perry, implemented by the Under Secretary of Defense for Acquisition and Technology, Dr. Paul Kaminski, the Services, and some

> have been enacted by Congress. One such initiative borrowed from industry that will fundamentally change the way the Department does business is Integrated Product and Process Development (IPPD). (Burt, Foreword)
>
> The IPPD process, initiated in the early 1990s
>
> is the DoD management technique that simultaneously integrates all essential acquisition activities through the use of multidisciplinary teams to optimize design, manufacturing, and supportability processes. One of the key IPPD tenets is multidisciplinary teamwork through Integrated Product Teams (IPTs). (acc.dau.mil)

IPTs have become a necessity in the development of technologies, and are an essential mechanism to ensure the right technology gets to the right person at the right time. Subject matter experts from all of the acquisition disciplines are brought together in a cohesive team to develop a technology from concept through sustainment. This is contrary to the traditional stovepipe development processes historically followed within DoD. IPTs are extremely user-oriented in how they approach development. Users are empowered to work directly with scientists, engineers, manufacturing specialists, logisticians, etc. to “shape” a solution that most appropriately balances the requirements with the “wants” and “like to haves.” This constant, open communication and interaction is of great benefit as a technology matures and is eventually inserted into a system solution. It has been demonstrated on several large acquisition programs that well-managed IPTs are extremely successful transitioning technologies through the TRLs and MRLs and their associated milestones.

C. INDUSTRY PROCEDURES

The business practices of industry are a great asset to DoD and provide valuable lessons learned. Although industry does not follow the stringent acquisition regulations that DoD is required to adhere to and their predominant focus is profit, the manner by which they have transitioned technology has proven to be very successful. According to a GAO study, industry leaders focus on three key techniques:

- Strategic planning at the corporate level
- A gated management review process that ensures a technology's relevancy, feasibility, and transition readiness
- Effective tools to solidify commitment, address transition issues, and gauge project progress and process effectiveness. (GAO, p. 9)

To expand upon these techniques:

> Successful transition in leading companies starts with strong strategic planning followed by a structured technology development process led by research labs and supported by tools that pave the way for a smooth handoff to the product line. Strategic planning is considered a precursor to transition and allows managers to identify market needs so the company can quickly adapt its technology portfolios to meet those needs. A gated technology development process continually tests for relevancy and feasibility of technologies and gauges the commitment of product line managers to accept them. Once a technology is ready to transition, management and funding responsibilities gradually shift from the lab to the product line. By the end of transition, but before product development starts, the technology is validated as mature enough for use in the intended product. (GAO, p. 3)

TECHNOLOGY DEVELOPMENT GATES		
Explore Technology ideas and concepts are being explored	**Develop** Technology development activities are underway	**Technology transition** Technology is ready to transition from lab to product line team
Review (between Explore and Develop)	*Review* (between Develop and Technology transition)	
Deliverables • Technology is consistent with overall business strategy • Technology is promising and is likely to meet needs for potential product lines • Lab identifies potential products where technology can be used • Key cost, benefit, risk, marketing, manufacturing, and life cycle management issues are identified • Scalability approaches are identified • Technologies considered to be intellectual property are identified	**Deliverables** • Technology is consistent with technology strategy and other relevant strategies • Labs have high degree of confidence the technology will work • Product line team agrees that the technology will meet its needs • Technical requirements are identified • Cost, benefits, and risks are quantified • Scalability approach is selected • Strategies for addressing intellectual property rights are selected	**Deliverables** • Technology project complies with technology strategy • Technology is sound • Technology meets product requirements • Cost, benefit, and risks are well understood • Technology can be scaled to a magnitude appropriate for practical application • Product line team agrees technology is ready • Intellectual property rights methods have been pursued • Technology is demonstrated in an operational environment • Technical documentation is ready to be given to product line team

Figure 7. Technology Development Gates (From: GAO, p. 12)

Depicted in Figure 7, each phase of an industry development cycle is gated and successful transition into the subsequent phase is predicated upon the completion of the deliverables. This strategy builds upon the concept of TRLs and MRLs as metrics throughout the acquisition life cycle. Both provide the PM with objective criteria to determine the maturity of a technology.

Relationship managers are another key industry technique that has rarely been implemented within DoD. These managers are a critical communication focal point throughout the entire product development life cycle.

> With the exception of DARPA, DOD does not use relationship managers in the same manner as leading private companies. According to an Air Force lab official, relationship managers market technologies being developed by the labs or gather data about ongoing projects for senior lab management. Most communication about technology transition in DOD takes place through integrated product teams or during annual reviews of technology projects by the senior-level oversight boards for each of the services. Use of relationship managers for these purposes are helpful, but the managers do not necessarily serve as points of contact within the labs and acquisition communities, do not devote time toward efficiently transitioning technologies to multiple weapon system programs, and do not help identify and address systemic transition problems.
>
> Within DARPA, senior officers, called operational liaisons, focus on marketing and transitioning DARPA-sponsored technologies. According to the DARPA director [Dr. Anthony Tether], the liaisons have been very helpful with transitioning technologies because they are well practiced at using the command chain of their respective services and finding the right service contact at the right time. The liaisons:
>
> - Provide operational advice for planning and strategy development
> - Provide an understanding of service perspectives, issues and needs so that potential customers can be identified and effective agreements can be written
> - Draft and coordinate agreements between DARPA and the services
> - Direct technology insertion in the services. (GAO, pp. 32–33)

As a direct link to the Case Study in Chapter V,

> The DARPA [prior] director [Dr. Anthony Tether] credits operational liaisons for the quick transition of the Boomerang, an acoustic shot-detection system, from the lab to troops in Iraq. DARPA developed the system in response to feedback from Iraq that convoys were being engaged by snipers yet remained unaware of sniper attacks until a windshield was broken, a soldier was hit, or a vehicle was visibly damaged upon inspection at the end of the convoy mission. Within 60 days of an urgent Army request, DARPA fielded the first Boomerang system. But DARPA's director said the system did not hold up well in the extreme weather conditions and under wartime conditions. As Boomerang II was being prepared for fielding, the director said the operational liaisons helped craft a more realistic concept of operations, training package, and logistical support package to ensure that Boomerang II not only was technologically ready for combat but was properly supported with spare parts, maintenance facilities, maintenance personnel, training, and lessons-learned feedback to DARPA and the Army. The liaisons also ensured that the Army acquisition community was alerted to Boomerang II's deployment so product developers would be ready to evaluate the final product for movement into the more traditional acquisition process. (GAO, p. 33)

An organizational transformation is slowly infiltrating DoD, yet traditional roadblocks are inhibiting a more rapid progression. DoD's lack of success is made evident in Table 3:

Table 1: Cost and Schedule Outcomes for 23 Programs Initiated under the Revised Policy (as of December 2005)

Program	Percent growth in estimated development cost*	Percent growth in estimated development schedule
Expeditionary Fighting Vehicle	61%	70%
Active Electronically Scanned Array radar (upgrade for F/A-18 E/F fighter/attack aircraft)	14%	1%
Global Hawk unmanned aerial vehicle	166%	Undetermined
Joint Strike Fighter	30%	23%
UH-60M helicopter upgrade	151%	25%
C-130 Avionics Modernization Program	122%	Undetermined
C-5 Reliability Enhancement and Re-engining Program	0%	25%
Joint Tactical Radio System Cluster 1	31%	44%
Joint Tactical Radio System Waveform	44%	Undetermined
Advanced Anti-radiation Guided Missile	7%	0%
Multi-Platform Radar Technology Insertion Program	0%	Undetermined
Future Combat System	48%	53%
E-2 Advanced Hawkeye	5%	0%
Warfighter Information Network-Tactical	0%	0%
Small Diameter Bomb	0%	0%
EA-18G	7%	0%
Joint Tactical Radio System Cluster 5	0%	2%
Multi-Mission Maritime Aircraft	0%	0%
Standard Missile-6 Extended Range Active Missile Block 1	0%	0%
Aerial Common Sensor	45%	36%
B-2 Radar Modernization Program	0%	0%
Patriot/Medium Extended Air Defense System Combined Aggregate Program (fire unit)	0%	0%
Mission Planning System	0%	0%

Table 3. DoD Major Programs Cost and Schedule Performance (Source: GAO, p. 36)

The topics addressed above are a select few of the contributing factors to the future success of DoD’s technology transition abilities. Despite the numerous programs, initiatives, and lessons learned from industry, DoD’s traditional methods of conducting business are still prevalent throughout the acquisition cycle, in particular, the technology transition phase. Unfortunately until sound processes, procedures, and techniques are fully implemented and adhered to the Warfighter suffers the greatest impact. It is incumbent upon DoD to not only promote an organizational transformation with regards to technology transition but to take a step back and look at the big picture; absorb the positive attributes of the current structure and discard the negative attributes. The organizational mindset alone can be a powerful tool to bridge the gap between S&T and Engineering.

IV. TECHNOLOGY METRICS

A. BACKGROUND

As stated in the DoD's report to Congress in July 2007, "Transitioning technology into established Programs of Record (PoR) is a longstanding challenge for the Department. The underlying problem has come into sharp focus in recent years with the adoption of Technology Readiness Levels (TRLs) as a common vocabulary for discussing the maturity of a technology and uncovering the disconnect between our S&T and acquisition communities. Our acquisition policies require a minimum of TRL 7 (″system prototype demonstrated in an operational environment") for a critical technology to be incorporated in a production program (an important best practice recommended by GAO to control technical risk, and strongly supported by DoD). On the other hand, expectations within S&T community have traditionally been to advance new technologies only to the TRL 5 level ("component and/or breadboard validation in a relevant environment″ (e.g., high fidelity laboratory)), with no particular capability deployment in mind, and then move on to the next technology. Although a technology maturity gap exists, one now has the ability to exploit a metrics-based system to measure the breadth of that gap through Technology Readiness Levels (TRLs). Therefore, TRLs are not simply an assessment tool but also a planning and risk mitigation tool.

> The introduction of Technology Readiness Levels (TRLs) over the last decade provided an accepted common language and measurement scale intended to strengthen communication within and between the DoD S&T and acquisition communities, both in government and industry. Stakeholders in all parts of the acquisition system now expect that a Critical Technology Element (CTE) will have an appropriate TRL, or level of maturity, prior to acceptance as a baseline technology for a weapon system. They also embrace the concept that technology should have only an acceptable level of risk in order to pass through each acquisition milestone decision point and that TRLs are a way of measuring and communicating that risk. (JDMTP, ES-5)

B. TECHNOLOGY READINESS LEVELS

In 1991, the Office of Aeronautics and Space Technology (OAST) of the National Aeronautical and Space Administration (NASA) developed an Integrated Technology Plan (ITP).

> The purpose of the ITP was to serve as a strategic plan for the OAST space research and technology (R&T) program […] conducting technology development that support future U.S. civil space missions. (NASA, ii)

Within the ITP, nine definitive levels of technology maturity were defined. Those nine levels (shown in Table 4) have become the backbone of measuring technology development; although the definitions have evolved somewhat over the years (and across different organizations) the general premise remains the same. Technology development requires a metric to measure the maturity of the technology to ensure the appropriate level of effectiveness is obtained prior to transitioning to the next phase. Until NASA's ITP, this uniform means of assessment did not exist.

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, including 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.

Technology Readiness Level	Description
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.

Table 4. Technology Readiness Levels

(Source: DAU, Ask a Professor)

Clarifying definitions (via DAU/Ask a Professor):

- BREADBOARD: Integrated components that provide a representation of a system/subsystem and which can be used to determine concept feasibility and to develop technical data. Typically configured for laboratory use to demonstrate the technical principles of immediate interest. May resemble final system/subsystem in function only.

- HIGH FIDELITY: Addresses form, fit and function. High fidelity laboratory environment would involve testing with equipment that can simulate and validate all system specifications within a laboratory setting.

- LOW FIDELITY: A representative of the component or system that has limited ability to provide anything but first order information about the end product. Low fidelity assessments are used to provide trend analysis.

- MODEL: A reduced scale, functional form of a system, near or at operational specification. Models will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.

- OPERATIONAL ENVIRONMENT: Environment that addresses all of the operational requirements and specifications required of the final system to include platform/packaging.

- PROTOTYPE: The first early representation of the system which offers the expected functionality and performance expected of the final implementation. Prototypes will be sufficiently hardened to allow demonstration of the technical and operational capabilities required of the final system.

- RELEVANT ENVIRONMENT: Testing environment that simulates the key aspects of the operational environment.

- SIMULATED OPERATIONAL ENVIRONMENTAL: Environment that can simulate all of the operational requirements and specifications required of the final system or a simulated environment that allows for testing of a virtual prototype to determine whether it meets the operational requirements and specifications of the final system.

Technology Readiness Assessments

The implementation within DoD of a TRL system to assess the maturity of a technology has more vividly exposed the gap between S&T and Engineering. As components/systems traverse through the various early development phases, the S&T,

Engineering and Test, and Stakeholder communities now have the appropriate technology metrics to prepare for the Valley of Death by exploiting the usage of Technology Readiness Assessments (TRAs).

> Per DoD Instruction 5000.2, the TRA is a regulatory information requirement for all acquisition programs. The TRA is a systematic, metrics-based process that assesses the maturity of Critical Technology Elements. The TRA should be conducted concurrently with other Technical Reviews, specifically the Alternative Systems Review, System Requirements Review, or the Production Readiness Review. If a platform or system depends on specific technologies to meet system operational threshold requirements in development, production, and operation, and if the technology or its application is either new or novel, then that technology is considered a Critical Technology Element.
>
> The TRA should not be considered a *risk* assessment, but it should be viewed as a tool for assessing program risk and the adequacy of technology maturation planning. The TRA scores the current readiness level of selected system elements, using defined Technology Readiness Levels. The TRA highlights critical technologies and other potential technology risk areas that require program manager attention. (dag.dau.mil, Section 4.3.2.4)

These analyses, along with a conducive organizational mindset, enhance the ability of the technology developers to plan for maturation to TRL 6 and ultimately TRL 7.

The more information a PM is able to obtain about their technology's developmental progression the better they can plan and develop technology transition agreements and establish the appropriate technology transition partners.

C. MANUFACTURING READINESS LEVELS

Another metric available to Program Managers are Manufacturing Readiness Levels (MRLs).

> Manufacturing Readiness is the ability to harness the manufacturing, production, quality assurance, and industrial functions to achieve an operational capability that satisfies mission needs—in the quantity and quality needed by the war-fighter to carry out assigned missions at the "best value" as measured by the Warfighter. (dag.dau.mil, Section 4.4.14.2)

Throughout the development process, even during the early phases, appropriate production planning is critical to a successful transition. During TRAs MRLs are influential factors in the decision to transition a technology from the S&T environment into the EMD phase. Evaluators will ask, “Is the item producible? “Can the item be produced in a cost effective manner?” and “Are there current processes to produce the item?” These questions, and many others, help define the readiness of a technology and its ability to bridge the gap between TRL 5 and TRL 7. Even if one conceptualizes the most amazing design, if you cannot practically manufacture it then it serves no purpose to the Warfighter.

There are ten MRLs. These levels directly relate to the nine Technology Readiness Levels that are in use with an additional MRL 10 that is equal to a program in full rate production. The first three levels are discussed as a single level, which is equal to TRLs 1 through 3. Below are definitions of each MRL and a description of the criteria necessary to each level and the associated acquisition phase:

MRL 1-3

The organization has identified manufacturing concepts. This is the Pre-Concept Refinement phase. Identification of current manufacturing concepts or producibility needs has occurred and is based on laboratory studies.

MRL 4

The organization has validated the system, component, or item in laboratory environment. This is the lowest level of production readiness. The Concept Refinement (CR) phase leads to a Milestone A decision. Technologies must have matured to at least TRL 4. At this point few requirements have been validated and there are large numbers of engineering/design changes. The organization has not defined component physical and functional interfaces. Materials, machines and tooling have been demonstrated in a laboratory environment. Inspection and test equipment have been demonstrated in a laboratory environment. DTC & Production drivers identified. Producibility assessments have been initiated.

MRL 5

The organization has validated component or item in an initial relevant environment. Engineering application/bread board, brass board development is occur-ring. This is the first half of the Technology

Development (TD) phase and merges with the second half when we begin system validation leading to a Milestone B decision. Technologies must have matured to at least TRL 5. At this point all requirements have not been validated and there are significant engineering/design changes. Industrial Base analysis has been accomplished to identify potential sources. Initial producibility of component technology has been completed. Form, Fit & Function constraints identified and allocated at component level. Key Performance Parameters allocated at component level and initial evaluation of Key Characteristics accomplished. Subsystem and major component level DTC goals established. Manufacturing cost considerations affect technology choices. Manufacturing cost drivers/goals identified. DTC/Production costs estimated and tracked. Required Manufacturing Technology (ManTech) efforts initiated. Yield/rate issues identified. Key Quality Characteristics identified. Science and Technology/ Special Test Equipment (ST/STE) requirements identified. Initial Manufacturing Plan is developed.

MRL 6

The organization has validated the system in an initial relevant environment. Engineering application/bread board, brass board development is occurring. This is the 2nd half of the Technology Development (TD) phase and leads to a Milestone B decision. Technologies must have matured to at least TRL 6. All requirements have not been validated and there are significant engineering/design changes. Component physical and functional interfaces have not been defined. Materials, machines and tooling have been demonstrated in a relevant environment but most manufacturing processes are in development (e.g. ManTech initiatives). Inspection/test equipment has been demonstrated in a laboratory environment. Producibility assessments are ongoing initial improvements begun. Production cost drivers and goals are being analyzed and set. DTC goals have been set.

MRL 7

The System, component or item is in advanced development. This is the System Development & Demonstration Phase (pre DRR). All technologies have matured to at least TRL 7. At this point engineering/design changes should be decreasing. Physical and functional interfaces should be clearly defined. All raw materials are in production and available to meet the planned LRIP schedule. Pilot line manufacturing processes have been set-up and are under test. Processes and procedures have been demonstrated in a production relevant environment. During this phase, the producibility improvements should be underway. DTC estimates are within 125% of the DTC goals. Production estimates are being established.

MRL 8

The system is in System Development & Demonstration leading to a Milestone C decision. Component or item is in advanced development and ready for low rate initial production. Technologies must have matured to at least TRL 8. Engineering/design changes should be decreasing significantly. There must be very few changes at the end of this phase. Physical and functional interfaces should be clearly defined. All raw materials are in production and are available to meet the planned LRIP schedule. Manufacturing processes and procedures have been proven on the pilot line, under control and ready for low rate initial production. During this phase, producibility risk assessments should be completed. The DTC goals should have been met. Production estimates meet production goals.

MRL 9

The system, component or item has been previously produced or is in production. Or, the system, component or item is in low rate initial production. This phase is Low Rate Production & Deployment leading to a Full Rate Production Decision (FRP). During low rate initial production all systems engineering/design requirements should be met and there should be minimal system engineering/design changes. Technologies must have matured to at least TRL 9. All materials are in production and available to meet planned production schedules. All manufacturing processes are established and controlled in production to three-sigma or some other appropriate quality level. Machines, tooling and inspection and test equipment deliver three-sigma or some other appropriate quality level in production. Production risk monitoring is ongoing. LRIP costs meet production goals.

MRL 10

The system, component or item previously produced or in production. Or, the system, component or item is in full rate production. This is the Full Rate Production or Sustainment phase. This is the highest level of production readiness. There are minimal engineering/design changes. System, component or item is in production or has been produced and meets all engineering, performance, quality and reliability requirements. All materials, manufacturing processes and procedures, inspection and test equipment, controlled in production to six-sigma or some other appropriate quality level in production. A proven, affordable product able to meet required schedule. Production goals meet actual. (JDMTP, 16–18)

During the era of stovepipe development, manufacturability and producibility were afterthoughts in the development process. As DoD has learned over many years, this lack of insight into downstream processes is a recipe for disaster. Hence, the introduction of MRLs and Manufacturing Readiness Assessments (MRAs) into the pre-EMD phases of the development cycle. These assessments are critical elements in determining the true maturity of a technology and the potential big picture impact on the system. Similar to TRLs, MRLs provide a direct correlation to the acquisition life cycle. Additionally, MRLs are an excellent tool to assist in the transition between a prototype and production units, which is critical to attain the higher TRLs.

D. SYSTEM READINESS LEVELS

Technology and Manufacturing Readiness Levels focus on the maturity of components and sub-component whereas they do not fully assess the interoperability and interfacing of the components in a system. To encompass the overall maturity and ability of a system to transition a broader metric is warranted. The Stevens Institute of Technology has suggested the usage of System Readiness Levels (SRLs), which combine TRLs and Integration Readiness Levels (IRLs).

> The SRL Model is a function of the individual Technology Readiness Levels (TRL) in a system and their subsequent integration points with other technologies, the Integration Readiness Level (IRL). (Sauser, p. 10)

The IRLs and SRLs are outlined in Table 5.

IRL	Definition [9]
7	The integration of technologies has been ***verified and validated*** with sufficient detail to be actionable.
6	The integrating technologies can ***accept, translate, and structure information*** for its intended application.
5	There is sufficient ***control*** between technologies necessary to establish, manage, and terminate the integration.
4	There is sufficient detail in the ***quality and assurance*** of the integration between technologies.
3	There is ***compatibility*** (i.e. common language) between technologies to orderly and efficiently integrate and interact.
2	There is some level of specificity to characterize the ***interaction*** (i.e. ability to influence) between technologies through their interface.
1	An ***interface*** (i.e. physical connection) between technologies has been identified with sufficient detail to allow characterization of the relationship.

Table 5. Integration Readiness Levels

(Source: Sauser, p. 11)

SRL	Name	Definition
5	**Operations & Support**	Execute a support program that meets operational support performance requirements and sustains the system in the most cost-effective manor over its total life cycle.
4	**Production & Development**	Achieve operational capability that satisfies mission needs.
3	**System Development & Demonstration**	Develop a system or increment of capability; reduce integration and manufacturing risk; ensure operational supportability; reduce logistics footprint; implement human systems integration; design for producibility; ensure affordability and protection of critical program information; and demonstrate system integration, interoperability, safety, and utility.
2	**Technology Development**	Reduce technology risks and determine appropriate set of technologies to integrate into a full system.
1	**Concept Refinement**	Refine initial concept. Develop system/technology development strategy

Table 6. System Readiness Levels
(Source: Sauser, p. 7)

The SRL table (less SRL 5 which is beyond the scope of this document) and the IRL table outline critical factors in the maturation state of a system and provide more thorough indicators to the readiness of a system (or a group of technologies) to transition. However, these authors would argue the Stevens Institute neglected the inclusion of MRLs in their SRL model. As indicated previously, in Section C, MRLs are a vital assessment tool and would factor well into the SRL model.

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V. DARPA CASE STUDIES

A. BACKGROUND

1. DARPA

> DARPA's original mission, inspired by the Soviet Union beating the United States into space with Sputnik, was to prevent technological surprise. This mission has evolved over time. Today, DARPA's mission is to prevent technological surprise for us and to create technological surprise for our adversaries.
>
> DARPA's main tactic for executing its strategy is to constantly search worldwide for revolutionary high-payoff ideas and then sponsor projects bridging the gap between fundamental discoveries and the provision of new military capabilities. (DARPA, Strategic Mission)

Mr. Kevin Wallace, one of the authors, has experienced first-hand the planning and insight that is required for a Program Manager to fulfill DARPA's strategic vision. PMs amalgamate users, requirements developers, stakeholders, subject matter experts within industry and academia, and transition partners to develop innovative ideas into practical solutions.

2. Dr. Karen Wood

> Dr. Wood joined DARPA in 2003, as Program Manager in the Tactical Technology Office. She joined the Strategic Technology Office in 2006. From 2002–2003, she supported SPO as an employee of ANSER working on chemical sensors for WMDs and large space structures with the ISAT program. While in TTO, she developed the Boomerang system, a rapid reaction, acoustic gunshot detection system, currently deployed in Iraq and Afghanistan. She also initiated the CROSSHAIRS, RPGnets and LASSO programs, along with numerous seedling efforts. From 1991 to 2001, Dr. Wood worked in various positions at NASA Langley Research Center in both the Advanced Materials Processing and Nondestructive Evaluation Sciences Branches. Her work included materials characterization and NDE of large space structures. (DARPA, STO)

B. BOOMERANG PROGRAM

1. Background

The Boomerang Program began in late 2003 as a result of an immediate need by U.S. troops in Iraq for a shooter detection system. There were several different types of detection systems already in use; however, there was a far less expensive system that could be more widely deployed and mounted on vehicles, as well as set up at a fixed location. The Boomerang was developed by DARPA as a Rapid Reaction Initiative. Under a Rapid Reaction Initiative, the goal is to field a solution within 60–90 days.

2. Capability Gap

The genesis of the Boomerang Program was U.S. Troops in Iraq experiencing a high number of causalities from small arms fire while driving in convoys. The adversaries were primarily using AK-47s while hiding along roadways at distances of less than 200 meters and would shoot in quick bursts from a concealed location (i.e., buildings, walls, etc.). Due to road noise often times the troops would not know they had been fired upon until they reached their destination and noticed bullet holes in their vehicle, a windshield was shattered by a bullet, or a casualty was incurred. The Boomerang program sought to remedy this problem by providing an affordable capability of detecting and located small arms fire.

3. Boomerang I

The prime contractor responsible for developing the Boomerang was BBN Technologies. BBN was involved in a previous DARPA effort aimed at developing counter sniper measures in the late 1990s, during which they developed Bullet Ears. Bullet Ears was a stationary system using two tetrahedral acoustic arrays separated by 50 meters that processed the sound of a muzzle blast and the shockwave of the bullet to locate the shooter’s position (CNN, 1997). That impressive effort by BBN lead DARPA to seek them out for the Boomerang Program (Montiz, 2005). On November 17, 2003, BBN was awarded a contract for the development of the Boomerang system. This contract included the development and demonstration of a first article prototype within 30 days after contract award and included a go/no-go decision based on the demonstration to produce 50 systems. It also included six months of research and development covering all engineering and software development spirals, six optional lots of not to exceed 190 systems per lot, and optional operations and support of the system. The initial Boomerang schedule is illustrated in Figure 8.

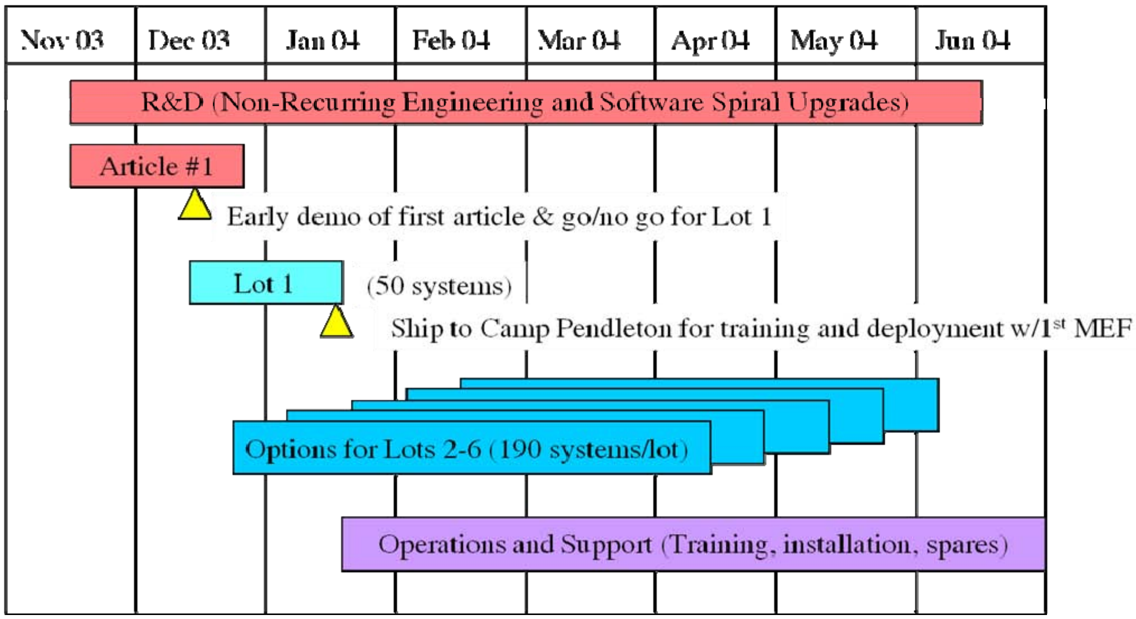

Figure 8. Boomerang Schedule

The Initial Performance Objectives of the Boomerang were as follows:

- Determines relative shooter direction to ± 15 degrees within 1 second of shot
- Shot Detection: 99% for bullet trajectory within 30 meters of sensor array
- Operates at up to 60 mph on rough terrain or highways
- Weapon Types: .20 cal to .50 cal (AK-47 = .30 cal)
- Voice announcement and LED visual rosette display of shooter location (‘hours of a clock’)

- Compact sensor array with full azimuth view
- Demonstrated performance in open fields and urban environments
- No false alarms due to wind noise, bumps, door slams, etc.

Boomerang Major Components:

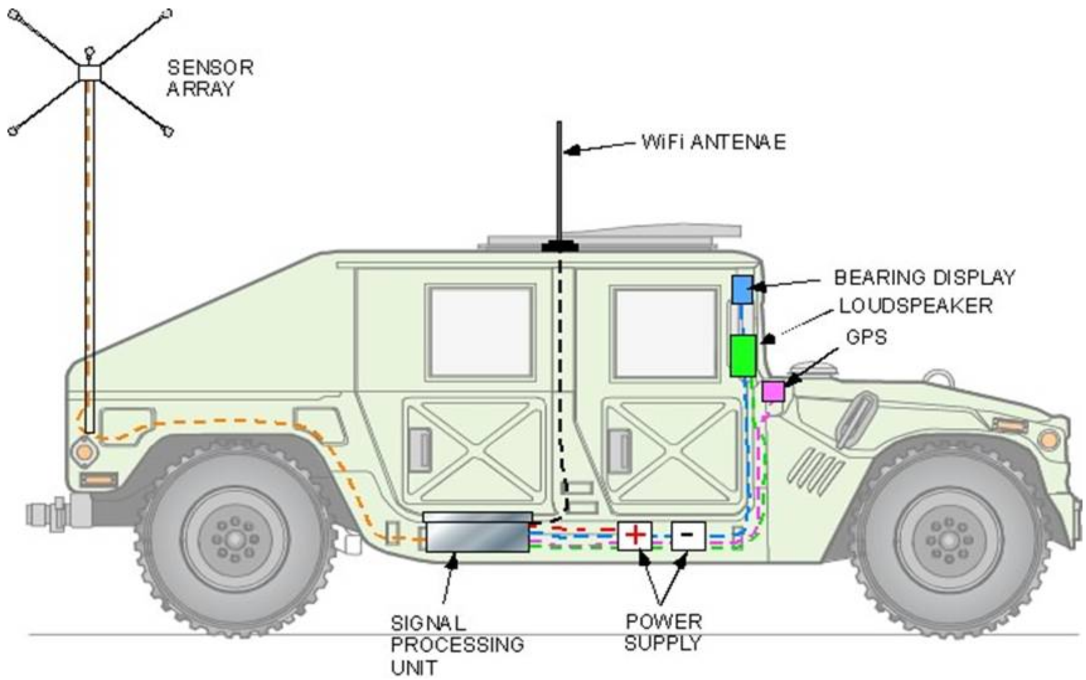

Figure 9. HMMWV-mounted Boomerang System

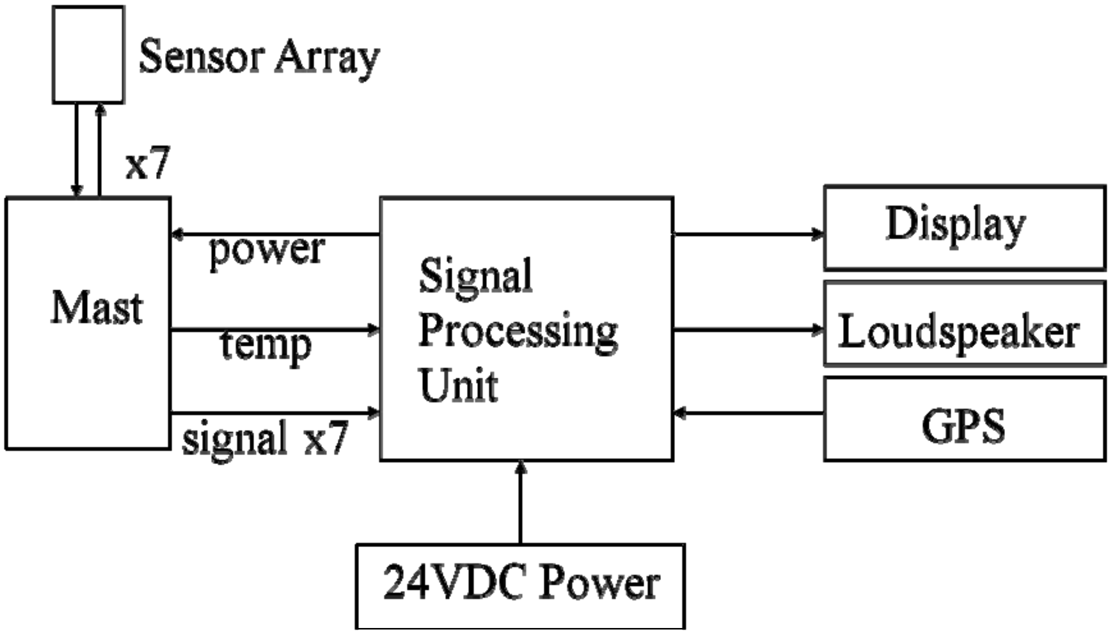

Figure 10. Boomerang Block Diagram

Boomerang I was designed, prototyped, tested, and the first lot of 50 units delivered in 66 days, only 6 days over the objective of 60 days. Out of first lot, 40 units were provided to the Army and 10 units were provided to the Marines. These units were deployed throughout Iraq. Users gathered data related to system performance and issues and communicated them to BBN and DARPA.

4. Boomerang II

As a result of areas for improvement identified by troops using the Boomerang I, upgrades were made to the system resulting in the second generation Boomerang or Boomerang II.

The following issues were identified from the deployed Boomerang I systems:

- High false alarm rate
  - EMI was determined to be the cause.

- Fix: Shielding throughout system; work with EMI experts to mitigate problems

- Overheated wiring
  - Power conditioners for 50 units were supplied by various vendors world-wide. Several were substandard.
  - Fix: Removed power conditioners and use jumpers for initial systems. Current systems does not require them
- Rubber hub isolation mount failures
  - Batch specific failures due to rubber variations. Drilled holes and used doubled-stranded wire to support hub.
  - Fix: Hub redesign
- Speaker bulky and falls off
  - Fix: Speaker integrated into display

As a result, the identification of these issues and areas for improvement Boomerang II's Performance Objectives were set as follows:

- Determines relative shooter direction to ± 5 degrees within 1 second of shot
- Shot Detection: 99% for bullet trajectory within 50 meters of sensor array
- Operates at up to 60 mph on rough terrain or highways or as a stationary stand- alone unit
- Weapon Types: .20 cal to .50 cal (AK-47 = .30 cal)
- Compact sensor array with full azimuth view
- Voice announcement and LED visual rosette display of shooter location ('hours of a clock')
- New display shows range and elevation along with 10-digit grid coordinate of vehicle
- No false alarms due to wind noise, bumps, door slams, etc.

- No false alarms due to outgoing return fire
- System cost is < $10K

In June 2004, lot 2 was ordered consisting of 50 Boomerang IIs. All of these units were provided to the Army and were deployed throughout Iraq. In order to address the identified issues with Boomerang I and meet the updated performance objectives Boomerang II improvements updates included a redesigned sensor array/hub, a redesigned display, a simplified hardware layout, and improved algorithms. In this upgraded configuration Boomerang II met all of its performance objectives. Figure 12 illustrates Boomerang II improvements.

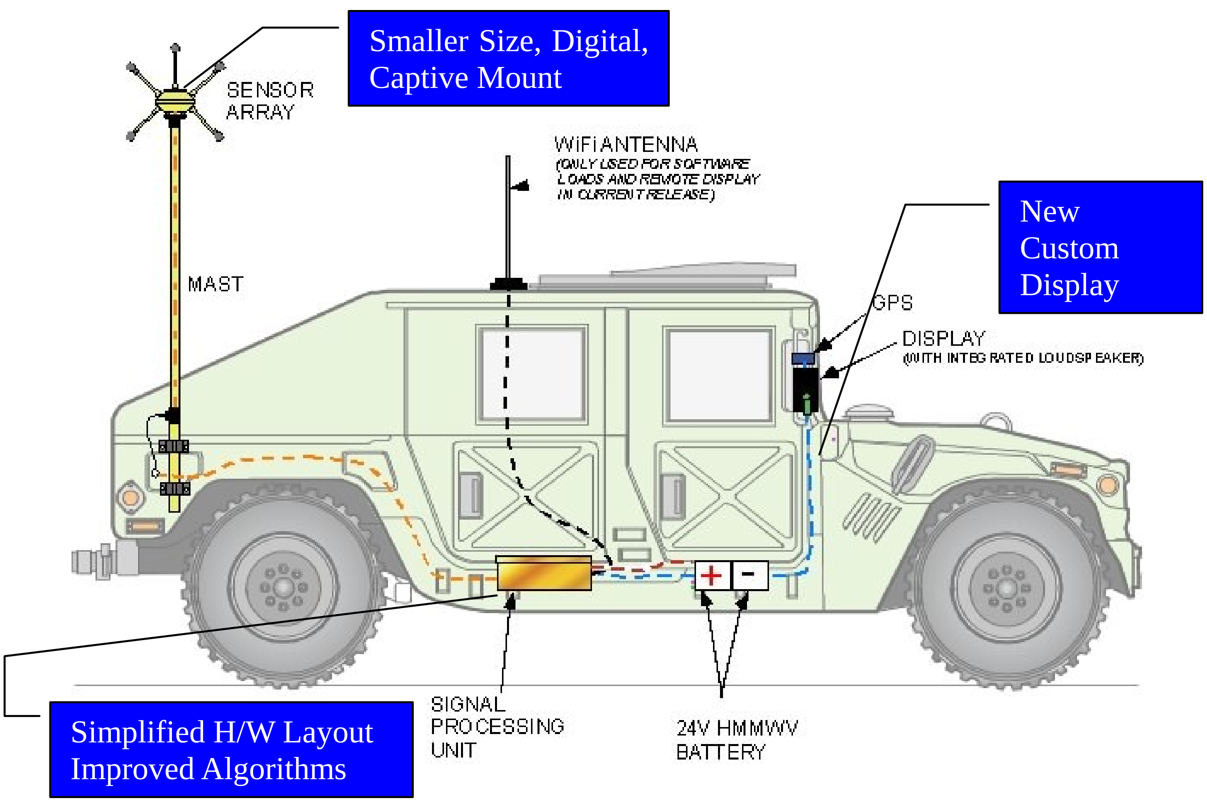

Figure 11. Boomerang II Improvements

In total, over 500 Boomerang II units were eventually ordered and fielded. DARPA involvement in the Boomerang system officially in ended in January 2006 when its contract with BBN expired. User feedback on Boomerang IIs deployed in Iraq eventually led to the Boomerang III.

5. Conclusion

Boomerang is a great example of technology being quickly transitioned out of the S&T community and into the hands of the Warfighter to meet an immediate need. Boomerang I was designed, prototyped, tested, and the first lot of 50 units delivered in 66 days. Once fielded, DARPA and BBN worked closely with users to identify areas of improvement to the system that resulted in Boomerang II. After DARPA's involvement with Boomerang ended, additional improvements to the system were made eventually resulting in the current system configuration, Boomerang III. Boomerang III is a commercial item available to U.S. military, law enforcement, and other authorized entities through the GSA schedule.

VI. SUMMARY AND RECOMMENDATIONS

A. SUMMARY

This Joint Applied Project has examined the current DoD technology transition practices in the context of organization, policy, and metrics along with a case study demonstrating a very successful technology transition. A significant hurdle in technology transition within DoD has been "bridging the gap" between the S&T and acquisition communities to successfully transition promising technologies from the lab into the hands of the Warfighter. Recommendations are provided below on ways DoD can improve the success of its technology transition capabilities.

B. RECOMMENDATIONS

Recommendation #1

Recommend DoD develop and implement an alternate mechanism to augment the JCIDS process to rapidly field promising technologies to meet immediate and short-term Warfighter needs. This would entail developing a more streamlined requirements approval process for immediate and short-term needs where the S&T community has identified potential technologies currently in development that have a high likelihood of meeting those needs and being matured, developed, and fielded. In addition, due to the difficulty obtaining funding to transition technologies that are not tied to a JROC vetted requirement, the alternate process would need to address a streamlined funding mechanism to allow the S&T and EMD community to rapidly secure funding to execute these projects.

Currently within the U.S. Army, organizations are implementing a mechanism similar to what the authors are suggesting. The Rapid Equipping Force (REF) was established

> to equip operational commanders with commercial-off-the-shelf and government-off-the-shelf solutions to increase effectiveness and reduce risk, [and] insert future force technologies and surrogates to validate concepts and speed capabilities to the Soldiers. (www.ref.army.mil, n.p.).

> The REF serves as a solutions catalyst, canvassing the military, industry, academia, and the science community for existing and emerging technologies. (www.ref.army.mil, n.p.)

Also within the U.S. Army, Prototype Integration Facilities (PIFs) have been established to rapidly deliver solutions to the Warfighter. These solutions can be organic, modified commercial-off-the-shelf, or a combination of the two. Mr. Kevin Wallace, one of the authors, is a Branch Chief within one of the Army PIFs and has worked closely with the REF on several efforts. He has experienced first-hand several successful technology transitions; however, the process to bridge the gap between the S&T and EMD communities remains to be a somewhat arduous task. The concept behind the REF and PIFs is a step in the right direction and similar mechanisms should be proliferated across the joint services.

Recommendation #2

Recommend DoD implements policy requiring the industry proven practice of using relationship managers in the S&T and acquisition communities. These relationship managers would be located within the military lab communities and assigned to support a portfolio of technologies. They would function as liaisons between the labs, requirements developers, industry, academia, and the acquisition community. They would be responsible for interfacing with these communities to market technologies within their portfolio and transition those technologies (when appropriate) into the hands of the Warfighter. As illustrated by the Boomerang case study DARPA has had success using the relationship manager concept. The authors believe that the relationship manager concept would greatly aid the S&T and acquisition communities in successfully transitioning technology if implemented throughout DoD.

Recommendation #3

Recommend DoD adopt a gated technology development process consisting of a strategic planning phase, exploration phase, development phase, and a transition phase. This process is a common industry practice that has proven to be very successful in transitioning technology. In industry, successful transition begins with strong strategic planning. During this planning process, market needs and technologies the company is developing (or potentially could develop to meet those needs) are identified. If recommendation two (2) were implemented by DoD along with recommendation three (3) the relationship managers would play a key role in this step by working with the users to determine their needs and the acquisition community to satisfy those needs. During this part in the process, the following questions must be answered:

- What is the specific Warfighter need? This entails open bi-directional lines of communication with the end-user enforcing the bubble-up approach.
- How soon is it needed? Is the need immediate, near-term or far-term, and is the timeline realistic.
- Are there potential solutions that meet the timeframe? A thorough search of potential applicable solutions is a necessity. Are there technologies readily available that meet the user need, are of sufficient maturity, and can be transitioned within the timeframe required?
- Can metrics be developed that lead to an operational user evaluation? TRLs, MRLs, and SRLs are critical to objectively measuring the maturity of a technology. These metrics as well as CTEs, Key Performance Parameters (KPP), and Measures of Effectiveness (MOE) help determine the extent to which the technology is appropriate for the solution and guide the development of downstream user evaluation criteria. Additionally, one could establish technical performance benchmarks which can be monitored throughout the maturation process to ensure the technology is remaining focused on the solution.
- What is the schedule that will drive the program? What are the factors driving the schedule? Both essential questions in detailing the path forward.

After strategic planning a gated process is followed going through exploration, development, and technology transition phases, with reviews taking place in between. When a given technology is ready for transition the technology transition community and the product development community work together to gradually shift management and funding responsibilities from one to the other. The authors believe that implementing policy within DoD in line with these practices would aid in the future success of DoD's transition capabilities.

Recommendation #4

Recommend the continual implementation of TRLs and MRLs as maturity metrics with the expanded usage of SRLs to encompass the bigger picture. The ability to discern the readiness of a technology in an objective manner is critical to the technology transition process. A system in development is only as mature as its least mature component. TRLs, MRLs, and SRLs aid developers in identifying the areas of risk. Once identified, strategic plans can be formulated to ensure all technologies are of sufficient maturity to transition to the next phase.

The maturation of a technology is only a portion of the decision to transition to the next phase of development. Metrics such as MOEs, Technical Performance Measures (TPMs), and Design-dependent Parameters (DDPs) should be established and monitored to ensure the technology will ultimately fulfill the established need. MOEs, TPMs, DDPs and other Systems Engineering metrics demarcate the technology as it develops through the TRL, MRL, and SRL maturity levels.

C. CONCLUSION

In conclusion, this Joint Applied Project has examined the current DoD technology transition practices in the context of organization, policy, and metrics. Within DoD their continues to be a gap between the S&T and acquisition communities that must be more successfully bridged in order to transition technologies out of the lab and into the hands of the Warfighter. In order to do this, the authors believe that an alternate mechanism to the JCIDS process should be developed to rapidly field promising technologies to meet immediate and short-term Warfighter needs, the use of relationship managers within the military lab communities should be required, a gated technology development process based on common industry practice should be adopted, and the use of metrics measuring not only the maturity of the technology but also the extent to which it meets the users need should be expanded.

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