TRANSITIONING DARPA TECHNOLOGY

FINAL TECHNICAL REPORT
For the Period
December, 2000 through May, 2001

CONTRACT NO. DAMD17-00-2-0033

Prepared for

Defense Advanced Research Projects Agency
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May 2001

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden to Washington Headquarters Service, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington, DC 20503.

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1. REPORT DATE *(DD-MM-YYYY)*
17 July 2001

2. REPORT TYPE
Final Report

3. DATES COVERED *(From - To)*
8 Dec 2000 - 30 May 2001

4. TITLE AND SUBTITLE
Transitioning DARPA Technology

5a. CONTRACT NUMBER
DAMD17-00-2-0033

5b. GRANT NUMBER
N/A

5c. PROGRAM ELEMENT NUMBER
N/A

6. AUTHOR(S)
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5d. PROJECT NUMBER
N/A

5e. TASK NUMBER
N/A

5f. WORK UNIT NUMBER
N/A

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Potomac Institute for Policy Studies
901 N. Stuart Street, Suite 200
Arlington, VA 22203

8. PERFORMING ORGANIZATION REPORT NUMBER
PIPS-01-04

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Defense Advanced Research Projects Agency
3701 N. Fairfax Drive
Arlington, VA 22203-1714

10. SPONSOR/MONITOR'S ACRONYM(S)
DARPA

11. SPONSORING/MONITORING AGENCY REPORT NUMBER
N/A

12. DISTRIBUTION AVAILABILITY STATEMENT
Distribution Statement A; approved for public release

13. SUPPLEMENTARY NOTES
The views and conclusions contained in this document are those of the authors and should not be interpreted as representing the official policies, either express or implied, of DARPA or the U.S. Government.

14. ABSTRACT

The goal of this study was to address how and how well DARPA has transitioned products to the Military Services. The report also addresses how that mission has been affected by the nature of the Agency and its output, and by the environment in which it operates. The report tracks program and product characteristics for the last decade (1990s) and new starts begun at DARPA during FY 1991. The study documents three canonical transition paths and five strategies commonly used by DARPA. It offers recommendations from conclusions suggesting ways to improve transition performance.

15. SUBJECT TERMS
DARPA, technology transition, transition history, transition paths

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			John Jennings
U	U	U	Unclassified	128+cvr	**19b. TELEPONE NUMBER (*Include area code*)** 703-696-0093

A POTOMAC INSTITUTE FOR POLICY STUDIES REPORT: PIPS-01-04

Transitioning DARPA Technology

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MAY 2001

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Cover design: Stephanie L. Tennyson

Cover Photos: U.S. Department of Defense

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Table of Contents

Preface

The study was performed under a DARPA contract. Mr. John Jennings, the DARPA program manager, contributed both information and ideas. In conducting case studies and preparing this report, the Institute also interviewed many people from within the Agency, industry, academia, and other government organizations. We cannot mention all of them here, but we would especially like to express our appreciation to: Trent Depersia; CAPT Dennis McBride, USN (Ret.); Rick Dunn; Dr. Mel Ciment; Pete Worch; Jeff Bullington; Bill Marks; Dr. Steve Wax; John Jennings; Sven Roosild; Dr. Robert Leheny; Dr. David Honey; Dr. Andrew Yang; Dr. Drew Glista; Dr. Raymond Balcerak; Dr. David Patterson; Dr. Hilarie Orman; Dr. John Toole; Dr. Hank Dardy; Dr. Paul Mockapetris; Dr. Robert Tulis; Dr. Darrel Hopper; Chris Spiegel; Dr. Mark Slusarczuk; Dr. Richard Koyama; J. William Doane; Gene Miceli; Michael Ciensinski; Dr. Frank Patten; Dr. William Barker; Dr. James Butler; Dr. Ben Wilcox ; Dr. Larry Fahrenbacher; Dr. Brian Boesch; Dr. Michael W. Masters; Riva Meade; Major Doug Deyer, USAF; Frank Schrenk; Dr. LN Durvasula; Dr. Bert Hui; Dr. Robert Rosenfeld; Dr. Ronald Kostoff; and Pat Sullivan. However, the contents of this report are the responsibility of the Institute and are not necessarily agreeable to other contributors.

A major part of this study was dedicated to finding ways to characterize the transition record of an organization like DARPA, one that spends much of its capital on high risk/high payoff and innovative technical solutions to large problems. Although volumes have been written about product insertion, one quickly finds the specifics of the products and circumstances under which they are developed and marketed dominate the way an organization transitions its wares and the degree of success it has in doing so. In this work we attempted to characterize those specifics. In some instances, this necessitated choosing and assigning values to descriptors of the products and the programs that led to them. We would have enjoyed soliciting more opinions on this process, particularly on the values assigned, but as in life itself, there was no time. We would be grateful for any comments on this or any other aspect of the report. Please send comments to tennyson@potomacinstitute.org.

Executive Summary

> *"I want an agency that makes sure no important thing remains undone because it does not fit somebody's mission."* Neil McElroy, Secretary of Defense, 1957

A. Background

The Defense Advanced Projects Agency (DARPA)[1] was formed in 1958 to address our nation's move into space. Since then the Agency has received many assignments, although its overall mission and character have remained fairly consistent. During this time, immensely diverse products have emerged to find their way into our nation's space, defense, academic, and private sectors. In this project, the Potomac Institute for Policy Studies (the Institute) was asked to develop and document an understanding of how well DARPA has transitioned these products into military systems over the past forty years. The above quote is a reminder that, as important as transition is, it is not the only responsibility delegated to the Agency. This and other factors affecting DARPA's transition rate were considered.

Earlier studies have substantiated the impressive array of products DARPA has developed and transitioned into various military systems. The Agency has provided basic work in science and technology that has enriched the programs of military laboratories and the defense industry alike. Significant "spin-offs" (from the defense sector to commercial industry) and "spin-ons" (from commercial industry to the defense sector) have also resulted from DARPA programs. Perhaps as noteworthy are the commercial and government organizations created to improve, manage, and apply DARPA-supported technologies, some of which have continued to set industry-wide protocols, perform precompetitive research, and insert technology and products into military systems.

DARPA has conducted programs at nearly all stages of acquisition, certainly spanning research (6.1) to application (6.3), to address customers across the spectrum of the Military Services, from researcher to user. Historically, a unique feature of DARPA is the breadth of its programs and its military customer base. Unlike most Service acquisition organizations, which most often address one or two groups of users, DARPA's approach has been to seek a broad range of customers. This flexibility also brings some complexities into the lives of Agency program managers. They must be familiar with a wide span of work in their field, application of their technology, and environment under which the technology is to be used.

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[1] DARPA, then called the Advanced Research Projects Agency (ARPA), was established by Department of Defense Directive Number 5105.15 on February 7, 1958. Public Law 85-325, dated 12 February 1958, called upon the Agency, "… to engage in advanced projects essential to the Defense Department's responsibilities in the field of basic and applied research and development which pertain to weapon systems and military requirements as the Secretary of Defense may determine after consideration with the Joint Chiefs of Staff…" Although the name of the Agency has changed back and forth from ARPA to DARPA, we will refer to it by its present name, "DARPA" throughout this report. Likewise, we have referred to organizations and positions by the names and titles they bear today.

B. Goals of the Project

This report is essentially a study of how and how well DARPA has transitioned products to the Military Services. The report also addresses how that mission has been affected by the nature of the Agency and its output, and by the environment in which it operates. The study had four goals:

1. To examine DARPA's history of transition to its military customer;
2. To empirically identify transition paths and strategies employed by DARPA;
3. To identify factors that affect DARPA's transition rates and to cite recent changes in those factors; and
4. To suggest how DARPA might improve transition.

C. Study Approach and Organization of This Report

In this Executive Summary, we offer a brief statement of our approach to the project. We also present several conclusions and recommendations developed and discussed throughout the five chapters. In order to accomplish the four study goals, we drew from the wisdom of past studies but we also collected additional data and developed new approaches to process and apply them.

Chapter I addresses how the Institute developed a taxonomy for understanding and assessing DARPA's transition record, and presents data on product and program characteristics pertinent to transition. We compiled a list of 124 past DARPA programs (see Table A-1 in Appendix A), but concentrated on two subsets of this program population.[2] Programs transitioned during the last decade (1990s) were chosen because it would be easier to obtain information on them than on earlier decades. Program and product characteristics for this period are listed in Table A-2. The second program population, a subset of the last decade, is the New Starts (or initiatives) begun during Fiscal Year (FY) 1991. We tracked each of these new starts until they transitioned products, failed and were abandoned, or continued development with possible transition pending.

Chapter II presents three canonical transition paths and five transition strategies commonly used by DARPA. We illustrated these paths and strategies with numerous examples drawn from past DARPA program and product transitions.

In Chapter III, we discuss other DARPA missions, organizational policies, and external factors that affect transition, either impeding or improving its prospects.

The 1991 "New Starts" study results are reported in Chapter IV, with a summary table on the program and product characteristics in Appendix A-3. The New Start case studies, featuring interviews with participants in DARPA's programs, are reported in Appendix B. These eighteen

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[2] We also incorporated insights gained from the Institute's study of DARPA's Technology Reinvestment Project (TRP), reported in [19].

New Starts represent a cross section of DARPA's programs and were objectively selected with no bias toward either success or failure.

Finally, in Chapter V, we offer seven recommendations from conclusions developed earlier, suggesting ways to improve transition performance.

Definitions of terms and acronyms used throughout this report are listed in Appendix C and references to pertinent publications are found in Appendix D. Through out this report, numbers in square brackets correspond to the numbered references in Appendix D.

D. Conclusions and Recommendations

This section highlights the principal conclusions and recommendations of the study—an integration of selected data, analysis, and ideas developed in the report. They are clarified and sometimes quantified over the next five chapters. (Major conclusions appear in bold italics.)

Goal #1. Document and assess DARPA's transition history. To address this goal, we examined the Agency's success in getting its products into the Military Services it supports.

First, we defined several program and product characteristics needed to understand this and subsequent goals of the study. We refer to DARPA's output and the system or component that is finally fielded as the "DARPA Product" and the "Final Product," respectively, in order to distinguish between the products at these two stages. The event that transforms the DARPA Product into the Final Product is the "Transition" and the path it follows, the "Transition Path." We identified the scale of the program under which each DARPA Product was developed as large (greater than $100 million) or small (less than $100 million). In order to describe the maturity level of the product as it leaves DARPA, we adopted NASA's Technology Readiness Levels (TRL) [30] as explained in Chapter I.

The Institute then rated the impact (or usefulness) of the Final Product as Significant, Very Significant, or Disruptive. The disposition of the Final Product was also noted either as a "system" or a "subsystem, component, or technology" in a fielded or major developmental system.

Three canonical transition paths from DARPA to fielded (or sometimes major developmental) systems were identified. A major distinction among these paths concerns the identity of the organization that sponsors the technology after it leaves DARPA. The DARPA-to-Service Acquisition (DSA) path moves products from DARPA to the Service acquisition system to be directly incorporated into a fielded system.[3] *Here the participating industry often does the marketing to the Service, but does so as a contractor to DARPA, and furnishes little or no funding. Funding responsibility for insertion is passed to a Service acquisition organization.* The DARPA-to-Industry-to-Service Acquisition (DIS) path moves products from DARPA to industry, which then transitions the product to the Services. *In this case, industry spends significantly of its own funds in developing or applying the product, and then transitions it to the*

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[3] Throughout the study, we also gave credit to transition for those DARPA Products adopted into major developmental programs, since this seemed auspicious to fielding.

Service acquisition organization, which funds the fielding and any necessary modifications needed to make the product work in a military role. The third path is DARPA-to-Service science and technology (S&T) organizations (DS&T). *In this approach, a technology moves from DARPA to a Service S&T organization, which develops the technology further (using S&T funding) and inserts it into a fielded or major developmental program through its acquisition system.*

Assessing transition performance for a research and development (R&D) organization, particularly one with DARPA's mission and operational strategies, is an inexact and argumentative undertaking—not given to a "single number" answer. After much thought, data collection, and analysis, we came to believe that DARPA's transition record should be viewed from many perspectives and that the best way to judge its accomplishments is through a composite of these views. We chose the four perspectives listed below that together describe DARPA's transition performance and affect the standards of success under which it should be judged. But, for the most part, that judgment remains somewhat subjective, principally because of the difficulties in arriving at an objective standard for success.

1. **Total number of products transferred to the Military Services by DARPA.** We tabulated transitions for three periods of DARPA's history (the entire forty year life span of the Agency, the 1990s Decade, and the FY 1991 New Starts). This provides an appreciation for the sheer volume of DARPA's contribution.
2. **Rate of transition, in terms of transitions per number of programs initiated.** Because of limited data, we could only provide this measure for two program populations, DARPA's Technology Reinvestment Project (TRP) and the FY 1991 New Start Initiatives. Industry has developed standards of success for this approach and we applied these to DARPA.
3. **Quality of products.** We chose three indicators of the quality of DARPA's transitioned products: maturity of DARPA's output, final product disposition and impact.
4. **Other factors that affect transition.** We must also acknowledge other Agency responsibilities that vie with transition for emphasis and resources. We did not attempt to set their priorities. For instance, we acknowledge that DARPA's mandate to take on high risk/high payoff goals must be balanced against the Agency's transition rates, but we did not suggest what that balance should be. Circumstances, both external and internal to the Agency, also impede or improve transition opportunities and affect performance expectations. So, these factors primarily affect the standard for success adopted.

These perspectives are established and reflected throughout this report. We believe that the major conclusions presented are well supported by facts and logic and, if adopted, the ensuing recommendations would improve an already impressive record of contribution by the Agency.

Conclusion 1. Analysis of DARPA's record from the four perspectives (number of products transferred, rate of transition, quality of products, and missions and circumstances), led us to the conclusion that the Agency's transition performance has been impressive. Moreover, there is ample evidence of many uncounted successful transitions, particularly during DARPA's early history.

Goal #2. Define frequently used transition paths. To address this goal, we investigated the three canonical transition paths: DARPA-to-Service Acquisition (DSA), DARPA-to-Industry-to Service acquisition (DIS), and DARPA-to-Service Science and Technology (DS&T). We also offered examples of products that have transitioned by each path. Conclusions listed below are clearly and consistently borne out by the data from both the 1990s Decade and the FY 1991 New Starts, and are further discussed in Chapter II.

Conclusion 2. Each of the three canonical transition paths examined for the 1990s Decade products had some unique features:

a. ***About 60 percent of DARPA's products followed the DSA path.*** The most commonly used path, DSA depends upon DARPA's ability to attract the Service acquisition community or the users they serve. This path has been especially effective for "customer pull" strategies.

b. ***Products moved along the DIS path 30 percent of the time.*** This path was particularly successful for small programs. On average, the impact of these products was rated highest. All of these programs attracted industry cost share, which may explain the relatively low percentage of large (high cost) programs under this transition category. Products on this transition path were more mature when they left DARPA—probably due to the contributing industry's interest in getting the product to market quickly. One would favor a DIS path if the product had potential for dual use.

c. ***The DS&T path was used 10 percent of the time.*** The availability of a Service Laboratory partner, especially one with influence on the Service customer, or the development of an immature military technology that DARPA wishes to move out of the Agency for further development and application, may lead to consideration of the DS&T path. This assumes that the Service S&T Laboratory has sufficient knowledge to complete the development of the technology in question. On average, products that followed this path had less impact than those taking either of the other two.

Goal #3. Identify factors that affect DARPA's transition rate. To address this goal, we analyzed the factors that either impede or improve transition potential at DARPA. Some of these factors stem from DARPA's mission or organizational characteristics and policies. Others are part of the environment under which the Agency must transition its products. We also looked at changes in these factors that have occurred as the result of new trends in our world during the past ten years—changes in political, military, business, and R&D environments that have, or should have, affected transition.[4] Our conclusions are listed below, and are further discussed in Chapter III.

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[4] Except for the data from the 1991 New Start Studies, we do not claim a statistically valid database to examine why transitions failed. Although we have documented over 120 successful transitions, and can usually identify contributors to success, we did not attempt to document all of the failed transitions, so we cannot claim to understand the absolute influence of that factor on success or failure. However, where we have found evidence of a positive or negative influence by these factors, we have reported it and have tried to give it proper weight.

Conclusion 3 (Organizational Characteristics).

a. *DARPA's mission elements.*
   i. *Solving national-level problems is an important DARPA mission, but the resulting products and technologies are generally more difficult to develop and transition than solutions provided for lower-level, single-customers.*
   ii. *DARPA's mission also emphasizes pursuing radical innovation with high risk/high pay-off programs. This also often results in products that are difficult to deliver and to transition.*

b. *DARPA's operational characteristics and policies.*
   i. *High program manager turnover makes transition more difficult. Combined with difficulties in record keeping, this factor has also resulted in a loss of credit for many transitions that received significant DARPA sponsorship.*
   ii. *Most of the Agency's successful research and development is accomplished and transitioned by industry, acting either as contractors to the Agency or independently as private sector entities. In either case, the industry partner often neglects to give DARPA's sponsorship the credit it deserves.*
   iii. *DARPA/industry/academia consortia have had major impacts on commercial and military markets.*
   iv. *The Agency's flexible management and contracting procedures have been a major benefit in dealing with industry and, ultimately, in transitioning to commercial and military markets.*

Conclusion 4 (Environmental Factors). The environment in which DARPA must operate also affect transition.

a. *Military Customer: DARPA's military customer is often extremely risk averse and channeled to conform to a specific schedule of technical and program events. DARPA's transitions will be affected by the weakening of the federal laboratories. New avenues for transition, initiated by Office of the Secretary of Defense (OSD) and the Services can be of great benefit as well.*

b. *Timing: There are numerous twists of fate that bend the path to transition. Difficult to predict, these factors must often be "waited out." But DARPA has few effective mechanisms for continuing to "market" its products after the program is over—particularly when the program manager has departed the Agency.*

c. *Regulations: The Planning, Programming and Budgeting System (PPBS) and other manifestations of the Department of Defense's (DoD) bureaucratic processes provide their share of pitfalls along the path as well.*

d. *Budgetary Considerations: It is to be supposed that reduced procurement budgets in DoD have diminished the market for new technologies, adversely affecting technology transition.*

Conclusion 5. Transition at DARPA is an opportunistic pursuit, greatly enhanced by skilled and dedicated DARPA and industry program manager and Service agent teams. It is likely that any structure or procedure that limits the program manager's sense of responsibility or options to transition his or her products will negatively affect the Agency's rate of transition.

Goal #4. Suggesting what DARPA should change. Chapter V offers some suggestions on implementing changes to DARPA's transition strategies and policies. We discussed each recommendation in light of our findings and analyses and other studies. Listed below are what we believe to be the five most compelling actions for DARPA to take.

Recommendation 1. Maximize the effectiveness of the DARPA and industry program manager and Service agent team. Transition success was highly dependent on the individual DARPA program managers, industry program managers, and Service contracting agents acting as a product champion team. In view of the importance of this team, it would seem logical for DARPA to concentrate on making it more effective. The strategy we recommend has four thrusts: 1) matching new program manager's tenure at DARPA to the expected length of the projects they will run; 2) helping new program managers become effective as quickly as possible through training and mentoring programs; 3) making program transfers from departing to incoming program managers as efficient as possible, and motivating new employees to treat inherited programs as their own; and 4) establishing incentives for product champion team members to transition their products.

Recommendation 2. Exploit recent avenues of transition initiated by OSD and the Military Services. By equipping the program managers to take advantage of special OSD- and Service-initiated mechanisms for transition, DARPA would make the most of the two major components of product insertion, product champions, and avenues suitable for the products to be transitioned.

Recommendation 3. Develop a better system of tracking and recording transitions and lessons learned and integrating the results. Essentially all world-class individuals and organizations assess their performance. Likewise, DARPA must constantly evaluate how well it accomplishes assigned missions. In the case of transition, the Agency should institute a better system for tracking and rating individual product insertions, and learning from their experience.

Recommendation 4. Address problems associated with "market timing." Related to the above, luck and timing often combine to define transition potential. Transition can go wrong (or right) through no fault of the program manager or the product. When this happens, and if the product in question has good potential, DARPA should sometimes stay in the game and continue to try to transition it when the timing is better, even after program completion.

Recommendation 5. Ensure sufficient technological maturity of products. Prototype demonstration, a common strategy at DARPA, is a logical way to improve maturity. Aided by the Agency's demand for demonstration, those products that successfully transitioned are surprisingly mature. But, many Agency customers have complained that DARPA tends to quit too early, well before a technology is ready to be incorporated into a military system. DARPA's technology offices may elect not to spend that much time on a technology, but they can transition it to a Service laboratory or continue working on it in one of their systems offices. At any rate, agreement should be reached on the TRL category for each product leaving the Agency.

I. DARPA's Transition History

This chapter examines DARPA's record of transitioning its products. We did not attempt to establish "parenthood" of the products or technologies transitioned. Certainly many were begun outside of DARPA. Also, while it is true that other organizations contributed to the development or application of most successful products along the way, we did not attempt to apportion credit. We only demanded that DARPA's role was substantial in either beginning or furthering their development, or in innovatively applying them to military needs. Finally, having established the most comprehensive record of DARPA's transitions, we proposed a way to assess it. This assessment is not completely quantitative, but we believe it provides a good understanding of DARPA's performance in the context of other important factors.

A. Approach. A fair question is, "how does one judge the transition record described in this chapter?" This is a question familiar to industry, which has conducted numerous studies into the marketing of its technologies and products, and has defined reasonable transition expectations for many commercial product areas.[5] It is admittedly easier to quantify success for a sector with a monolithic goal—profit—than one whose responsibilities are as broad and diverse as those required to maintain our nation's defense, and even then it is difficult. In attempting to discover indicators of how well a defense organization transitions its products to the military, we looked at numerous metrics that have been used or proposed by R&D organizations [29]. Many provide important insights into an organization and are easy to count, but few lead directly to measures of transition success—or suggest how to improve performance in inserting products.

After surveying secondary indicators, the Institute arrived at the not-so-startling conclusion that one must focus on the individual fruits of transition—those products that make our equipment superior—to understand how well an organization accomplishes this job. Therefore, in conducting this study, we concentrated on the products DARPA has made available to its military customers. We have counted and described them, and sought to understand how they were finally put in place to serve our Armed Forces. This is an amazingly difficult effort, particularly since DARPA, like nearly all defense organizations, does a poor job of counting its successes.[6] But, it is well worth the effort—we cannot maintain excellent R&D organizations in DoD if we are afraid to measure the principal indicator of that excellence—the quality and quantity of products inserted in fielded systems.

Once we have the data, how do we measure transition performance? First, we must develop transition metrics and criteria that are not just countable, but which are fundamentally important indicators or measurements of transition success. Metrics used in the past have been transition rates (either per-year or per-dollar invested) or some measure of benefits gained, such as profit. None of these seem to work very well for the Department of Defense, unless some cost-savings or value of capability-gained can be determined. Second, we cannot focus on transition to the

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[5] Just one of these studies [27] is referenced later in this chapter.

[6] There may be method in this madness. In the past, Congress has misunderstood or misinterpreted the resulting numbers. Further, Congressional expectations are frequently higher than history supports.

exclusion of other important facets of an organization's mission, unless transition is its *only* mission. So in DARPA's case, we must consider the development of cutting edge technology, the solution of national problems, and efforts to ensure avoidance of technological surprise, as well.

We came to believe that DARPA's transition record should be viewed from all of these perspectives and that the best way to judge its accomplishments is through a composite of these views. We chose four perspectives (or criteria) that together describe DARPA's transition performance and affect the standards of success under which it should be judged: total number of products transferred to the Military Services by DARPA; rate of transition, in terms of transitions per number of programs initiated; quality of products; and other factors that affect transition.

Clearly, fewer criteria would be inadequate. For instance, if DARPA only transitioned one product during 1982, it would seem unworthy, unless that product was the Internet, stealth, or one of similarly high impact.[7] All criteria will be applied in the following paragraphs. The first three will also be derived in this chapter, while the fourth will be developed in Chapter III.

B. Total Transitions (Criterion 1)

The first criteria for a successful transition record lies in the quantity of products inserted into the Military Services. It provides an appreciation for the sheer volume of DARPA's contribution. We developed a list of transitions accomplished during the life of the Agency and during the 1990s Decade (see Tables A-1 and A-2 in Appendix A). Inputs came from over 25 documents, and several interviews and records searches at DARPA. The results of these efforts are summarized below.

Documentation exists on at least 124 unclassified transitioned products from DARPA to the Military Services over the forty-year life of the Agency (1.6 per year). Focusing on the past decade, there have been approximately 50 documented unclassified transitions—or about 5 per year.[8]

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[7] During an interview with the Navy's Chief Technology Officer, Dr. James DeCorpo, he referred to this point, "The world is different because of DARPA. We will fight wars differently because of DARPA; because of contributions such as stealth and the Internet. Measuring transition performance is important because you get what you measure. But, racking and stacking numbers alone is dangerous. One must consider the impact of the product and adjust the metrics of transition performance to risk. You need to ask questions like, 'are we developing the right technologies and not capitalizing on them, or are we simply not fostering the right technologies?' "

[8] These totals reflect only unclassified products. A conservative estimate of classified transitions, arrived at through interviews with several former DARPA employees, is .5 per year. In order to maintain this report as unclassified, we did not include these 20 or so products.

C. "Lost Records"

Many other successful transitions are unaccounted for, particularly during the 1960s and 1970s.

We listed all of the transitions we could identify in the time allowed for this study. Unfortunately, although data to support such findings are more available now than at any recent time in the life of the Agency, they remain difficult to find for the reasons given below.

- By the time most of DARPA's long-term technology development projects are applied to fielded or developing systems, they have gone through many changes and many hands, often losing their DARPA identity.
- Much of DARPA's funding goes to industry. Industry generally transitions the results to the Services and the Agency contributions often go unnoted.
- The high rate of turnover in DARPA program managers means a poor memory of successes (and failures). While this situation could be overcome by good record keeping, historical records are not a noted DARPA strength.[9]

D. DARPA's Rate of Transition (Criterion 2)

In the New Starts study, 18 new initiatives were identified as beginning in 1991 and of these, 12 have transitioned products. This is an impressive transition rate of 67 percent, even higher than the 33 percent projected for the Technology Reinvestment Project (TRP) in 1996 [19].

Examining DARPA's rates of transition requires the development of a set of baseline programs. Because of limited data, we could only provide this measure for two program populations, the TRP [19] and the FY 1991 New Start Initiatives. For instance, we have identified the number of transitions per year in our study of the 1990s Decade, but we do not know how many programs the Agency managed during those years. On the other hand, the 1991 New Start case studies began with a set of new starts and we tracked them to their completion. So, we know the success rate of this population. We can also gain some idea about what rates to expect. In a well-known industry study, researchers developed data from market successes for products at various stages of development, from a raw idea to a product launch (stages of the product were defined by the report in terms of man-hours expended). In Figure 1 we show the data in a plot slightly modified from their presentation. Certainly, commercial industry's bid to get products to market are different from a defense agency trying to insert products into fielded military systems, but the Industry Research Institute (IRI) study which formed Figure 1 chose five different aspects of the private sector and all produced essentially the same plot.

Since the New Start and TRP studies both chose to view transition rate as the number of successes per new start, it seemed appropriate to compare their results with Figure 1. These projects generally fit between significant developments and major developments so, if one can

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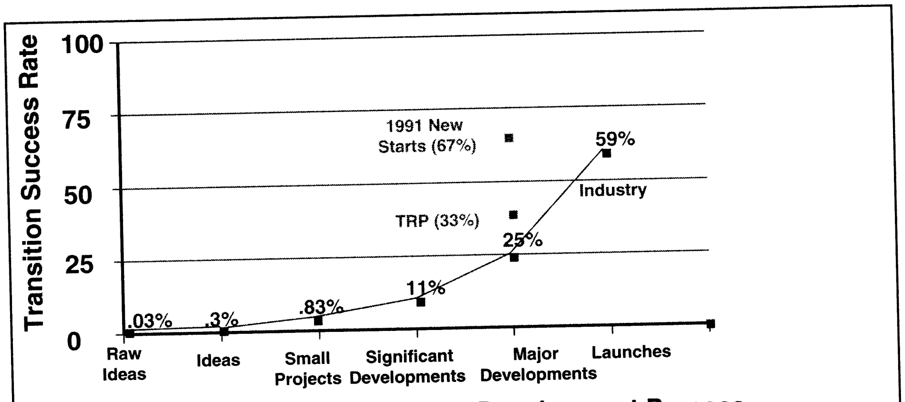
[9] Bushnell and Havelock ([20], p. 29) stated that, "DARPA is especially crippled by weak institutional memory… DARPA programs deserve more self-conscious scrutiny, and case studies of both on-going and completed projects in selected areas could yield numerous targets for system improvement. Such studies should take special note of technology transfer issues." The authors also quoted agreement by Barber [26].

draw a parallel between standards of success for insertion into a commercial market and that for transitioning military products into fielded systems, the expectation for DARPA's products would be from 18 to 25 percent. As discussed in Chapter IV, the success rate of the 1991 New Starts is extremely high (67 percent) and, as shown on the plot, the TRP success rate (33 percent) is also higher than one would have predicted from the industry study. Although not a complete case, this comparison provides evidence that DARPA is doing at least a credible job when compared with industry.

We attempted to reason why the transition rate of the 1991 New Starts was so high. Though we were unable to arrive at a definite conclusion, there are at least two possible explanations. One is that the rate was influenced by special circumstances in that year's programs that skewed the results, creating increased transition opportunities. In 1991 there were five insertion and four consortia programs. These programs appear to have increased transition opportunities. Indeed, the transition rates for the insertion and consortia programs, taken separately, are a relatively high 78 percent. If we delete them from the 1991 dataset entirely, its transition rate drops to 56 percent. This difference in transition rates could have at least two causes: i) an insertion program's primary goal is to transition a product, so one would expect a higher rate in these programs; ii) industry and government collaboration and cost sharing in a consortium may tend to reduce program risk (during the R&D phase of a product, industry partners may be more sensitive to risk than those representing the government). This latter explanation seems to be supported in a finding discussed later that the average 1991 New Start had a lower impact than that of the 1990s Decade of which they are a part. If higher risk programs at DARPA imply higher payoff, this seems to indicate that the 1991 New Starts may have been lower risk than the average 1990s program.

But, another explanation may simply be that we found more transitions because we looked harder at this year than at any other. Indeed, after we completed our intensive efforts to identify 1991 New Starts, we found that our original 1990s Decade products listing (compiled earlier) included only half of them. If true, and FY 1991 is typical, it means that DARPA has dramatically undercounted its successes (by half). Whether that is true or not will remain conjecture, but it is certainly arguable that many successful DARPA transitions are unaccounted for.



Industry Data Source: Stevens and Burley, "3,000 Raw Ideas = 1 Commercial Success!" Research-Technology Management, May-June 1997.

FIGURE 1. SUCCESS RATE FOR VARIOUS STAGES OF NEW PRODUCT DEVELOPMENT

E. Quality of DARPA's Products (Criterion 3)

We chose three indicators of the quality of DARPA's transitioned products: maturity of the Agency's output, and disposition and impact of the Final Product.[10] We began by defining the technology or system that leaves the Agency as the "DARPA Product" and the fielded system which incorporates it as the "Final Product." The event that moves or transforms the DARPA Product into the Final Product is the "Transition" and the path it follows, the "Transition Path." Qualitative and quantitative values assigned for each characteristic and listed in Appendix A (Tables A-1 through A-3) also help to understand how different products transitioned, or failed to transition. The format is described in Table 1.

DARPA OUTPUT			FINAL PRODUCT	
1. Scale of Program	**2. DARPA Output Maturity**	**3. Transition Path/Strategy**	**4. Disposition**	**5. Impact**
Small (<$100M) or Large (>$100M)	1-5 or 6-9	DSA, DIS, or DS&T/ CP, TP, DU	Either in a fielded or major developmental program System. As either a "system," or a "subsystem, component, or technology"	Significant (1), Very Significant (2), or Disruptive (3)

TABLE 1. DARPA PROGRAM AND PRODUCT CHARACTERISTICS

1. Scale of Programs to Develop the DARPA Product. The first column in Table 1 describes size of the program under which the DARPA Product was developed. The program scale refers to the estimated funding level of the DARPA program (a large program was one with a funding line over $100 million). There have been periods when DARPA's focus seemed to be on large programs. During the early days of the Agency's existence it was involved with large spacecraft and satellite programs. During the eighties, work on stealth and cruise missiles took a large portion of the budget, and unmanned air vehicles in the late 1980s and 1990s. But most of DARPA's programs have been much smaller. It would be interesting to examine the influence of program size on transition success. One would have to establish average program cost and sort out which end of the cost spectrum has been favored through product acceptance.

Of the fifty successful 1990s Decade transitions, 68 percent were developed through small programs. The 1991 new initiatives had a similar finding, of the twelve successful transitions, 83 percent were small-scale programs.

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[10] Although we believe the characteristics chosen support the analysis of the four goals of the study, we would suggest that a two-day panel of current and former DARPA program managers and office directors could improve the quality and specificity of both the values assigned to the characteristics and their application to the analyses. For example, we would have liked to determine the degree of innovation (as opposed to evolution) employed in the programs under which successful products were developed or applied. Several important conclusions could have been made with this information, but the scope of our study did not support this difficult effort.

2. Maturity of DARPA Product. In order to describe the maturity level of the product as it left DARPA, we adopted NASA's technology readiness levels (TRLs).[11] We could not specify exactly where each DARPA Product fit on the TLR scale from 1 to 9, so we considered two divisions of the rating system.

- **a.** 1-5: Maturity represented by the spectrum from demonstration of basic principles (proof of principal), through component and/or breadboard validation in a relevant environment
- **b.** 6-9: Maturity represented by the spectrum from system/subsystem model or prototype demonstration in a relevant environment, through an actual system completed, and "flight qualified" through successful mission operations.

Successful 1990s Decade and 1991 New Start products were surprisingly mature—at a TRL of 6 or higher nearly 90 percent of the time. For the 1991 population, 11 of the 12 successful transitions were at the 6 or higher TRL maturity level. At the very least, these products were demonstrated as prototypes in a relevant or operational environment and sometimes were actual systems, "flight proven" through successful mission operations. Again, it would be instructive to know the maturity level of DARPA's failures to fully understand the influence of this product quality on transition.

3. Transition Path and Strategies. These will be discussed in the next chapter.

4. Disposition of the Final Product. The Final Product was employed as a fielded system or part of one. That is, it can be the system itself or a subordinate technology, component, or subsystem that forms a part of the fielded system. We also gave credit to a DARPA product that is currently embedded in a major developmental program.

Many of DARPA's large systems developments have been quite successful, such as the early spacecraft, Army Tactical Munitions System (ATACMS), Simulation Network (SIMNET), and the Ada programming language, even though many view Ada as a very bad idea. Some have just been downright disappointing, such as the Arsenal Ship and Warbreaker. Perhaps the most common element among successful transition of systems, especially large ones, is the necessity for major funding commitments by the military customer. This has been true for such systems as Pegasus, Predator, Taurus, and uncooled infrared (IR) sensors. Often the problem is not the high level of funding, but the necessity for immediate "up-front" money in a rigid PPBS structure.

Technology areas have unique transition modes that are dependent on the source of the technology and who uses the final product in the DoD. Of greatest consequence, beyond making the technology work, is finding a way to mature it sufficiently to meet an application. As noted in the 1991 Superconducting Electronics Consortia case study (see Appendix B), DARPA has

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[11] The GAO Best Practices Report [30] lists the TLRs as:

1. Basic principles observed and reported
2. Technology concept and/or application formulated
3. Analytical and experimental critical function and/or characteristic proof of concept
4. Component and/or breadboard validation in laboratory environment
5. Component and/or breadboard validation in relevant environment
6. System/subsystem model or prototype demonstration in a relevant environment
7. System prototype demonstration in an operational environment
8. Actual system completed and "flight qualified" through test and demonstration
9. Actual system "flight proven" through successful mission oprations

invested over 15 years in the development of high temperature superconducting (HTS) material. Of the nearly $200 million expended on HTS technology, only 10 percent to 20 percent went toward the early development phase. The remainder of the funding was used to test form, fit, and function on identified applications to ensure transition into fielded military systems. Another difficulty in technology development is staying ahead of the fashion—on the cutting edge. DARPA has done marvelously well at this, although it is becoming more difficult with rapidly moving technologies, many of which are fairly esoteric, combined with the hardship of competing with an industry voracious for talent and able to pay for it. It is instructive to look at how the Agency has had to shift its attention over the years to maintain its reputation for divining which technology fruit is likely to fall next.

Recently, the Defense Science Board (DSB) advised DARPA to conduct programs in six areas: biological warfare defense; counter transnational threats; underground facilities characterization; information warfare defense; affordable precision target engagement; and unmanned, distributed command control, and communications ([10], p. 18). Interestingly, the first three of these thrust areas did not even appear on DARPA's 1980s manifest.

Final Products have been fielded in the form of technologies, components, or subsystems (as opposed to systems) about 74 percent of the time. The 1991 case studies yielded no system insertion projects. Products from the 1990s Decade were incorporated as 13 fielded systems and 37 technologies, subsystems, or components within fielded systems or in major developmental programs.

5. Impact of the Final Product. The "impact" of the Final Product is our subjective rating of its significance to the Military customer. We used three levels of impact:

- Significant Impact means the product was successfully transitioned;
- Very significant Impact was used to indicate widespread or important application of the product, such as the Marine Corps' Predator missile; and
- Disruptive Impact was reserved for DARPA contributions that dramatically changed the way the Service operates. The six DARPA products rated as "disruptive" were:[12]
  - ATACMS: Here, DARPA sponsored work on a new concept for a low cost, long-range tactical artillery rocket system, using guided and unguided submuntions by merging several technologies such as Synthetic Aperture Radar with moving target indication, intelligence fusion, and terminally-guided submunitions. ATACMS is the centerpiece of the Army's precision strike modernization effort. The system served in Desert Storm, where it neutralized or destroyed several surface-to-air missile sites, and many other targets [21].

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[12] In its July 2000 report ([31], p. C-21), the DSB listed ten disruptive innovations adopted by either the commercial or military sectors. Four had major DARPA involvement: ballistic missiles, stealth technology, personal computer, and the Internet. In a 4 April 2000 briefing to Congress, Dr. Delores Etter [33], Deputy Under Secretary of Defense (Science & Technology) suggested five revolutionary capabilities derived from DoD's science and technology efforts included phased array radar, global positioning system (GPS), night vision, stealth, and adaptive optics and lasers.

- SIMNET: Information technologies were integrated to form a system of simulators representative of various platforms (e.g., M1 Tank, BFVS, FIST-V, HMMWV). The simulators share real time situational information over a network that can be worldwide. In addition to sharing the information, players interact with the operational situation, producing and sharing state changes. SIMNET transitioned to many customers under various names (e.g., BDS, CCT). Many of the enabling technologies and techniques for the SIMNET system were developed by DARPA, including Packet-based networks originally developed for ARPANET, Protocol Data Units (PDU) that facilitate connectivity, and Distributed Interactive Simulation (DIS) technology [3, 21].
- Computer Workstation: The fundamental technological advancements that resulted in powerful and accessible desktop computers began with this program, conducted with emerging industry movers, such as Apple, Inc. [21].
- Internet: The Internet began in 1969, when four computers were networked, using techniques based on Licklider's concept of interactive computing and time sharing. The first large-scale application of these concepts was called the ARPANET (data-packet switching technologies integrated into an information network). The DoD and many universities and research laboratories adopted DARPA's ARPANET. It was moved along by the National Science Foundation (NSF), and later exploded into international use by the commercial sector. The resulting Internet is now used in millions of homes, businesses, universities, and governments around the world. More to the point, the DoD has taken full advantage of these improvements in adopting the Internet for many special military uses [3, 21].
- Phased Array Radars: DARPA broke the ground on large phased array radars, which today have become the backbone of Air Force and Navy radar capabilities, featured in such systems as Pave Paws and Aegis [21].
- Stealth: In preparing for the realization of everyone's favorite example of a disruptive military technology, DARPA developed signature reduction technologies for aircraft, including: radar cross section reduction (shaping and radar absorbent materials), IR shielding, active signature cancellation, exhaust cooling and shaping, and windshield coatings. DARPA's stealth program ultimately led to the F-117 Fighter and B-2 Bomber [3, 21].

Several reports that appear under Appendix D contributed to this rating effort (for example, see [3], [19], [21], and [24]). Table 2 summarizes our impact ratings for the forty-year "Life of DARPA," the 1990s decade, and the 1991 New Start populations.

PROGRAM POPULATION	SIGNIFICANT -1-	VERY SIGNIFICANT -2-	DISRUPTIVE -3-	AVERAGE
LIFE OF DARPA	38 (30%)	81 (65%)	6 (5%)	1.7
1990s	24 (47%)	26 (52%)	0	1.52
FY 1991 NEW STARTS	8 (67%)	4 (33%)	0	1.33

TABLE 2. IMPACT OF DARPA PRODUCTS

The average impact rating of all fifty 1990s Decade products is Very Significant. The average impact of the 1991 New Starts is lower than that of the decade as a whole. It is also interesting to note that, while over DARPA's lifetime, there have been six products rated as "disruptive," about one and one-half per decade, we found no disruptive products during the 1990s Decade products. This may be due to an Agency shift toward more near term products or it may just reflect the fact that time is required to reveal a product as disruptive.[13] For example, technologies fostered by DARPA during the 1990s that may become disruptive are microelectronic mechanical systems (MEMS), micro-satellites, and micro-robots.

F. Other Factors that Affect Transition

It is also important to acknowledge other Agency responsibilities that vie with transition for emphasis and resources. We did not attempt to set the Agency's priorities. For instance, we acknowledge that DARPA's mandate to take on high risk/high payoff goals must be balanced against the Agency's transition rates, but we did not suggest what that balance should be. Circumstances, both external and internal to the Agency, also impede or improve transition opportunities and affect performance expectations and thus, standards for success. These other factors are discussed in Chapter III.

G. Value for Funds Received

Another perspective from which to view DARPA's performance is to consider the value-added by the Agency. That is, if the DoD were General Motors and DARPA its corporate R&D division, would the Agency survive corporate examination?[14] Typically, corporations look at

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[13] Yet, the 1999 DSB study [10] suggested that, "[a] complex set of factors has resulted in a DARPA program portfolio in the post Desert Storm era that has many programs focused on near-term demonstrations. ...the task force believes that DARPA does not have enough high-risk, high pay-off programs."

[14] Still another approach is often referred to as the "but for" analysis. Under this approach the analyst attempts to imagine what the world would be like if the organization being evaluated did not exist. This approach presents

expenditures versus profits made from delivered products. Because the R&D process is a long one, such a division is generally exempt from a year-by-year assessment, but must prove its worth over the long run.

DARPA has received approximately $60 billion (constant year 2001 dollars) over the forty years of its existence, about the expected cost of the F-22 major developmental program. The payoff from this investment includes the 124 or so transitioned products mentioned in this report. To examine the adequacy of this return, we would suggest establishing the value of some of these products to the Military Services. This task would be much easier for products entering the commercial marketplace because profit is more simply measured than military utility, or even the worth of a new military capability. If the transitioned product substitutes for a more expensive or harder to maintain product already in the military's inventory the required calculation is made easier, but DARPA's products rarely fit that niche. We would limit our value assessment to military utilization even though we realize that civilian use of many of DARPA's products is both extensive and profoundly valuable to the nation.

An examination of just five transitioned products: the Internet, ATACMS, Stealth, Javelin, uncooled infrared, and integrated opto-electronic modules (IOEM) illustrate the astonishing impact that the Agency has had on the military and, for that matter, on society as a whole. Again, a commercial analysis of the value of these products would be relatively simple, for example by assuming profit on sales. For instance, according to the Department of Commerce, the Internet retail sales alone totaled nearly $26 billion last year. The commercial application of IOEM is predicted to be a $10 billion per year market. A commercial market forecast by Frost and Sullivan projected an IR sensor market of $1.4 billion in 2001.

This would be an interesting and perhaps even fruitful approach to categorizing DARPA's contributions and worth, but it is an effort far beyond the resources dedicated to this project.

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another set of problems. For example, if DARPA had not existed, would the Internet have been developed, or would it have come along a little later? Would large, shared computers have dominated the market rather than desktops, creating several national or regional computers for time-lease? Would the alternative outcomes be better or worse?

II. The Paths to Transition

Past experience shows that it is vitally important for the DARPA program manager to develop a transition plan early in the program, with probable paths for their product.[15] But it is equally important to acknowledge that these plans are subject to shifting circumstances and must be reviewed, and often changed.

A. Three Canonical Transition Paths

There are at least three canonical paths to transition at DARPA. For individual programs these paths and their particular routes are affected by circumstances, the nature of the product, and participants in the program, such as the DARPA program manager, and the customer. Often others (e.g., Congress) become involved as well. As illustrated by numerous examples (some of which are presented below), transition at DARPA (and perhaps everywhere else) is an opportunistic pursuit. Success in product insertion is greatly enhanced by the program manager's dedication to that goal and his or her perseverance in exploring roles for the product, demonstrating its performance, and seeking customers. No single, prescribed approach to transition will be as effective as a proactive product champion, who is allowed the flexibility to seek utilization of his or her product.[16]

Initially choosing a transition strategy and mechanism is vitally important, but strategies must often be changed or abandoned because of shifting circumstances. This is not to deny the existence of guiding principles in transitioning products. Some are presented in this report. These principles involve lessons learned about the effects of time, budgets, customer participation, prototype demonstrations and experimentation, the health of the military and private R&D sectors, and other factors.

The three canonical paths to transition chosen for consideration in this study are the Direct, Industry, and S&T Transition paths described below.[17] Tables A-2 and A-3 in Appendix A characterize DARPA's products and programs in terms of the transition path most likely to be successful. In this chapter, several examples are offered to illustrate how transitions were actually accomplished and how these canonical paths were used.

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[15] As illustrated by the HiPer-D case study in Appendix B, transition plans are generally submitted as part of a DARPA's initial program documentation.

[16] This was well-stated by DARPA's Uncooled IR program manager, Trent DePersia, in an earlier interview. He stated that "A principal role for the program manager is to persist in selling and transitioning his product. Without persistence the system will pass over even the best technology."

[17] There are numerous ways to partition the paths to transition. For example, the Technology Transition Study [21] suggests four paths, transfer of (1) system and program, (2) system but not program, (3) subsystem or component technologies, or (4) operational facility or institute. On the other hand, RAND's study [4] cites only two, direct insertion and insertion through industry. Finally, a recent Defense Science Research Council (DSRC) study [6] arrived at essentially the same paths as those used in this report. The path definitions chosen in this report emphasize the participants, rather than the products transitioned.

1. **DARPA-to-Service Acquisition (DSA):** These DARPA Products moved from DARPA to the Service acquisition system to be directly incorporated into a fielded system or a major developmental program.[18] *Usually this transition was accomplished by the participating industry, which served as a contractor to DARPA, and contributed little or no funding.*
2. **DARPA-to-Industry-to-Service Acquisition (DIS):** These DARPA products moved from DARPA to industry (perhaps through a university or a DARPA/industry/university partnership). *The participating industry contributed substantially of its own funds* and then transitioned the product to the Service. Products using this path were often commercial or dual use products.
3. **DARPA-to-Service S&T (DS&T):** Here, a technology moved from DARPA to a Service S&T organization, which developed the technology further (using S&T funding). Eventually, the Service S&T organization inserted it into a fielded or major developmental program through its acquisition system.

These paths are illustrated schematically in Figure 2. In this figure funding is represented by the color of the organizational "boxes." The blue (or dark) box represents DARPA funding, the white box, industry funding, and the green (or gray) box, Service funding. So, for instance the DIS path, represented by the middle set of figures, depicts DARPA funding of an industry/academia team, which transitions the product to industry. The industry then provides funding for further work and eventually transitions it to the Military Service (and perhaps into the commercial marketplace). The Military Service, in turn moves it through its acquisition system to the user, using its own funding (often provided to the same industry, acting now as a Service contractor to integrate its product into a fielded system). The next section will discuss these paths further and offer examples of each.[19]

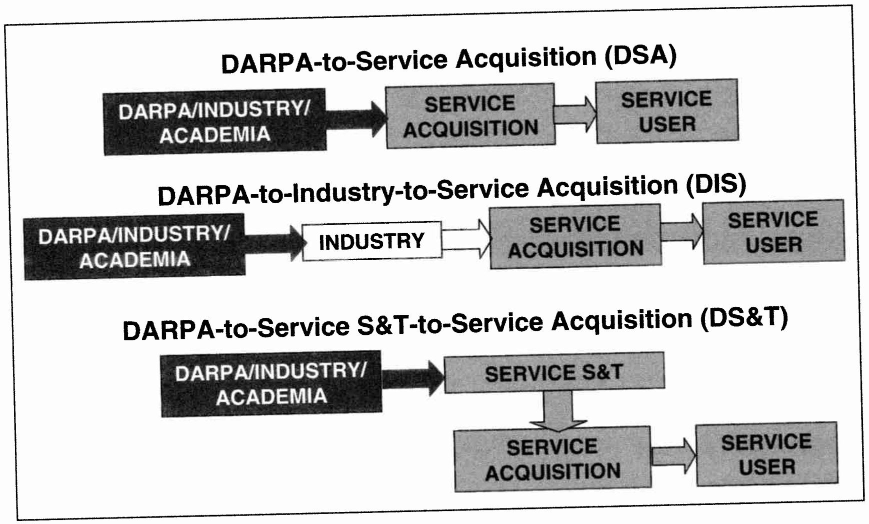

FIGURE 2. TRANSITION PATHS

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[18] We allowed credit for adoption of DARPA products into major developmental programs as a significant step toward fielding.

[19] The National Security Industry Association (NDIA) ([18], p. 21) refers to the DSA path as "infusion" or direct, and to the DIS and DS&T as "diffusion."

B. Direct (DARPA-To-Service Acquisition) Transition (DSA)

Sixty percent of the successfully transitioned products moved along this path. The Final Products using this path constituted a higher percentage of systems (as opposed to subsystems, components, or technologies) than those transitioned along any other path. The FY 1991 New Starts Study found six programs that transitioned by this path. Their case studies can be reviewed in Appendix B. Other examples of this transition path follow:

Javelin: This missile, which joined the Army's inventory in 1994 was derived from a DARPA concept called Tank Breaker. The two enabling technologies (principally having to do with the infrared seeker) and the concepts of employment (Top Attack) were sponsored by DARPA. Tank Breaker was motivated by customer pull and had early customer involvement. It was a military unique product, developed through conventional contracting that featured a system prototype demonstration. This was a direct transfer from DARPA to the Army MICOM,[20] championed by the Agency's contractors, Texas Instruments (now Raytheon) and Hughes, following the path shown in Figure 3. The major barrier to transition was Army MICOM's bias toward a competing concept, which was overcome by the vision and persistence of DARPA, Texas Instruments, and Hughes, finally vindicated by the shoot-off results, and Source Selection Authority process. This success is a tribute to the tenacity of the product champions in DARPA and its contractors. The shoot-off could be viewed as similar to an Advanced Concept Technology Demonstration (ACTD), although it was conducted with an emphasis on measured technical performance.

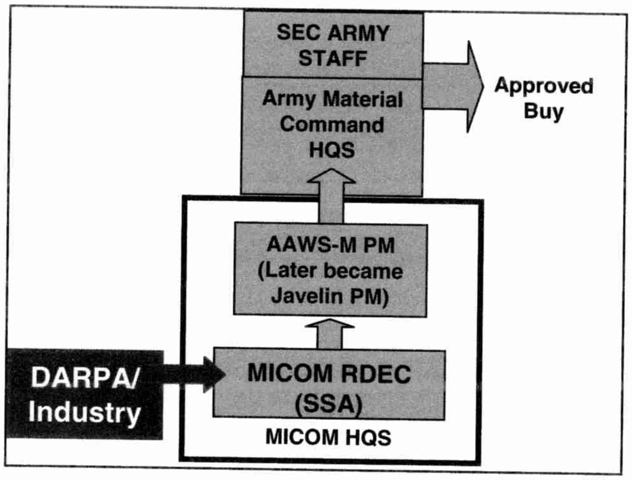

FIGURE 3. JAVELIN TRANSITION PATH

M-16: During the Vietnam War, DARPA became convinced that the standard U.S. military rifle, the 30 Caliber M-1 Garand, could be replaced with a rifle that used a smaller, higher velocity round (5.56 mm). Fairchild, Inc., proposed the 5.56 mm AR-15 as a prototype. The choice of a smaller, lighter weapon and ammunition, which would significantly decrease combat load, was rejected by the Chief of Staff of the Army in favor of the heavier 7.62 mm M-14 because the Army felt the former lacked stopping power. DARPA's demonstration of the AR-15 Rifle led to

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[20] The Army Missile Command is now AMCOM, the Aviation and Missile Command.

DoD's decision to develop and adopt what became the M-16 Assault Rifle (now the standard issue shoulder weapon in the U.S. military). According Institute for Defense Analysis (IDA) ([3], Volume I, p. 14-8), this happened only at the intervention of Secretary of Defense Robert McNamara, the Inspector General (who found bias in the Army's choice of the alternate candidate, the M-14), and the Secretary of the Army, Cyrus Vance. In 1963, Secretary McNamara ordered a stop to M-14 manufacture, and applied M-14 production funds to purchase the AR-15. The Army assumed procurement responsibility for 8,500 rifles, which grew to 104,000.

The initial cost (for purchasing 1,000 AR-15 rifles to test in Vietnam) was about $500,000. The total program cost was probably less than $1 million. The procurement cost for the M-16 was $2 to $3 billion, and the program duration was about two years (early 1960s). Production occurred from about 1965 to the present day.

Figure 4 illustrates the path to transition. DARPA championed the smaller, faster round to replace the standard .30 caliber round used in the current inventory (M1 rifle). The AR-15, with a 5.56 mm round, was proposed and demonstrated by Fairchild, Inc., but rejected by the Army (the Air Foce bought some in 1962). Colt bought Fairchild and sold DARPA ten AR-15 rifles for testing. Convinced, DARPA bought 1,000 rifles for Service testing under combat conditions in Vietnam in late 1961. The test reports convinced the Army to form a project office to initiate a development program that eventually created what became the M-16 rifle, which added features important to the Services. It is fair to say that while DARPA had no role in developing the rifle, its role in transition was decisive. DARPA changed people's minds through the insights and perseverance of the program managers.

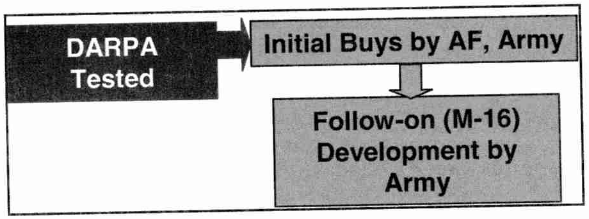

FIGURE 4. M-16 TRANSITION PATH

C. DARPA-to-Industry-to-Service Acquisition (DIS)

About one-third of the time, products moved from DARPA to industry (perhaps through a university or a DARPA/industry/university partnership). Products using this path were often commercial or dual use. The DIS path was particularly successful for very mature products, developed under small programs. The impact of products transitioned by this path was higher on average that those following the other two paths, perhaps because it is often a commercial goal of dual use products to attract widespread use, an element in our definition of "Very Significant" impact.

Many of these programs attracted industry cost share (through dual use efforts such as TRP), which may explain the relatively small percent of large (high cost) programs under this transition category. On average, products on this transition path were more mature when they left DARPA than was the case for either of the other two transition paths. This was probably due to participating (and contributing) industry's interest in getting the product to market quickly. Four

FY 1991 New Starts followed the DIS transition paths. All are described in Appendix B. Other DIS transition path examples from DARPA's history follow.

Integrated Opto-electronic Modules (IOEM): This program, performed by Lucent Technology, produced a device to convert photonic signals into electrical signals. Satisfying a clear military need, it was necessary to market the IOEM to an immense commercial sector in order to gain economies of scale and design efficiencies to make it viable for the military buyer. The commercial market chosen by Lucent was the Fiber-to-the-Home (FTTH). By 1996, the company had successfully negotiated a $6 billion contract with NTT, a Japanese firm to address this market. The steps in this process are shown in Figure 5. First, a DARPA/industry partnership was formed under the Technology Reinvestment Project. The module was developed under this program that featured cost share between DARPA and industry. At completion, the industry partner moved on alone to fund its introduction to the commercial sector. The last step occurred when the product was inserted into the Service as a dual use item through the commercial market. Thus far, the module is being used in a Fiber Optic Gyroscope (FOG) to replace the mechanical gyros in the Army's Bradley Fighting Vehicles (reflecting an Army savings of about $400 per unit). If all 6,500 Bradleys are so equipped it will represent a savings on $3 million. The FOG was also being tested in a major Navy guided munitions program.

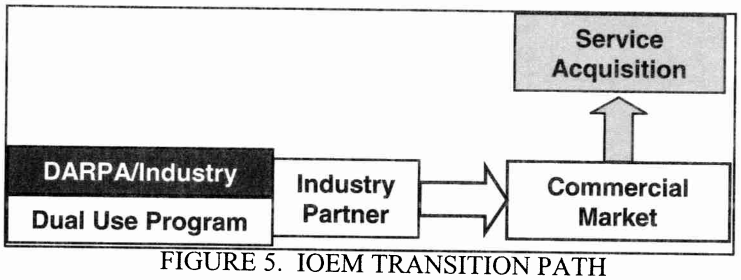

FIGURE 5. IOEM TRANSITION PATH

Uncooled IR technology: The Uncooled IR thrust was to develop an IR system that was both transportable and affordable for the individual soldier, employing detectors that do not require cryogenic cooling. Benefits are low cost, lightweight, and low noise, somewhat offset by a performance penalty.

As illustrated in Figure 6, Night Vision Opto-Electronics Laboratory (NVOEL) personnel came to DARPA as program managers during the late 1980s to continue work begun in an Army laboratory on Uncooled IR technologies.[21] In the beginning, DARPA's programs were principally dedicated to detector materials and cost about $10 million. Later $20 million was spent on integrating sensor systems. DARPA spent approximately $34 million under the TRP and later under the Dual Use Science and Technology (DUS&T) Program. This, along with the

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[21] The Army's role as a proactive customer was vital. According to one of the DARPA program managers, "Linkage with the military laboratories has been important, although the labs are not the customers. The Javelin program manager has been forward-looking from the beginning. Often pressure from top officials on program managers of major systems and developmental systems is needed to force them to take the risk of going outside of their prime contractor for innovative solutions. DARPA Director's Office could help in this respect by fostering the case for innovative (outsourced) solutions with these top officials."

$10 million prototyping effort, brought DARPA's total to about $100 million. In addition, NVOEL spent about $50 million during the early stages of development.

The principal military customers were the Army's Javelin Program Office and the program manager for Night Vision and Reconnaissance (NVR) for roles in the Javelin night sight military base security, and most importantly, vehicle night driving aids. The devices also have the potential to replace light intensification optics for rifle sights. Commercial sector sales for handheld and mounted products (e.g., camcorders, thermal measurement devices, sensors for immigration patrol and police) reached approximately 3,000 units during 1997. The Cadillac motorcar Division included the Raytheon Uncooled Focal Plane Array as an option on its model 2000 Cadillac Devilles.

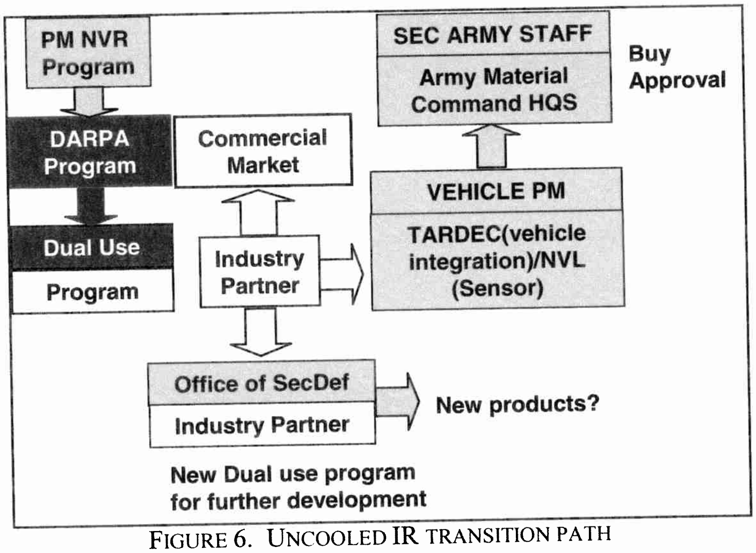

FIGURE 6. UNCOOLED IR TRANSITION PATH

For the military, these products were motivated by a customer pull, but that pull was not sufficient in itself to continue funding the development without the influence of a commercial market. At the end of the Cold War, when military budgets (and IR device procurement) declined, these companies were less willing to continue this research. Then DARPA's TRP provided a way to open a civilian market to military technologies and the companies to continue research. In order to maximize the chances for transition, DARPA teamed with Army researchers in sponsoring the TRP projects. Consortia included defense and commercial companies, providing good connections to both worlds. A transition strategy was developed and broadened as success and new markets allowed.

D. DARPA-to-Service Science and Technology (DS&T)

In only about ten percent of the 1990s Decade transitions studied did the product move from DARPA to a Service S&T organization. On average these products have had less impact than products following the other two paths to transition (all were rated significant). In this case, products that are not technically mature are sometimes transitioned from DARPA to the Service S&T as a technology or a prototype. The Service then continues the development and ultimately applies the technology. The FY 1991 New Start initiatives studied revealed two programs that followed the DS&T transition path—the SPEAKeasy Advanced Tactical Radio System and HiPer-D (High Performance Distributed Experiment). The SPEAKeasy program is summarized below and discussed in more detail in Appendix B.

SPEAKeasy was a program to develop and demonstrate an affordable, highly advanced, programmable radio frequency (RF) communications resource featuring simultaneous, multiband, multimode operations and networking across the frequency band of 2 MHz to 44.5 GHz. Its premise was that software wave forming would enable one radio to simultaneously perform functions that previously required separate radios. The ultimate goal was the achievement of a framework that all DoD tactical communication systems could evolve to, thus creating a seamless environment that is flexible, reliable, and cost effective. In the context of this report, SPEAKeasy is important because it illustrates the twists and turns many "normal" programs take to eventually deliver useful products. Figure 7 diagrams how SPEAKeasy moved in and out of DARPA, and was funded under several auspices until, at a critical juncture, a dedicated DARPA program manager grasped a chance opportunity to ensure its continuity under a major system developmental program. Thus, also demonstrated is the criticality of a program manager motivated to transition his or her product and the influence of fortune that often means the difference between customer adoption and neglect of a technology. Finally, the program is beginning to illustrate the viability of government/industry consortia, and the power of the commercial market combined with a dual use leveraging approach.

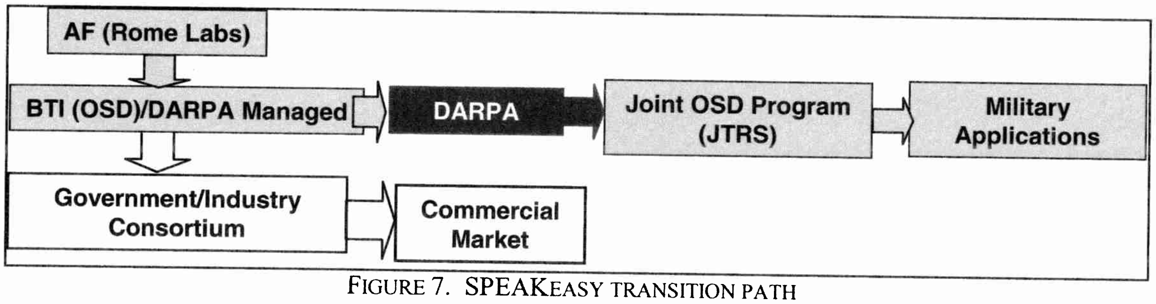

FIGURE 7. SPEAKEASY TRANSITION PATH

In 1991, after initial funding by the Air Force's Rome Laboratory, SPEAKeasy received substantial funding from the Balanced Technology Initiative (BTI), a DoD-managed, Congressionally mandated effort to initiate several programs selected with considerable Service input—SPEAKeasy was requested by the Air Force and the Army. BTI placed the program under DARPA management, and a joint Service development office was established with Rome Laboratory as the executive agent. Existing Air Force, Army, Navy, and National Security Agency agreements were continued.

When BTI funding was eliminated in 1993, the Air Force asked DARPA to continue the research. DARPA agreed and set up a five-year program. In late 1995, a consortia was formed, the Multi-Band Multi-Mode Radio (MBMMR) Forum, later renamed the Modular Multifunction Information Transfer System (MMITS) Forum. The forum was dedicated to developing or adopting common interface standards, specifications, and protocols. It was open to industry and government, allowed for the exchange of ideas between developers and users, engendered an enlarged market base, and created new market opportunities. Recognizing that SPEAKeasy-type technology has global application, MMITS Forum members are participating in discussions with International Telecommunications Union (ITU) and the European Union (EU) groups that are planning for the development of global deployment of third generation wireless systems.

DARPA developed and tested models employing SPEAKeasy technologies and protocols. The resulting software reprogrammable modem was tested during the Task Force XXI exercise in April 1996. It exceeded expectations and proved immensely successful in allowing ground to air communications. However, six months later, the new DARPA Director determined that the Agency should discontinue research in this area and directed that the program be transitioned immediately. The final thirty months of the program funding was swept.

At this point, DARPA approached the Air Force and Army to accept the SPEAKeasy technology that had been developed to date. But both Services were hesitant. The Army said they lacked funding in the Program Objective Memorandum (POM) to continue the program and the Air Force said they wanted a product, not just a technology. Eventually they did agree to carry on the technology development for a while at the Air Force's Rome Laboratory, but at a low level of funding. As all of this was happening a quirk of fate occurred. At a retirement ceremony, the DARPA SPEAKeasy program manager happened to mention his program to an OSD staff person, who became very excited about the concept and shortly thereafter formed a working group to investigate the technology. Working group recommendations led to a Management Implementation Plan on what was called the Joint Tactical Radio Systems (JTRS). In late 1997, the implementation Plan was signed by Dr. Jacques Gansler, then Under Secretary of Defense for Acquisition, Technology and Logistics (USD(AT&L)). The JTRS was based largely on technology and protocols developed under SPEAKeasy. In effect, the USD(AT&L) directed all Services to integrate the JTRS open architecture and incorporate hardware and software modules into all their weapons and communications systems.

Surprisingly, the first application of SPEAKeasy/JTRS was by the Navy, which had never contributed financially to the program. In 1997, they decided to leverage SPEAKeasy technology for their Digital Maritime Radio (DMR) and have been buying production quantities from Motorola. This technology is also central to the DARPA Airborne Communications Node (ACN) program. Moreover, although SPEAKeasy was dedicated to military radio usage, current commercial cell phones have adopted and are using SPEAKeasy technology.

E. Some Transition Strategies

Our survey of the fifty 1990s Decade programs revealed four common transition strategies used by DARPA: Prototype Demonstrations, Customer Pull (CP), Idea or Technology Push (TP), and Dual Use (DU). The last three of these are designated in the fourth column of Table A-2 as CP, TP, and DU. These strategies were used to push the products along essentially all transition paths, although as discussed below, some are more applicable to a particular path.

1. Prototype demonstration has been an important step in transitioning DARPA products. Used for all transition paths, prototype demonstrations have spawned many successful transitions, especially when customers were involved in the demonstrations. Essentially all successes cited in the tables of Appendix A were consistent in this respect and the reasons are obvious. For instance, if DARPA had simply developed packet technologies without demonstrating them in the ARPANET, the Internet would have taken longer and may not have been attributed to DARPA. The Light Appliqué System Technology (LAST®) armor was transitioned to a Marine Corps skeptical about its ability to remain in place during combat. Only after outfitting a Light Armored Vehicle with a LAST® kit and testing it in a Marine Corps exercise were the Marines convinced. When the vehicle was inadvertently driven off of an arroyo and suffered major damage without losing a single armor tile, the Marines bought it. DARPA's head mounted display prototypes were a major factor in their successful introduction to all Services. And, of course, Dragon's Voice Recognition System prototype was a hit in Bosnia, where it allowed real–time language translation. In a 1999 study, however, the DSB warned against a tendency at DARPA to press for demonstrations conducted too early, with immature technology ([10], p. 7).

2. Customer Pull Strategy. This strategy demands either working directly with a customer or addressing formal needs or requirements (recognized by the customer). For customer pull programs, DARPA generally seeks early user Service/Agency involvement and even management responsibilities for projects, and makes greater use of Service inputs in establishing the needs that drive the program. Needs can be defined formally in such documents as Required Operational Concepts (ROC) or even through direct Service inputs. Among the programs that were called for by the customer are: the Advanced Load Phasing System to satisfy an Air Force need for faster load planning; the Advanced Medium Range Air-to-Air Missile; the Army's Tactical Missile System (TACMS), a long-range surface-to-surface missile system; and Joint STARS, derived from DARPA's Assault Breaker program. Although it is difficult to draw a clean line between customer pull and technology push in most programs, the Institute felt that approximately 74 percent of the products delivered during the 1990s were motivated principally by "customer pull" (see Table A-2).

3. Idea or Technology Push Strategy. This is the "build it and they will come" strategy, where DARPA has an idea or technology that it develops and demonstrates to a usually hard-to-convince customer. Notable examples of this strategy, described in Appendix A, include the M-16, stealth, the Internet, and MEMS technologies. The Institute rated about 26 percent of the products delivered during the 1990s decade as motivated by a technology push (see Table A-2).

4. Dual Use (or Co-Development). About 26 percent of the 1990s program population, nearly all DIS transitions, used this strategy. Often an industry-led transition involved co-development by DARPA and universities or industry. This strategy is appropriate when an undeveloped technology has obvious application to both the military and commercial marketplaces. In this instance, a partnership is formed to develop the technology and then to apply it with both DARPA and industry furnishing capital. The program ends when both worlds are assured of receiving its benefits. During the past few years, military transition has often depended on the efficiencies and affordability resulting from commercial economies of scale and manufacturing practices. The dual use product requires unique development and transition strategies and often calls for a longer DoD involvement, which assures the product design continues to be suitable to the military and to ensure its consideration for Service adoption. Commercialization can take years, but once it happens, it is a powerful ally in military transition. Examples are SEMATECH, telemedicine (e.g., digital x-ray, and portable ultrasound), and the development of design and manufacturing techniques for low cost flip chips (components of Multi-Chip Modules (MCMs)).[22]

A subset of the dual use strategy is spin-off/spin-on, which moves a military technology into the commercial world, only to spin it back into the military sector after commercialization and the resulting efficiencies occur. The products delivered using this route frequently perform better and are less expensive. Uncooled IR technology, pyrotechnic devices with laser igniters, and some voice recognition system technologies, were developed using the spin-off/spin-on strategy. Obviously, systems such as Javelin, the M-16 Rifle, and Stealth could not have used it.

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[22] Work in telemedicine and the flip chip were performed under DARPA's core programs and the TRP. SEMATECH was a major pre-competitive government/industry consortium initiated during the late 1980s to improve U.S. industry competitiveness in MCM production.

III. Factors That Affect DARPA's Transition Rate

During the course of this study we collected a list of factors that affect transition at DARPA. These factors were divided into two categories: DARPA's organizational and operational characteristics and policies, and the environment under which the Agency operates. Information was gleaned from specified references in Appendix D, the FY 1991 New Start case studies reported in Appendix B, and several interviews. After discussing each factor, we judged whether it improved or impeded transition rates at the Agency. We also commented on other benefits of these factors, which in some cases overshadow their effects on transition.

It is important to emphasize again that, except for the 1991 New Start Studies, we do not claim to have a statistically valid database to examine why transitions failed. We have documented over 120 successful transitions and can point to causes of success in most cases. For example, we suspect that demonstrating a product as a prototype helps in transitioning since essentially all transitioned products were so demonstrated. But, since we did not attempt to document all of the failed transitions, we cannot claim to understand the absolute influence of that factor on success or failure—all failed programs may have produced prototypes as well. However, where we have found evidence of, or even logical reason for, a positive or negative influence by these factors (as opposed to statistical "proof"), we have reported it and have tried to give it proper weight.

A. Factors Associated with DARPA's Organizational Characteristics

Many aspects of DARPA's mission, functional strategy, and operations profoundly affect the Agency's rate of transition. Table 3 provides a list of factors considered. Judgments of their effects on transition were augmented by conclusions from past studies.

1. **DARPA's Mission:**
a. Solve national-level problems
b. Enable operational dominance
c. Avoid technological surprise

2. **DARPA's Functional Strategy:**
a. Favor revolutionary products and programs
b. Flexibility to exploit emerging situations
c. Emphasize competition
d. Investment firm—not a laboratory

3. **DARPA's Operations:**
a. Flat, small
b. High employee flux (including Director)
c. Highly flexible processes

TABLE 3. SOME IMPORTANT DARPA OPERATIONAL CHARACTERISTICS

1. DARPA's Missions

In 1958 the first DARPA Director, Roy Johnson, called for an innovative Agency, "[DARPA] is in business to provide for the DoD expedited and forward-looking research programs which in the past have been retarded by the necessity for a formal military requirement… If an end requirement, be it military or other, must be established before we embark on research, then by definition it is no longer research. In addition, [D]ARPA will place emphasis on those R&D projects that are of immediate national interest and importance. [D]ARPA is the manager and expediter of these very important projects." Forty years later, in his presentation on the Agency [1], DARPA's most recent past-Director, Dr. Frank Fernandez, reiterated these basic elements of the Agency's mission. While mission statements have shifted from time to time to emphasize a particular area of responsibility, they have remained essentially consistent over the life of the organization. In the following, we discuss three mission elements that may affect transition rates.

a. Solve national-level problems [1]:[23] ***Solving national-level problems is an important DARPA mission, but the resulting products and technologies are generally more difficult to develop and transition than solutions provided for lower-level, single-customers.*** This mission element has been a defining characteristic of DARPA since its inception, providing an important niche for both large and small programs. By definition, solving national-level problems is important work, but it also often results in products that are expensive to develop and hard to transition, in that they are frequently time and resource consuming, and require visionary and high-risk programs.

b. Enable operational dominance [1]: This mission element was added by Dr. Fernandez, presumably to align DARPA with DoD's recent doctrinal publications, Joint Vision 2010 and 2020.[24] Although "operational dominance" is a relatively new phrase, the element is consistent with earlier stated goals that sought to clarify and broadly interpret military needs, as opposed to specific military requirements. Operational dominance is a satisfyingly grand and unconstrained concept—just the sort of guide that DARPA relishes in choosing its program pursuits. Although differently expressed in the past, this sort of language has allowed the Agency the flexibility to innovate across broad areas of technology, application, and even doctrine. The results have sometimes been too far afield from common experience to interest the Services, but it has occasionally produced DARPA legends.

c. Avoid technological surprise: This is an original and important mission that entails a technological intelligence role. But, it has often failed to capture DARPA's full attention. The extent to which DARPA accomplishes this mission takes energy away from transition goals, but it is a vital Agency responsibility.

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[23] "ARPA's role was to respond to Presidential issues…" Dr. Charles Herzfeld, DARPA Director, 1966.

[24] See *Joint Vision 2010* and *Concept for Future Joint Operations, Expanding Vision 2010,* Chairman of the Joint Chiefs of Staff, May 1997, and *Joint Vision 2020,* Chairman of the Joint Chiefs of Staff, June 2000.

2. DARPA's Functional Strategy

a. Favor revolutionary products and programs. ***DARPA's output spans a broad spectrum of products: technologies, processes, organizations, components, systems, and even management practices, which frequently lend themselves to classification as revolutionary and high risk.*** These and other characteristics form the nature of a product and affect its likelihood of transition, as well as often dictating the time and effort required to get it into a customer's hands. Unlike Service laboratories and systems command R&D centers, which generally operate within one or two funding categories, DARPA's programs have spanned the spectrum from research to application, as well as straddling many categories of products.

i. *DARPA's strategy favors revolutionary products* [1, 10]. The strategy to favor revolutionary products and new applications (or markets) usually requires more time to mature and market. Often a risk-averse customer, which military major systems program managers generally are, will be less willing to accept revolutionary products.

ii. *DARPA emphasizes high technology risk and a willingness to fail* [1, 10]. Dr. Rechtin, DARPA's Director in 1969, said of Project Agile, "[It] was a failure, a magnificent failure. When we fail, we fail big." DARPA tolerates failure. Much of DARPA's reputation is built on its ability to take immense technological risks and deliver radical and successful products to fill a need in ways never envisioned by the customer—who often did not even perceive the need, itself. The programs to develop these innovative products are the DARPA legend. As a matter of fact, the Agency often prefers a large, spectacular failure to a mundane success—and for good reason, for trading high risk for high pay-off is DARPA's principal niche. But of course, more failures lead to fewer transitions.

iii. *The Agency tends to respond to military needs, rather than formal requirements.* The 1999 DSB study suggested that, "DARPA needs to avoid requiring Service endorsement or financial support at the outset of a program, the Agency must not allow near-term military deficiencies and the need for immediate military acceptance of its research and development programs to bias the portfolio mix. High-risk programs are not likely to gain early military buy-in, but these are the type of projects DARPA was created to pursue." ([10], p. 17). According to Dr. Sproull, DARPA Director in1963, "I would say that in general...[D]ARPA has two advantages. It can get a very quick response as requirements come up, and secondly, it can have a more scientific involvement, a more long range point of view, than the Services can very appropriately take." Whatever the benefits of this approach, it still makes transition harder.

Many models have been developed by industry to portray the nature of the product and the market it is launched toward. A common model, adapted to the DoD, is shown in Figure 8. In this simple diagram, new technologies or ideas are represented in the upper two quadrants (2 and 3), while existing technologies (or accepted ideas) are placed in the lower two quadrants (1 and 4). Similarly, New Applications (or markets) are found in the quadrants on the right, while those on the left are Existing Applications. DARPA's technology products are seldom found in quadrant 1. As one moves to the right, innovation in applying a technology (or in creating a new market) increases. On the left side of the chart, the fielded disposition of DARPA's Products are arguably more likely to be in the form of subsystems or components, while the right side may allow the insertion of entire systems. As one moves upward, innovation in conceiving a new idea or product, and the time required to mature the product, sufficiently increases. So, within a given program time, the maturity of a technology will be greater for programs conducted in the lower two quadrants. Moreover, while the left side of the chart represents "customer pull" or military requirements, the right side is technology or solution push—tough ground in the military marketplace. The impact of the Final Products does not seem to be influenced by their position on the chart. As can be seen by the examples cited in Figure 8, high impact products have emerged in all quadrants, except perhaps quadrant 1.

We provided examples of products one might expect to find in each quadrant. Often, the Agency's new technologies will find application in an existing final system, such as applying DARPA-sponsored warhead technology to an existing TOW (tube-launched optically-tracked wire-guided) missile system. This case would fit in the second quadrant. Innovation can take place in any quadrant, but is far more likely to occur in quadrant 3, where one is attempting to employ new technology for new applications. For instance, the Internet was founded on new packet-switching technology work sponsored at DARPA and eventually applied to a system that did not exist (and was not even conceived by the public or military) when the "ARPANET" program began, so it fits in quadrant 3.

	EXISTING MARKETS (MilitaryRequirements, System Upgrades)	**NEW MARKETS (Military Requirements, System Upgrades)**
NEW TECHNOLOGY	**2. DARPA** (e.g., Javelin, Uncooled IR, and Extended Melios)	**3. DARPA** (e.g., Internet, Stealth)
EXISTING TECHNOLOGY	**1. SELDOM DARPA** (e.g., Service product improvement programs)	**4. DARPA** (e.g., M-16, Global Hawk)

FIGURE 8. MARKET/TECHNOLOGY CHART

Clearly, although DARPA often downplays its more evolutionary programs, aimed at either applications or using technologies that are established, even a casual look at the list of successful transitions in Appendix A reveals many that represent logical progressions from one level of capability to another. These include the Ada programming language, ball bearing technology, body armor, much of the technology DARPA contributed to Desert Storm, many of the advancements in conventional materials, and the AR-15 effort (leading to the M-16). All of these evolutionary products, and there are many more, have made important contributions to the Military Services. On the other hand, it is probably safe to say that DARPA's programs are, on average, much more revolutionary than any other DoD science and technology organization.

b. Maintain flexibility to exploit emerging solutions at nearly all stages of acquisition and to address customers across the spectrum of the Military Services, from researcher to user [1]. Unlike most Service acquisition organizations, which generally target one or two groups of users, DARPA's approach has been to seek a wide range of customers. In the TRP Case Study, 55 percent of the participating consortia felt that DARPA's tri-Service coverage was valuable. This advantage also applies to the Internet and SIMNET case studies, and has provided an enviable amount of freedom. However, it has also presented difficulties. For example, DARPA lacks the strong organizational links that exist between program managers of a fielded or developing weapons system and the system command that supports them. These shared roots can provide important continuity, access, and support, while DARPA's connection is most often through its products and contacts by individual program managers.

Finding the customer is another problem. There are numerous stories of new DARPA program managers, unfamiliar with the Service they are addressing, who became lost in DoD's maze of organizations and personalities.[25] And few of their busy colleagues are available to help.

c. Emphasize competition. Though not a unique DARPA operational strategy, the Agency has been singularly successful in reaching out to a wide swath of the private sector and academia. The Broad Area Announcement (BAA), as opposed to the often overly prescriptive Request For Proposal (RFP), has historically been a powerful Agency tool for soliciting new ideas and approaches and broadening the competitive field. To the extent that the tactic results in multiple alternatives to the problem addressed, the Agency's transition opportunities have increased. A case in point is the TRP, which yielded DARPA over 2,000 technology development proposals. Out of these proposals, 131 programs were selected (7 percent), yielding nearly 49 transitioned final products.

d. Serve as an investment firm—not a laboratory. DARPA has no laboratory of its own, diminishing (but not eliminating) the "not invented here" syndrome of many agencies which do. Following a rule of "DARPA pays and manages and industry and academia does the work," allows program mangers to accept the best technologies and components for their systems, whatever their sources. From several interviews with participating industries and universities, it was clear that this division of responsibility encouraged a pride of ownership among contractors and produced important product champions on both sides of the private sector/government line.

e. Employ government/industry/academia consortia. Much of DARPA's recent history (e.g., the TRP, SEMATECH, and five examples described under the 1991 New Starts case studies) vindicates the Agency's decision to pursue consortia and other partnering vehicles with industry and academia. These vehicles, originally criticized by some defense experts, have paid large benefits in cost savings and in effectively developing and transitioning technology. Initial problems in cost share and convincing government to allow industry to retain intellectual property ownership proved to be tractable only after visionaries within the Agency gained approval of Congress and then worked out the details to make things happen. In particular, DARPA's willingness to consider a broader latitude in controlling intellectual property, combined with the Agency's "industry-friendly" contracting and management processes, made

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[25] For instance, in 1991 approximately 16 DARPA program managers (over 10 percent) were IPAs from industry or academia. This number has doubled today and will probably become larger in the future.

consortia the success they have been. The effects of consortia on transition are discussed later in this report.

4. DARPA's Operations. These operations call for:

a. Small, flat organizations: Although the Agency is certainly tiny compared to Service S&T organizations, DARPA augments its small staff by enlisting support contractors, who also help maintain continuity and often become very knowledgeable about transition and other areas of a program manager's responsibility. The important feature of this structure is that the small and flat organization ensures that program managers are the focus of power at DARPA, empowering them to make the difference between success and failure and driving them to become champions of their products.

Still, DARPA program managers are often assigned ten to fifteen programs or projects[26] to manage. Transition is a time and effort intensive activity and may severely overburden one person (even with help from support contractors).[27]

b. High employee flux, with continuity provided by industry, other government organizations, and customers. DARPA has always emphasized the need to bring new people into the Agency frequently, in order to stay on the cutting edge of technology and to remain flexible enough to pursue new areas of opportunity. This philosophy is certainly right for the Agency, but it has created difficulties. High employee turnover has had some unfortunate impacts on program continuity and transition. In studying the TRP program, the Institute learned that another problem with a program turnover, from a departing to an incoming program manager, is that the new program manager frequently has less interest in the program success since he or she could not claim parenthood. A common complaint among companies participating in the TRP was, "the new guy was more interested in his start-up program than in helping us to transition the older one." This same concern, albeit from a different perspective, was voiced by some of the program managers during our 1991 case study interviews. The DSB suggested that, "While the program manager rotation policy [rotation after four years] allows for the infusion of fresh ideas and a staff familiar with the cutting edge of technological developments, it also causes program objectives to shift when research efforts are handed off from one program manager to the next." ([10], p. 7.)[28] A natural strategy, in keeping with the fact that "projects" is DARPA's middle name, is to encourage a negotiated duration period tailored to the likely project length.

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[26] The definition of the terms "program" and "project" can have a different interpretation depending on the audience. For purposes of this report, either term reflects a specific effort being managed by a program manager. In technical terms, a program is usually composed of several projects. However, in the budgetary vernacular, a program element is composed of projects. Under these projects one or more programs are identified.

[27] The National Security Industrial Association (NSIA) report ([18], p. 10) suggested that, "the oft-stated high number of contracts per cognizant program manager (up to 15 or more in some cases) is felt by many to be excessive for any reasonable expectation of adequate cognizance and management."

[28] Several other studies remarked on the penalties and benefits of DARPA's program manager rotation policy. For instance, the DSRC study [6] and the NSIA report ([18], p. 10) expressed concern over its effects on continuity within the Agency.

c. Highly flexible processes. DARPA's innovative contracting, hiring, and program management processes are part of its legend. Numerous comments during interviews of DARPA alumni yield unsolicited assertions that the Agency is the one place in government where bureaucratic constraints allow room to breathe. Moreover, few features of the Agency are as helpful to successful transitioning as this one. DARPA has been able to operate more effectively because it can act faster and make better deals (that focus on end results rather than process) with industry and the customer alike. Innovation in developing or adopting smart business practices (such as partnerships with industry and universities, cooperative agreements, other transactions, and special hiring rules), and actually getting permission to use them, has greatly enhanced DARPA's effectiveness in managing its programs, leveraging industry, and transitioning its products.

B. Environmental Factors

One cannot insulate DARPA's transition performance from the environment in which the organization must operate. Changes in the environment can affect nearly every other aspect of DARPA's operation as well—its organization, funding, and program technology areas.

Many factors that affect the transition potential of DARPA's products lie outside of the Agency's direct control (see Table 4). In the private sector these factors collectively comprise the environment under which an organization must "sell" its products to potential customers. For DARPA, the environment reflects the influences of timing, regulations, customer attitudes, and budgetary considerations that greatly affect chances of transition. Some of these stem from important events and trends, such as the end of the Cold War and the remarkable growth of global commercial competitiveness and cooperation. Others originate in rules, regulations, and laws that present detours in otherwise viable development and transition paths. But both have important consequences, such as lower DoD procurement budgets, a more diffuse threat spectrum, and the ascendancy of commercial industry as a source of defense technologies. In the following, we discuss some of their effects on DARPA's transition options.

1. Nature of the customer
2. Growing importance of industry's R&D
3. Timing
4. Acquisition system regulations
5. Budgetary considerations

TABLE 4. CHANGES IN FACTORS AFFECTING TRANSITION RATES AT DARPA

1. The Nature of the Military Customer. DARPA's real customers are the Military Services, although sometimes there are intermediary customers, such as industry or Service S&T organizations that apply DARPA technology to military needs. The military customer is usually very conservative and driven by schedules and funding streams outside of their control. Of course this risk aversion varies significantly among individual customers and, more importantly, on where the customer resides in the acquisition system. For instance, the program manager of a weapons system that is either fielded or is late in the developmental cycle will be especially cautious about accepting a new and unproven technology, while the manager of a laboratory technology applications project may be quite comfortable with it. But, it is generally true that there is a large difference in risk tolerance and other factors between the DARPA program manager and the military customer. A NSIA report ([18], p. 12) cited some of these differences: "lack of a common goal, mismatches in time horizon of interest, risk preference, and often lack of agreement on the appropriateness and suitability of the technology to be transferred." It is also true that DARPA program managers cannot be expected to be experts on military doctrine and lore. This may be particularly true in the technology offices, where many are IPAs from commercial industry or academia.

Another subtle but important barrier to DARPA/customer understanding occurs because many of these customers are also in budgetary competition with the Agency. For instance, it is often difficult for a Service laboratory to acknowledge a contribution by DARPA when, in their perception, that praise may be taken by Congress as a good reason to shift funding from them to the Agency.

Military customers and their relations with the Agency deserve a good deal of study, but it is a subject that falls beyond the scope of this effort. However, two changes should be noted.

A Change—Federal laboratories may be weaker partners. On many occasions the military S&T community has served as DARPA's customer and colleague, and both National and Service laboratories are experiencing reductions in budget and personnel. A recent DSB study ([28], p. C-8) revealed that between FY 1990 and FY 1997, the S&T and acquisition workforce fell from 131,000 to 93,000, with plans for a further ten percent reduction by 2005. Another DSB study, conducted in 1999, concluded that, "...the Services not only have reduced their overall investments in science and technology, but have also directed much of their funding priority toward modernization" ([10], p. 11). What will this mean to the DARPA program manager less competition or less help in transitioning his or her technologies? In the past there have been fruitful relationships formed between DARPA and the national laboratories. What effect would smaller national laboratories have on DARPA? Unfortunately, these important questions lie outside of the scope of this study.

A Change—There are new avenues for product insertion into the Services. The most exciting improvement in transition opportunities may well be the increased approaches to market military technologies and products. This began with the warfighting laboratories, which have appeared, in some form, in every Service. These laboratories have provided common grounds for warfighters and technologists to meet and experiment with different solutions to problems of defense. The recent emergence of the Joint Forces Command may well make this opportunity available to the joint warfighting arena as well. New positions are also being contemplated by the Services to encourage transition, for example, the Navy's Chief Technology Officer. The Advanced Technology Demonstration (ATD) and ACTD programs "try out" technological solutions on a field of simulated battle, broadening the number of technology players that actually get to the soldier. Finally, special efforts, such as DUS&T, a descendant of the TRP, reach many commercial industries and successfully solicit their ideas.

2. Growing importance of industry R&D. As most people know, commercial sector dominance continues to grow, in terms of capabilities, funding of R&D, product development, overall size and creativity, importance (from the public's perspective), and the applicability of commercial products to satisfy modern warfare needs.[29] So, the commercial sector holds extremely robust solutions for affordably meeting military needs. While the inefficiencies of DoD's acquisition system are driving away many of the most creative commercial companies, DARPA has been able to continue to attract much of the private sector. This is an important role and should include a mission to expand the techniques of leveraging industry into the Military Services. A facet of this mission is to learn how to better involve industry to a greater degree in actively transitioning products into the Services.

3. Timing. Luck is often the forgotten factor in technology development and transition. Most often fate affects transition through the schedule, for although timing is not everything, it can dictate transition success or failure. Here are a few examples of circumstances beyond the control of DARPA that foiled transitions that should have happened. In two cases, victory finally yielded to persistence—a worthwhile lesson.

The opportunity to apply the technology is sometimes time-dependent. For instance, during the 1970s, DARPA worked on a sensor for a semi-active laser guided missile that was to replace the Army's 2.75 inch Rocket. After an intense and successful program to significantly reduce the aperture size, the Army decided not to fund the more expensive guided missile application. At approximately the same time, however, interest was growing in the Army for a more accurate artillery round (named the Cannon Launched Guided Projectile (CLGP)). It was found that the seeker would fit the need, if it could be sufficiently hardened to withstand the immense g-loading imposed by an artillery piece. This problem was eventually solved and the "recycled" seeker found itself on the CLGP, eventually renamed Copperhead. Copperhead has been very successful in precision attack of targets, and has been procured in large numbers.

In another case, a "Buck Rogers" rocket belt was designed for the Army during the 1970s under a DARPA contract. Although it was never fielded, its especially efficient "Williams" engine was used in the Tomahawk and Air Launched Cruise Missile, giving these weapons systems needed payload and range capabilities.

Unlike the previous two examples, the Arsenal Ship has not risen from the ashes of a failed transition. In this case, DARPA and the Navy agreed on a program to develop a revolutionary approach to naval firepower. The idea was to develop an inexpensive ship design that would house a variety of weapons systems. The design was to feature commercial shipbuilding approaches and techniques that would reduce crew size significantly. Unfortunately, under a new Chief of Naval Operations the program was cancelled.

Almost half of the program managers we interviewed for the 1991 case studies made a statement that timing usually plays a significant role in the success or failure of a program. If the commercial market or the Military Services aren't ready, there is not much that can be done to

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[29] Just a few examples of the essentially commercial technologies that are applicable to the battlefield are information and bio-medical technologies.

change the circumstances. If you're too late, someone else has the market. If you're too early, you can't sell it.

Two prime examples of timing (one good, one bad) are articulated in the 1991 case studies. In the first instance, the program manager for the Consortia for Optoelectronic Interconnects stated that had his program been initiated one or two years sooner or later, VCSEL technology may not be a reality today. Could he have predicted the right timing? He said no, that luck played as much a part of the huge success as most of the other components. On the flip side, the Thermal Management Diamond program most likely could have succeeded with the right timing. This program represented a dichotomy. It was a success from the technical and commercial standpoint in that the price of the diamond substrate was reduced drastically, from $1,000 per karat to less than $1 per karat, making it a commercially affordable component. However, when it came time to actually insert the product, DARPA and the Services found that most of the current and in-production systems would have to be completely re-engineered to accommodate the materials change. The Military Services determined that they could not afford, and were not willing to invest in, significant systems changes for the sole purpose of gaining thermal conductivity, especially since it was not a critical problem. Will their needs change in the future? Most likely they will. Will this technology be available? Probably, but not in the United States, the market has been lost.

These, and other examples suggest that transition can go wrong (or right) through no fault of the program manager or the product. It also suggests that, perhaps if the product in question has good potential, DARPA should stay in the game and continue to try to transition it when the timing is better, even after program completion. But, DARPA has no mechanism to do this. In a recent paper [32], Stanford University's Dr. Gio Wiederhold, a former DARPA program manager stated, "Vic Reis, when director at DARPA, recognized that many research results will not be of immediate use and will rest on shelves until needed. However, no overt provision was being made in Vic Reis' model to establish shelves, making delayed use unlikely."

4. Regulations. The difficulties of working efficiently to develop and transition products under the Federal Acquisition Regulations and the DoD's acquisition system are well documented. Although DARPA has been less fettered by these regulations and procedures than the Military Services, they have been penalized as well. The DSRC study [6] referred to DoD's procurement process as Byzantine—perhaps this is a harsh judgment on Byzantium. By developing and applying innovative business procedures (such as using a "value-based" approach to procurement and accepting activity-based private sector accounting approaches), DARPA has not only reduced its own bureaucratic burdens, but has introduced its solutions into the DoD mainstream, as well.

DARPA led the effort to develop the philosophy and techniques to make it easier to work with commercial industry. The Agency's success is illustrated by the fact that nearly all ideas behind new DoD commercial leveraging programs, such as DUS&T and the Commercial Operations and Support Savings Initiative (COSSI) are derived from DARPA. The Services are gaining skills in working with industry and what was once recognized as a DARPA niche may be proliferating throughout the DoD.[30]

A Change—Unconventional S&T procedures are more acceptable. This means less reliance on dogmatic requirements and more opportunity for flexibility in technological and operational solutions. It may allow DARPA to appeal to a broader customer base (e.g., dual use in civilian law enforcement, disaster control, and counter-terrorism agencies). It will certainly provide opportunity for the Services to compete on a more equal basis on what was previously "DARPA's turf."

5. Budgetary Considerations. Figure 9 shows DARPA's budgets in constant FY 1997dollars from 1958 to 1998 compared with other research agencies. Note that NASA's R&D science budget has historically been much larger that DARPA's. NIH is also much higher and climbing, while the NSF budget runs on a par with DARPA. In fact, all but NSF show a larger rate of increase that DARPA's.

Even so, long and sometimes unpredictable funding cycles can also produce opportunities or ruin chances for transition. For instance, when a military acquisition official is given funding, it is for one or two years. He cannot bank it and collect interest. Nor can he save it for a future opportunity. He must spend it or return it to the U.S. Treasury. Sometimes the success or failure of a technology to transition depends upon the presence of dollars that must be spent—this year. A case in point was the insertion of a DARPA-developed detachable cermet armor system, called LAST®, which occurred only after a member of Congress decided to include upgrading the armor on the Marine Corps Light Armored Vehicles in the budget.

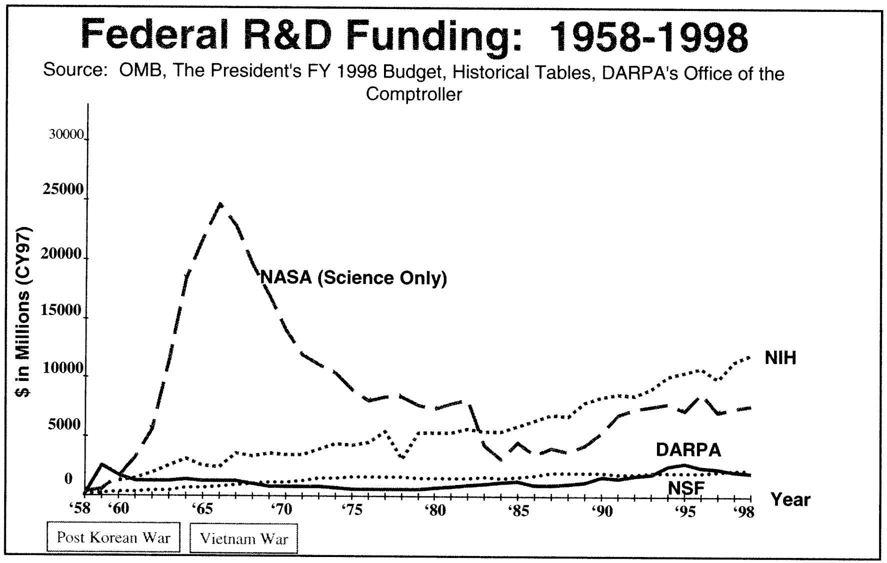

FIGURE 9. FEDERAL R&D FUNDING: 1958-1998
(Source: OMB, The President's FY 1998 Budget, Historical Tables, DARPA's Office of the Comptroller)

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[30] A 1999 DSB study stated that, "DARPA should continue to use and pioneer innovative contracting vehicles for prototype development and the same authority should be extended to the military sources to allow for seamless transition of DARPA-developed systems to military-led acquisition programs." ([10], p. iv.)

A Change—Smaller DoD procurement budgets. In general, smaller procurement budgets mean that there are fewer opportunities to transition DARPA products into fielded military systems, simply because there are fewer systems being built and fielded.[31] During the early days of the Clinton Administration, then Secretary of Defense Les Aspen suggested that DoD should develop technology, but leave it "on the shelf," presumably to wait for larger procurement budgets. The Bush Administration has also alluded to this strategy lately. Figure 10 illustrates the dramatic reduction in procurement funding levels as compared to RDT&E spending. Note that the procurement budget is two and a half times the RDT&E budget in FY 1983 and they become almost equal in 1997. It is important to point out that the effects of reduced procurement on the technology base may not surface immediately, since many of its results are first incorporated into the 6.4 to 6.7 funding categories of RDT&E. This block of money is the reason for the "hump" in the RDT&E budget curve in Figure 10, so it has actually grown and may have accommodated the 6.1 to 6.3 output to some extent, by allowing adoption of advanced technologies into major developmental programs, the F-22 Program, for instance.

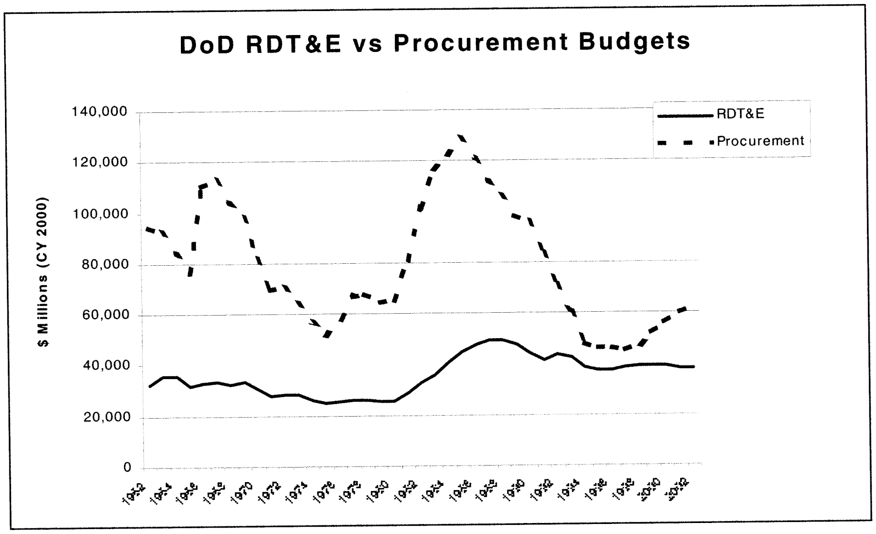

FIGURE 10. DOD RDT&E VERSUS PROCUREMENT BUDGETS

But, the real purpose of the technology base is to affect fielded systems. Obviously it will be more difficult to ingest the new technologies emanating from the relatively robust RDT&E budget expenditures in the 1990s than during the Cold War era (and especially during the Reagan build-up). This is a situation that would seem to call for a dramatic increase in procurement budgets, which is unlikely, or an equally dramatic decrease in DoD's RDT&E funds. There is another option, however, and that is to see R&D funding in the military differently—in fact, to view it as it has actually become—much less concerned with the "DoD technology farm" and much more directed toward harvesting across our "national technology farmland." To continue an overworked analogy, this strategy, which has been progressing in DoD for some time, broadly

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[31] The DSRC study [6] states that, "Technology for a new military system must fit the cycle of acquisitions or it is doomed to wait years on the shelf. New systems are becoming rare."

sows seeds across the private sector and academia. This generates a situation where the DoD has a better opportunity of skimming the best technology from a far larger source, rather than trying to develop the technology within the defense community. It should also encourage DoD's technologists to become more proactive in finding out who is doing what outside the DoD, because they are funding some of it. Finally, from the perspective of this model, the procurement budget becomes enormous, since it also involves serving the commercial marketplace. All this seems to imply that DARPA should be engaging more in DIS transition paths. In fact, we suspect that this is happening, although we did not collect the data to prove it.

IV. Fiscal Year 1991 DARPA New Start Study

This chapter describes the processes utilized in conducting the FY 1991 case studies, and provides conclusions derived from them. The purpose of choosing a single year as a dataset, in this case FY 1991, was to remove any bias towards success or failure. A complement to the 1990s Decade transitions, of which are all successes, the FY 1991 new initiatives allowed us to review DARPA programs from a well-rounded perspective that included failures as well as successes. We tracked each of these new starts until they transitioned products, failed and were abandoned, or continued development with possible transition pending. This was the only requirement levied on us for the study. The year selected had to be far enough in the past to allow sufficient time for technology maturity and possible transition, or provide enough knowledge that the program was not successful and why. But, the year also had to be near enough to the present for programmatic data to be easily retrieved. The following paragraph describes how and why FY 1991 was selected for the New Start case studies.

A. Selection Process

Previously documented transition data indicated that it typically takes anywhere from five to twenty years, depending on the system or technology, for transition to occur from inception at DARPA to a fielded system. Using this model, we determined that approximately ten years was an appropriate period to target. By process of elimination, FY 1991 data appeared to come closest to our criteria, and would provide a sufficient sampling of data. The program information was still more or less available, and many of the programs begun in 1991 had already been completed. We did encounter some difficulty in determining exact start dates on some programs. For this reason, although we consider this data set representative of FY 1991, there are a couple of instances where the programs actually began in 1990. Such instances are noted in the individual case studies.

Based on our own pre-defined guidelines, the Institute ultimately selected 18 programs. As stated above, because of the difficulty encountered in positively identifying "new initiatives" there is a possibility that some programs may have been overlooked. If this did occur, it was unintentional except for one specific instance—the Counter-Drugs Program.[32]

Resources from the DARPA library that we utilized to determine a program start date included: DARPA Director's statements from FY 1989-1992; January 1990 descriptive summaries; and Commerce Business Daily (CBD) BAAs from the 1990-91 timeframe. An additional and extremely helpful resource was a historical budget computer run provided by the Comptroller's office. This run included budget data on all programs on-going at DARPA between 1989 and 1992. By carefully examining this budget data, we were able to identify potential 1991 "new

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[32] The Counter-Drugs Program was considered not to be a typical DARPA program in that it dealt with a subject that was more within the scope of the National Institute of Justice's mission, and was transferred within two years to the Justice Department. The Counter-Drugs Program is the only instance of deliberate exclusion or inclusion of a program from this study.

start" initiatives and compare them with our other data. This painstaking process yielded the list of selected programs.

B. Case Study Process

We reviewed all the material obtained from DARPA to determine which programs were new initiatives based on our criteria. Once these programs had been identified, we composed a list of questions to ask during the interview phase. Our primary targets for program interviews were the DARPA program managers themselves. We contacted both current and past program managers, and had discussions with them either in person or by phone depending on whether or not they were in the local area. Many of the program managers provided us with names and phone numbers of additional individuals to interview, e.g., the DARPA contractor who worked on the program or the Service representatives. We followed up on all leads and were able to complete fairly comprehensive studies for most of the programs. In one particular case, thanks to the timing and location, we were able to attend a demonstration day for a particular program (High Definition Systems). We also relied extensively on the Internet for background information. It is interesting to note the amount of information actually available on the web pertaining to past DARPA programs. Most of this data is in the form of news items but there are also many articles and papers written by industry that had been sponsored by DARPA. All case studies are summarized in Appendix B.

C. Conclusions from the FY 1991 Case Studies

Technology development/transition is a lengthy and intensive process.

Most of those interviewed remarked that it can take a long time to get a new technology ready for transition. Also it was noted that it is difficult to predict new technology and that due diligence is important. In other words, you need a sound business strategy. As our case studies demonstrate, there is no single way to achieve transition. Timing plays a major role in DARPA transition success along with technology maturity, the market, and defense needs.

Most program managers noted that transition is an extremely intensive pursuit, taking a lot of time and effort on their part. A program manager must continuously look for transition paths and identify where the technology or research can be transitioned. One impediment to the transition process suggested during our interviews was the current "four year" policy that DARPA maintains—a program manager has a presumably predetermined finite amount of time to initiate a program and ensure a successful transition path. Many programs do not fit a four-year model. It was suggested that a more feasible policy would be to engage a program manager for the duration of a program rather than four years. A tour molded around the anticipated length of a program would enable a champion to see a new technology from beginning to end. This would also provide continuity, which is currently often lost when multiple program managers rotate throughout the life of a program. Another suggestion was that for a relatively low cost, a champion may be hired to ensure the momentum continues both in industry and the Services. This tends to contradict DARPA's philosophy that there is a clear beginning and ending to a program.

Motivations for transition are strong, but often different for DARPA, industry, and the Service agent.

Also noted during the interviews was that DARPA has a stake in ensuring that technology gets transitioned, and should work closely with the Services and the Service labs to facilitate transition. An observation was that it is very important that the DARPA program manager work to promote a team effort with the Services, universities, and industry involved in their program. Only teamwork will result in the greater possibility of a successful transition.

DARPA has sometimes lacked long-term commitment to its programs.

DARPA consistency was another area of concern addressed by former and current program managers. Several noted that industry is hesitant about investing their own money before making sure there is a long-term commitment on behalf of the government. A related comment was that the Services and other partners are a bit gun-shy when it comes to working with DARPA because they might not see the program through to completion. For example, DARPA terminated the SPEAKeasy program two and a half years early, with no viable sponsor to continue the work.[33]

This consistency also matters in the sense that DARPA is a critical player in basic research. As was demonstrated in the FY 1991 case studies, a technology or research area may be on the verge of a breakthrough and an investment by DARPA will push it over. An example of this was the Optical Consortia. In this case, according to the DARPA program manager, their investment in optical technologies was the cornerstone of the telecommunications revolution. Prior to DARPA's investment, the Japanese were taking the lead and U.S. industry was without direction. DARPA's involvement inspired the organizations to form consortia and to further research in this area. DARPA needs to be aware that it often represents the only "bridge" between research or early technology development and application.

Contractual and procurement processes are often impediments to technology transition from DARPA.

Many program managers remarked that it could take up to a year to solicit proposals, select one, and then negotiate a contract. This is a lifetime for a small start-up company and an entire year out of a program manager's four-year duty at DARPA. During the interviews, the observation was made that bureaucratic requirements need to be streamlined and aligned with the time allotted for a program manager's term at DARPA. Some suggestions included shortening the proposal process and easing deadlines for money obligation. One former program manager commented that good ideas are not scheduled by fiscal year, yet money needs to be committed by early spring and obligated by the summer or it is potentially swept for another effort. This is primarily predicated on the budget process that all government agencies are held to. Funds are appropriated annually and if their commitment and obligation rates have not been met, DARPA

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[33] Fortunately, as discussed in the SPEAKeasy case study in Appendix B, the DARPA program manager found a home for SPEAKeasy, but through a chance opportunity.

(as all government agencies) increase their risk of having a reduced budget the next year. This causes undue problems for a DARPA program manager who does not have the ability to change direction quickly and is often locked into a mixed message—slow down for competition sake but speed up for budget purposes.

D. Summary

For the FY 1991 new initiatives, 18 programs were identified. The percentage of transition successes for the entire FY 1991 data population is 67 percent (12 out of 18). The transition rate is higher yet for certain types of programs: insertion 80 percent (4 out of 5) and consortia 75 percent (3 out of 4).

A transition rate of 67 percent was definitely a surprise. This number could go even higher, given enough time. There is still a program pending in the S&T organizations (RF Vacuum Electronics) that may yet achieve technological success and eventual insertion into a fielded military system. But, based on past numbers that had appeared on DARPA transition, we had expected to see something on the order of 25 percent. However, this was the first time that someone followed all the new initiatives from a single year. Perhaps a second effort on another single year would lend more credence to the numbers we uncovered. If it is proven that these transition figures are the norm, then it appears that DARPA has overlooked counting, and taking credit for, many transitions over the years.

Since the transition rate is much higher than we would have expected, we looked at our data to see what circumstances could have caused this remarkable success. In 1991, there were five insertion and four consortia programs. These programs appear to have increased transition opportunities. Indeed, the transition rates for the insertion and consortia programs, taken separately, are a relatively high 78 percent. If we delete them from the 1991 dataset entirely, its transition rate drops to 56 percent. This difference in transition rates could have at least two causes: i) an insertion program's primary goal is to transition a product, so one would expect a higher rate in these programs; and ii) industry and government collaboration and cost sharing in a consortium may tend to reduce program risk (during the R&D phase of a product, industry partners may be more sensitive to risk than those representing the government). This latter explanation seems to be reflected in the observation that the average 1991 New Start had a lower impact than that of the 1990s Decade of which they are a part (1.3 versus 1.5, respectively). If higher risk programs at DARPA imply higher payoff, this seems to indicate that the 1991 New Starts may have been lower risk than the average 1990s program.

There were six failures (actually only five—based on our criteria the RF Vacuum Electronics program could not be counted as a successful transition since research is still being performed on this technology). Of these six programs, five were being funded at the 6.1/6.2 technology base research level. Risk and uncertainty is highest at this level so a high failure rate would not be surprising. Three of the six programs had similar traits that would point toward a potential failure from the beginning. We could see no evidence of a clear-cut program objective, and no transition plan had been written. In addition, the Services appeared to show little or no interest in support of the program. Two of the programs (UUV (unmanned underwater vehicle) Fuel Cell and RF Vacuum Electronics) were addressing tough technology problems. DARPA and industry gave up on the aluminum oxide semi-fuel cell (after about six years worth of investment) as a viable alternative power source for UUVs. This fuel cell example is similar to the Thermal Diamond program—no long-term champion. This is exceedingly hard for DARPA, knowing when to continue pursuing a technology and when to stop.

Based on our transition path definitions, two programs (17 percent) transitioned via the DS&T route to Service S&T organizations (military or DoD labs); four (33 percent) transitioned via DIS; and six (50 percent) were transitioned by the DSA path.

All programs fell into the very significant and significant categories of impact. Unlike the overall transition rate, both of these patterns follow the 1990s Decade characteristics (as evident in Tables A-2a and A-3a). Of the 1991 new starts, the ones that were deemed to have a very significant impact used the DIS transition path—this is very similar to the results found in the overall 1990s Decade.

The impact of DARPA's pursuit of consortia-type work with the commercial industry has been substantial not only for the commercial market but the overlapping military benefits. In the cases identified above, if DARPA had not been in the forefront, primarily in pushing a new way of doing business, there is a distinct possibility that today the country would be reliant on Japan and the European Community for all or most of our optical electronics.

In the early 1990s, DARPA and DoD had become very aware that the government way of doing business was outmoded by commercial standards and required modernization if U.S. technology superiority was going to be maintained in the future. Since its inception, DARPA had been at the forefront of leading research and development in most technologies. But in the mid 1980s (primarily in the electro-optics and computer technologies) industry was pulling ahead. In addition, the Cold War had ended. The big build-up of earlier years was over. DoD had to put in place measures to ensure that the military requirements were not adversely impacted by this phenomenon. As the commercial market strengthened and grew, the defense market diminished. New ways had to be found to protect DoD interests and at an affordable cost. One of these measures was the use of consortia. This was a group usually comprised of representatives from government, academia, and industry working together under a formal agreement whereby they agreed to share ideas and costs for a common goal. This works especially well for dual use efforts. If the technology is successful, the commercial entity can expect a return on their investment and the military can expect to receive their product at a reasonable price. Prior to this time DoD had shied away from doing cooperative agreements and other incentive-based contracts with traditional companies. Now, however, it became apparent that DoD must use commercial business practices and take advantage of the commercial market place. Fortunately, DARPA pioneered the use of special relationships with industry. Of course, the crucial problem, aside from cost share, was convincing government to allow industry to retain intellectual property ownership. DARPA's willingness to do so, or at least to consider a broader latitude in controlling intellectual property, combined with the Agency's "industry-friendly" contracting and management processes, made consortia the success they have been.

In FY 1991, Congress provided $50 million (and an additional $60 million in FY 1992) to DARPA specifically for the purpose of entering into precompetitive technology development cooperative projects. The then DARPA Director initiated an internal DARPA competition for these funds. Two of the projects selected under this competition resulted in successes far exceeding anyone's expectations. According to the DARPA program manager, both projects (the Optoelectronics Interconnection and All-Optical Networks) revolutionized the industry in these areas. Under the first consortia, the Optoelectronics Interconnection, Honeywell produced a breakthrough technology, the Vertical Cavity Surface Emitting Laser (VCSEL). VCSEL technology, currently a $10 billion a year market, is now the gigabit Internet industry standard. Where the U.S. was languishing in the 1980s, this breakthrough allowed the U.S. to surge ahead of the Japan and the European Community markets in the 1990s. The DARPA program manager stated that the technology was on the verge of a breakthrough but the DARPA involvement pushed it through. Industry was searching for a direction, which this program was able to provide. The second consortium, the All-Optical Network, resulted in the 1993 establishment of MONET (Multi-wavelength Optical Networking). This is a consortium of five organizations (Bell Atlantic, BellSouth, Pacific Telesis, Southwestern Bell Technology Resources Inc., and Bell Labs in cooperation with the National Security Agency (NSA) and the Naval Research Laboratory (NRL)) that defined, demonstrated, and arrived at industry consensus of the best multi-wavelength optical network on a national scale that serves commercial and government application.

Insertion programs, those programs designed specifically to improve technology to fielded system time, do not ensure success. The Diamond Pilot Line was a technology success but failed for other reasons as cited in the case study. However, there does appear to be merit in this type of program. Perhaps DARPA should pick those technologies with the greatest chance of succeeding—it is worthwhile if there are compelling and cost beneficial reasons for introducing new technology into the legacy systems. For example, in the HiPer-D case, it was determined that open architecture would reduce costs over the life cycle of the systems.

It appears that DARPA became concerned (and took action) in the early 1990s that technology was not being inserted quickly enough into the fielded military systems. We found five insertion programs begun in FY 1991. Four were successful giving insertion programs an 80 percent success rate. All five insertion programs (HiPer-D, Diamond Thermal Management, Advanced Ceramic Technology Insertion Program (ACTIP), Ceramic Bearings Insertion Program, and ARPA/Rome Planning Initiative (ARPI)) were initiated specifically for the purpose of finding a way to help the Services obtain a product in reduced time. These four successful programs had a particularly solid similar trait—each program had a champion in the form of the program manager or a contractor that helped push the program.

Although both of the large (high expenditure) 1991 New Start initiatives were great successes, contributing over $100 million is not the sole reason that a program is successful. Eight of the ten successes we identified were considered "small" dollar items. The military benefits will far outweigh the dollar contribution by DARPA.

In researching the FY 1991 new initiatives, we discovered only two programs where DARPA had contributed over $100 million toward the technology. None of the programs identified were large systems. Due to time constraints that prevented further research, we are unable to provide a conclusion as to why there were no large system items identified in our 1991 study. An assumption can be made that this possibly occurred because of the end of the Cold War. It could have been a period in which DARPA was re-structuring and determining how best to proceed in light of the new environment. It could prove valuable to research another year (a few years pre- or post-1991) to determine if the results would be dramatically different.

The programs that we have examined and the results of their efforts are listed in Table A-3 in Appendix A, and the individual case studies are in Appendix B.

V. Should DARPA Change?

Most critics would rate DARPA's history of technological contributions a success. Even so, DARPA can improve its rate of transition through increased and consistent emphasis on transition and better strategies. In the past, the quality of individual program transition plans has been spotty. Little training was offered to new program mangers on how to transition. There is no dedicated course or handbook on how to maximize the success of this important aspect of program management. DARPA's transition circumstances are different in many aspects from the Service laboratories, defense industry, and commercial industry, although each has lessons to teach the Agency. DARPA should learn these lessons and develop a DARPA philosophy and strategy that facilitate the program mangers' accomplishment of technology transition. Policies should explicitly state the importance of developing and updating transition strategies (Urban's third point in [22]) and suggest some approaches to be taken. All program reviews should continue to include an examination of transition strategies and plans. During an interview with the Navy's Chief Technology Officer, Dr. James DeCorpo, he noted that "Businesses match the technology with the business plan, but the Services do not. The largest impediment to transition is not the technology, but rather the business case. Technical people tend not to understand this. They believe that a perfect demonstration guarantees a transition, but it does not work that way."

Perhaps the simplest recommendation is one stressed in many reports—*DARPA should place greater emphasis on transition.* For example, Havelock and Bushnell's ([20], p. 8) overriding recommendation was that DARPA should, "greatly increase the priority of transfer issues at DARPA, and the professional personnel of the Agency should significantly increase their concern for the full range of tech transfer issues covered in this report." However, having said this, the problem then becomes how one effects this emphasis, and how one determines the proper balance between the goals of transitioning products to the Services and the other factors discussed in Chapter III, such as pursuing national or high risk/high payoff solutions. We have included a number of suggestions from our study as well as from other studies in Table 5. These criticisms are discussed throughout this chapter. Our work found the first five of these recommendations to be critical.

1. Maximize the effectiveness of the DARPA/industry program manager team
2. Develop a better system of tracking and recording transitions and lessons learned and integrating the results
3. Address problems associated with "market timing"
4. Ensure sufficient technological maturity of products
5. Take advantage of new avenues into the Services
6. Overcome PPBS-based funding obstacles
7. Solve problems associated with DARPA's willing to fail vs. Services risk-aversion

TABLE 5. COMMON RECOMMENDATIONS ON IMPROVING TRANSITIONS

Maximize the effectiveness of the DARPA and industry program manager and Service agent team. Transition success has been highly dependent on the individual program managers acting as product champions. We found no other mechanism as effective in transitioning products as a highly-charged and knowledgeable program manager. Most often the impetus for transition rested with the DARPA program manager, but frequently the industry program manager or the Service agent took on the task of product insertion into the military. Certainly at least one must see transition as a major goal or it will not happen.[34]

The strategy we recommend has four thrusts: 1) matching DARPA program manager's tenure at DARPA to the expected length of the projects they will run; 2) helping new program managers to become effective as quickly as possible through training and mentoring programs; 3) making program transfers from departing to incoming program managers as efficient as possible and motivating new employees to treat inherited programs as their own; and 4) establishing incentives for program teams to transition their products.

At the time of their study, NSIA [18] felt that DARPA's criteria for choosing personnel seemed appropriate to their needed technical, entrepreneurial, and management strengths, but some problems were cited. One was the relatively short tenure of personnel. While probably appropriate, program manager flux leads to poor continuity. Moreover, DARPA's relatively large budget and few program managers result in each manager being responsible for a large number of programs or projects. NSIA also felt that the small size of DARPA is a dilemma—but, that DARPA should avoid major growth. When necessary efficiencies are found through cutting bureaucratic procedures, the result is generally good. But when important aspects of program management (such as transition planning) are neglected it is not. Perhaps the most expeditious hiring action needed, given our finding that departing program managers often take much of the enthusiasm with them, is to match tenure to program length, as much as possible. This would avoid the program turnovers that can be so disruptive.

We believe the Agency should avoid overly prescriptive transition paths and techniques that may inhibit a program manager's creativity and zeal. At the same time, it would seem to be a good idea to provide courses and mentorship on transition, particularly to new program managers (and perhaps to industry participants and Service agents).[35] This action would serve as a first step toward eliminating the poor transition planning that sometimes has led to failed products and technologies that could have been inserted into the military with additional effort and a plan. Special studies could be conducted on new DARPA programs, in order to help develop transition plans, which could then be used as learning tools.

One effective approach would be to ask successful program mangers in industry and DARPA to share their experiences and techniques. In fact, perhaps a reasonable way to begin the process is

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[34] Of these individuals, the DARPA program manager is the focal point of the program and is responsible for most aspects of management, including apportioning funds for various areas of effort—such as transition planning and implementation. He or she must also "sell" DARPA on the program, or all is lost. For these reasons, a DARPA program manager who is indifferent to transition can be major impediment, even if there is a highly motivated industry product champion.

[35] The 1999 DSB study ([10], p. 14) suggested that, "DARPA has a very limited training or mentoring program for new program managers and thus it may take as long as a year for new program managers to establish a set of programs."

to hold a symposium with several DARPA and ex-DARPA program managers to speak about their transition experiences at the Agency.[36] Case studies of successful and failed product transitions would also be helpful. One course segment should be dedicated to a summary of how the Military Services are organized to accept new technologies and ideas, including the identification of organizations and officials within the Services who can be helpful. This is particularly needed for IPAs who have had little DoD experience. During the late 1980s DARPA initiated a three-day orientation course for new program managers that emphasized these aspects of program management. The course was an unqualified success. Today, as a group, DARPA personnel are as diverse as they were then. Yet, there is no comprehensive orientation course structured for program managers—arguably the most important members of the DARPA community. Such a course could address the mix of backgrounds (civil servants, IPAs, and academia).

It has been the perception at DARPA that the ad-hoc approach to transition is appropriate "because every program is different." The assumption is that with good people and the right directors, DARPA programs will be relevant and will be coupled to the Services/Agencies early. But, a more deliberate approach is needed to maximize transition [18].

Incentives for program managers to transition their products, in addition to producing significant technological advancements, would also help to establish the Director's emphasis on transitioning. There have been awards given for successfully transitioning products at DARPA, but the Agency should formalize a strong reward system to recognize excellence.[37] This point was made by the DSRC [6], "There are few incentives, other than intellectual satisfaction, for doing noteworthy T4 [technology transfer/technology transition], and fewer penalties for insufficient attention to T4." In a recent interview, Dr. James DeCorpo, the Navy's Chief Technology Officer remarked that, "The Draper Award is a good model. It rewards application of a technology. It is also prestigious, since few of them are given."

2. Develop a better system for tracking and recording transitions and lessons learned, and integrating the results. Essentially all world-class individuals and organizations assess their performance. Likewise, DARPA must constantly evaluate how well it accomplishes assigned missions. In the case of transition, the Agency should institute a better system for tracking and rating individual product insertions, and for monitoring products that the Agency feels represent a high potential for transitioning to the Military Services, but for various reasons have not. This is not merely to "take credit" for successes, but more importantly to ensure that DARPA's investments pay off.

In 1985, Havelock and Bushnell ([20], p. 3) declared that DARPA has no mechanism for either self-examination or peer review, and therefore, no means of answering many important questions on project management and transition. They recommended an online retrieval system for tracking data on all projects and proposals, particularly through critical stages and outcomes for

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[36] A number of them have volunteered to speak at such a symposium.

[37] We did not attempt to identify the nature of such incentives, but obviously monetary awards and recognition are two. We did discuss yearly transition awards, presented at a DARPA event (Christmas party or picnic) to the product champions who accomplished the most innovative, the most difficult, and the largest product transition. Industry and Service Agent personnel should be candidates for these awards as well.

purposes of conducting transition analyses. Since then, much has been done to computerize DARPA's records and processes, but, as we found in conducting this study, pertinent data remains difficult to find. Indeed, a 1999 DSB study ([10], p. 7) advised that, "DARPA needs to set in place a process for capturing, understanding, and learning from project failures." It also suggested that the Agency needs better procedures for handing off programs to new program managers. The NSIA report ([18], p. 11) suggested that, "DARPA should establish and make available to all program managers a central historical data base or corporate memory of successful technology transfer strategies based on actual program experience."

3. Address problems associated with "market timing." Related to the above, luck and timing often combine to define transition potential. Transition can go wrong (or right) through no fault of the program manager or the product. When this happens, and if the product in question has good potential, DARPA should sometimes stay in the game and continue to try to transition it when the timing is better, even after program completion. For a product that the Agency has spent a good deal of its time and money to develop, its transition into use is vitally important, whether it occurs immediately upon completion of the DARPA program or four years from then. However, DARPA has no mechanism to accomplish this.[38] A number of ways to approach the task of continuing to influence a product's destiny after releasing it have been suggested.

One is to appoint a special office or person within DARPA to facilitate transition. This has an appeal in that it centralizes the responsibility for all "late transitions." In discussing the problem of transition with Chief Technology Officers in industry, Dr. H. Lee Buchanan, formerly a Deputy Director of DARPA and then the Assistant Secretary of the Navy, told us that nearly all had appointed a transition facilitator. Havelock and Bushnell also suggested a technology transfer facilitator be appointed ([20], p. 8). The problem is that a transition czar tends to remove responsibility from those who are more knowledgeable about the product. Like the Prototype Office that enjoyed a brief life at DARPA, these special "process-niche" organizations lack this important ingredient to selling a product. Hundley recommended a "half-way house" for transitioning DARPA's products ([4], p. 44), but this suffers from the same difficulties as the facilitator or office idea.

Another alternative is to form an advisory board from the Services, OSD, and industry to help in planning and implementing transitions. NSIA ([18], p. 9) suggested that such an advisory board could review large technology demonstrations, and help to shape and transition them.

Finally, the Agency could simply delegate the transition responsibility for each program in this category to the best product champion, whether industry, a Service agent, or a DARPA systems office. A small amount of funding would be available from DARPA to carry out this function. The advantage of this option is that the transition responsibility would be vested in the best organization and person to do the job. The downside is that this is an ad hoc process that would consume the time of DARPA and office directors.

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[38] DARPA has established a "DARPA Legacy" page on its website. This is a good step, but it does not affect products that did not make it into the military.

4. Ensure sufficient technological maturity of products. Product demonstration is vital to transition because it helps to ensure product maturity and visibility. DARPA has prototyped and demonstrated its products for years, demonstrating technologies, components, and systems to customers who were sometimes very skeptical. It is clear from Table A-1 that the approach has paid off. An interesting idea is to transition the program to the Services (or under joint DARPA/Service management) for the prototype testing stage. This was done in the stealth programs, where, in the words of NSIA ([18], p. 24) "technology push" is turned into "requirements pull."

Aided by the Agency's demand for demonstration, those products that successfully transitioned are surprisingly mature.[39] But, many Agency customers have complained that DARPA tends to quit too early, well before a technology is ready to be incorporated into a military system. This failure, on the part of DoD in general was the subject of a recent GAO study [30], where the Office claimed that, "problems with the [immature] technologies were a main contributor to an 88 percent cost growth and a 62 percent slip in schedule [for the Brilliant Anti-armor Submunition]"—a program fed by DARPA technologies. On the other hand, the same report praised the Agency for its non-penetrating periscope technology, which left the Agency at a TRL of 9, and was incorporated on the Virginia-class attack submarine.

The GAO report suggests that technological maturation should be the responsibility of the S&T organization, rather than being left to the program office that takes it over for integration. DARPA's technology offices may elect not to spend that much time on a technology, but they can transition it to a Service laboratory or continue working on it in one of their systems offices. At any rate, agreement should be reached on the TRL category (or perhaps by a grouping of the nine TRLs, similar to that used in this report) for each product leaving the Agency.

5. Take advantage of new avenues into the Military Services. A number of studies have suggested that DARPA's rapport with their military customers was poor. For example, the NSIA study ([18], pp. 7-9, 14) indicated what even when the Agency connects with the Services it is accomplished too late in the program to be of much assistance. Their panel felt that "an increase in awareness and sensitivity to the Services needs and problems need not destroy DARPA's essential free thinking... The panel concluded that a principal driver of a successful transition is a close supplier/user relationship (DARPA/Service) that is promoted and encouraged throughout the life cycle of a given technology opportunity, namely from selection through transition." In the past, many DARPA programs used formal joint program structures to bind them to the candidate Service customer. This works well for large programs, but is probably too cumbersome for smaller efforts.

Havelock and Bushnell ([20], p. 4) cited some mechanisms that work well to engage the Services in DARPA's work, such as using Service contracting agents, employing military units as test beds for DARPA demonstrations, and recruiting military personnel to serve on the Agency's staff. However, perhaps the best additional opportunities today, are to be found in the new avenues constructed by the DoD to encourage transition.

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[39] It would be interesting to determine the effects of not demonstrating products on transition success or failure by examining that subset of DARPA programs that did not involve a prototype of demonstration.

These avenues, discussed in Chapter III, include warfighting laboratories, the Joint Forces Command, the Navy's Chief Technology Officer, as well as the ATDs, ACTDs, and DUS&T. DARPA should expand and exploit all of these, and make program managers aware of their potential through the program manager course recommended earlier.

6. **Overcome PPBS-based funding obstacles.** Although we did not have the time and resources to exploit this aspect of DARPA's environment, it is an obvious impediment to transition, in that the funding cycle seldom allows the flexibility necessary to support DARPA's swashbuckling style.[40] Moreover, the famous gap between development and application is often the death knell for technologies that are washed out of the system because they have found no place in the five-year POM cycle.

In the 1991 New Start case study interviews, many program managers remarked that it could take up to a year to solicit proposals, select one, and then negotiate a contract. This is a lifetime for a small start-up company and an entire year out of a program manager's four-year duty at DARPA. During the interviews, the observation was made that bureaucratic requirements need to be streamlined and aligned with the time allotted for a program manager's term at DARPA. Some suggested goals included shortening the proposal process and easing deadlines for money obligation. Under current budget processes, funds are appropriated annually and if their commitment and obligation rates have not been met, the following years budget may be reduced accordingly. This causes undue problems for a DARPA program manager who does not have the ability to change direction quickly and is often locked into a mixed message—slow down for competition sake but speed up for budget purposes. Solutions to this set of problems desperately need addressing, particularly since they are exacerbated by currently low procurement budgets.

7. **Solve problems associated with DARPA's willingness to fail versus Services risk-aversion.** This probably cannot be overcome easily, without disrupting an important balance between the Agency and the Services. DARPA should take technological and even conceptual risks, because no one else is likely to do so. On the other hand, the Services must ensure maturity of both concept and technology to maintain reasonably stable major systems development programs and to provide the warfighter with proven technology. So, if manageable, perhaps this tension between the Services and DARPA works to DoD's advantage. But, it may be helpful to more clearly define standards of transition success, so that the Services know what to expect.

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[40] This is often worsened by Congressional admonitions against new starts that have not been thoroughly reviewed and approved by their staffs.

Appendix A. Listing and Rating of DARPA Transitions

This is a list of technologies and systems that were extensively supported by DARPA. The table includes the program or product title, some remarks about the adoption of the products delivered under the program, the Military Service(s) using the product, and a subjective index indicating the level of impact on the using Service(s). The Impact index was assigned by the Institute, using the following guidelines:

- Significant Impact means the product was successfully transitioned (1).
- Very significant Impact was used to indicate widespread or important application of the product, such as the Marine Corps' Predator missile (2).
- Disruptive Impact was reserved for DARPA contributions that dramatically changed the way the Service operates (3).

TABLE A-1 DARPA TRANSITIONS

Product or Program Name	Remarks	Service	Impact
1. ADA Programming language	Adopted as DoD's primary language for developing mission-critical software systems, 1980s—[21]	Multiple	1
2. Advanced Air Load Phasing System	Software development reduced planning the loading and balancing of the C-141 for Bosnia missions from 6 days to 2 hours, 1980s—[21]	AF	1
3. Advanced Command and Control Architectural Testbed (ACCAT)	Applied AI, computer, and networking technologies to military command and control. Developed the ACCAT facility at NOSC in order to contribute to wargames. ACCAT included prototype mobile remote terminals linked by satellite by a secure subnet of ARPANET, 1970s—[3]	Multiple	1
4. Advanced Medium Range Air-To-Air Missile (AMRAAM)	AF missile currently in use, 1970s—[21]	AF	2
5. Advanced Pictorial Archiving Communications System	Demonstrated up to $2 million savings in hospitals with 250 radiological exams per day. Being used in almost all DoD hospitals with digital imaging capability 1990s—[19]	Multiple	1
6. Affordable Short Takeoff Vertical Landing (STOVL)	Transitioned to Joint Strike Fighter Program, 1990s—[21]	AF	1
7. Affordable Tooling For Rapid Prototyping	Led to the demonstration and validation of parameters of metal arc spray tooling process used in C-17 leading-edge fairing and other applications, 1990s—[21]	AF	2

8. Aircraft Undersea Sound Experiments	Contributed to development of automatic aircraft detection algorithms integrated within the submarine sonar processing system, 1970s—[21]	Navy	2
9. Aluminum/Lithium Alloy	Used in the Titan, the AF primary rocket booster, this alloy yielded a ten percent weight reduction and an $8 million cost reduction, 1970s—[21]	AF	2
10. Analog Optoelectronic Module	Inserted into the Integrated Defensive Electronic Countermeasures system, 1990s—[19]	Multiple	2
11. Antenna Booms	DARPA designs used extensively, including the Hubble Telescope, 1980s—[21]	AF (Space)	1
12. Army Tactical Missile Systems (ATACMS)	Army's long range surface to surface artillery rocket, 1970s—[21]	Army	3
13. ARPA Maui Optical Station: AMOS Facility	Operational measurement and R&D in space object identification, 1970s—[3, 10, 21]	AF	1
14. ARPI	During the mid-1990s, DARPA funding and the innovative researchers it supported advanced the state-of-the-science in the areas of knowledge-based scheduling, control of planning systems, and human-machine interactions. Compiling knowledge derived from domain theories led to automatically-generated schedulers capable of 400X speedups for domains studied. Products included Dynamic Analysis and Replanning system (DART), used by U.S. TRANSCOM during the first weeks of Operation Desert Storm, which moved tanks and heavy artillery from Europe into Saudi Arabia at least three weeks faster than would otherwise have been possible. In 1992, A Department of Commerce study credited the $4 million DART with having saved more during the war than the total U.S. Government investment in artificial intelligence research to date.	Multiple	1
15. Artificial Intelligence	DARPA can be credited with a significant role in the growth of AI, which has yielded automatic speech recognition and image understanding algorithms that have benefited both the civilian and military worlds, 1980s— [3]	Multiple	2
16. Asynchronous Transfer Mode (ATM)	Resulted in widespread adoption of ATM technology. Also established a Synchronous Optical Network prototype, 1960s—[21]	Multiple	2
17. Battery Technology	Materials and manufacturing technologies for li ion battery development—Batteries for military hybrid electric vehicles, aircraft, TOW missile control system, Land Warrior systems, advanced Seal delivery system, 1990s—[19]	Multiple	2
18. Bearings; Precision, High Performance Ceramic	Used in gyroscopes for the F-18, AV-16, F-16, various helicopters, and IR seeker bearing for Navy standard missile and AF Sparrow missile, 1990s—[91CS, 21][41]	Multiple	1
19. Body Armor	Improved troop protection through ceramics, procured by SOCOM, 1980s—[21]	Army	1
20. Bosnia C3 Augmentation System	C3 capabilities in Bosnia, 1990s—[21]	Army	1

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[41] [91CS] refers to the FY 1991 New Starts Case Studies.

21. Brilliant Anti-Tank (BAT) Munition	Army acoustic sensor/terminal guidance submunition, 1990s—[21]	Army	2
22. Camp Sentinel Radar	Ground surveillance radars, 1960s—[3, 10, 21]	Army	1
23. Centaur Program	Upper stage engines for Atlas and Titan booster stages, 1950s—[3, 21]	AF (Space)	2
24. Ceramic Materials For Armor (LAST®, Aircraft)	Insertion of ceramic armor using unique application technology on USMC LAVs, aircraft, 1990s—[21]	Multiple	1
25. Comanche Ann-Based ATR	Longbow Automatic Target Recognition using wavelet technology and neural networks, 1990s—[21]	Army	2
26. Composite Materials for Aircraft	Fan and doors for the C-17—transitioned to the Joint Strike Fighter, 1990s—[19]	Air Force	1
27. Computer Aided Design (CAD)	Largely responsible for development of the CAD industry, 1970s—[21]	Multiple	2
28. Computer Workstation	Mouse, industry standard graphic user interface, scalable parallel computer architecture, 1970s—[21]	Multiple	3
29. Consortia for All Optical Network Technology	Developed components for all-optical communications network, now being used in the Internet and other military-useful systems, 1990s—[1991 CS]	Multiple	2
30. Consortia for Optoelectronic Interconnection	Honeywell's laser emitter device called the Vertical Cavity Surface Emitting Laser (VCSEL) is regarded as the "transistor" of optoelectronic, the gigabit Internet industry's standard. Currently also used in military helicopters, ships and other platform for C4ISR, 1990s—[1991 CS]	Multiple	2
31. Copperhead	Semi-active laser guided artillery round in Army's inventory, 1980s—[21]	Army	2
32. Defender Project	Foundation for BMD, early 1960s—[21]	AF	2
33. Diffractive Optics	200 eyepieces delivered to "Land Warrior" Program. Scatter codes developed in this project have been incorporated into the FLIR system being developed for the A2GF helicopter and are under evaluation for the LRAS3 System, 1990s—[19]	Army	2
34. Endurance Unmanned Air Vehicles	Amber led to the Gnat and the AF-operated Tier 2 Predator, 1990s—[21]	AF	2
35. Engine Ceramic Parts	Advanced Ceramics Technology Insertion Program transitioned several ceramic nozzles, insulators, bearings, and contact wear surfaces. Used in M-109 Howitzer, M998 Ammo Carrier, and C-130H ground support APU engines, 1990s—[1991 CS, 21, 24]	Multiple	1
36. Enhanced Armor For LAV (LAST®)	65 kits were mounted on USMC LAVs, 1990s—[21]	USMC	1
37. Enhanced Survivability For HMMWV	The HMMWV was armored through a DARPA program to protect from enemy fires and mines. Used in Somalia and Bosnia, 1990s—[21]	Army	1
38. Explosive Forming	A manufacturing process used on the SR-71 afterburner rings and other applications, 1970s—[21, 24]	AF	2
39. Extended Long-Range Integrated Technology Experiment (ELITE)	ELITE pioneered the development of Carbon-carbon technologies for higher temperature engines for AF turbines, 1980s—[21]	AF	2

40. F-1 Engine	Powered the SATURN V Booster, 1960s—[21]	AF (Space)	2
41. Federal High Peformance Computing and Communication (HPCC)	Developed numerous computational and communications products and technologies that have been incorporated in military systems or by the military as dual use, 1990s—[1991 CS]	Multiple	2
42. Fore Systems, Inc.	Supplier of Advanced Network Systems for DARPA, DISA's DSN Leading Edge Service, 1980s—[21]	Multiple	2
43. Gallium Arsenide	Insertion into digital signal processors (DSP) to improve the resolution of the ISAR on the P-3 Orion, 1970s—[21]	Multiple	2
44. Hand-Emplaced Wide Area Munition	DARPA contributed the C3 technology for the Army's Wide Area Mine (WAM), 1990s—[21]	Army	1
45. Head Mounted Displays	Family of displays being integrated into Army's Land Warrior and Generation II Soldier programs, 1990s—[21]	Multiple	2
46. High Definition Systems	Most projection systems use mirror devices developed by TI under this program. Helmet mounted display program began as a result of this effort. The Army is using Eagle-5M display for he AH-64 Apache Attack Helicopter and is evaluating others for an M1A2 Tank upgrade, 1990s—[1991 CS]	Multiple	2
47. HiPer D: Processor interconnection Project	Distributed computational architectures and systems for shipboard computing/local area network. The high performance computing demonstrated in HiPer-D is being incorporated into naval shipboard platforms, and is having significant impact on next generation AEGIS Weapons System, 1990s—[21]	Navy	1
48. Hydrodynamic/Hydroacoustic Technology Center	Facility for acoustic research transferred to Naval Surface Warfare Center, 1990s—[21]	Navy	1
49. Hypervelocity Technologies	A large research effort yielded fundamental and practical information on hypervelocity flight and penetration—transferred to the Army Research Laboratory, 1990s—[21]	Army	2
50. Infrared Focal Plane Arrays	PtSi material has proven more affordable and maintenance-free than its predecessor, HgCdTe. Used on B-52 camera, for cost savings of $10 million per year, 1980s—[24]	AF	1
51. Infrared Materials Producibility (Crystal Growth)	Service Labs tested/evaluated Industry components and carried thru to production, 1990s—[1991 CS]	Multiple	1
52. Infrared Optics Materials	Advanced optics materials and coating techniques for IR application on Pave Tack, LANTIRN, and F-18 FLIR, 1970s—[24]	AF	1
53. Integrated Circuit reliability, processing, and Automation Advancement	Building-in, rather than testing-in reliability, through processes developed under DARPA funding have saved millions of dollars per year for the Trident missile and other programs, 1970s—[24]	Multiple	1
54. Integrated Optoelectronic Modules	6000 fiber optic gyros inserted into the Bradley Fighting Vehicle over the next five years (more than 300 sold thus far), 1990s—[1991 CS, 19]	Army	2
55. Internet/Milnet	ARPANET formed the basis for the Internet, 1970s—[21]	Multiple	3

56. Javelin	Army's primary anti-tank missile, 1980s—[21]	Army	2
57. Joint Stars	Assault Breaker Program developed technology for the AF Joint Stars system, 1980s—[21]	AF	2
58. LEGOS: Object-based Software Components for Mission-Critical Systems	This capability to reuse software is in use at 400 sites, including the Air Force Phillips Laboratories, the Naval Sea Command, the Naval Ordinance for an ordinance management system, Rome Laboratories in their Imaging Laboratory, and DoD systems houses such as TRW and Lockheed. TRW uses it in their Nuclear Readiness Management System, 1990s—[19]	Multiple	2
59. Low Probability Of Intercept (LPI) Airborne Radar	LPI radar technology was transitioned to the B-2 Bomber, 1980s—[21]	AF	2
60. M16 Assault Rifle	Originated as DARPA-supported AR-15, 1960s—[3, 21]	Army	2
61. Mark 50 Torpedo Propulsion System	Currently serving as the power plant for the Navy's Mk 50 torpedo, 1970s—[21]	Navy	2
62. Massively Parallel Systems	DoD parallel computers, 1980s—[21]	Multiple	2
63. MELIOS Improvement	These improvements added precise location of targets and rapid reporting from the field, 1990s—[21]	Army	1
64. Metal Matrix Composites	Now part of the F-22 program, 1990s—[21]	AF	1
65. Microelectronic Mechanical Systems (MEMS)	DARPA initiated development and application of MEMS into an array of systems, including IMUs for personal navigation and miniature instruments, 1990s—[21]	Multiple	2
66. Meteorological Satellite Program (TIROS)	Transferred to NASA in 1959, 1950s—[3, 21]	Space	2
67. Microwave and Millimeter Wave Monolithic Integrated Circuits Technology (MIMIC)	Made possible numerous military systems within cost, volume, and power constraints, 1980s—[21]	Multiple	2
68. MIRACL Anti-Ballistic Missile Defense	Basis for several developmental laser systems, including the AF Air Borne Laser, 1970s—[21]	AF	2
69. Multicast Technology	DoD is leading user for advanced distributed simulation, collaboration, C^2—RSVP is the industry standard, used by DISA, 1970s—[21]	Multiple	2
70. National Astronomy And Ionospheric Center	Part of the Defender Project, 1960s—[21]	AF (Space)	2
71. No Tail Rotor For Single Rotor Helicopters (NOTAR)	NOTAR produced the world's quietest helicopters and is incorporated in three new McDonnell Douglas helicopters, MD 520N, MD 600N, MD 900, 1980s—[21]	Army	2
72. Non-Penetrating Periscope	Using fiber optic technology this effort greatly reduced visibility of submarine periscopes Navy has demonstrated the technology and continues to improve on it, 1990s—[21]	Navy	1
73. Nuclear Monitoring Seismology Technology	Remains an integral part of U.S. Atomic Energy Detection System, 1970s—[21]	AF (Space)	2
74. Pegasus-Air-Launched Vehicle Program	This air-launched vehicle provided a quick response, low-cost launch of tactical satellites and was	AF	2

	transferred to the AF, 1993—[21]		
75. Phased Array Radars (ESAR)	DARPA program called Electronically Steered Array Radar pioneered construction of large ground-based phased array radars, such as the FPS-85, 1960s—[3, 21]	AF	3
76. Pilot's Associate Program	Developed techniques for pilot's situational awareness. Made part of F-22 program, 1980s—[21]	AF	2
77. Precision Emitter Location	Currently fielded in Army Communications High-Accuracy Airborne System on the Guardrail aircraft, 1980s—[21]	Army	2
78. Predator Missile	USMC's shoulder-fired anti-tank munitions, 1990s—[21]	USMC	2
79. Predator UAV (Amber, Condor)	UAV saw action in Desert Storm, 1980s—[10, 21]	Multiple	2
80. Praeirie, Calere UAVs	Vietnam era UAVs, 1970s—[10, 21]	Multiple	2
81. Pyrotechnic Devices and Laser Igniter	Product improvement for Army artillery systems—Paladin (850 units) and Crusader (1,100 units) (over 10,000 LIS ignited rounds have been fired), 1990s—[19]	Army	1
82. High Performance Fortran	Programming language, 1980s—[21]	Multiple	2
83. Rapid Solidification Rate Materials Technology	Materials technologies For The F-15 and F-16 for high temperature resistance, 1980s—[21]	AF	2
84. Rare Earth Magnets	Applications include high performance TWTs used on the F-15 and the Navy EHF SATCOM program and in cryocoolers for IR sensors on the Cobra helicopter and the F-18, 1970s—[24]	Multiple	1
85. Reduced Instruction Set Computing	Microprocessor performance/cost gains, 1980s—[21]	Multiple	2
86. Redundant Aray of Inexpensive Devices	Input/Output system architecture, 1980s—[21]	Multiple	2
87. Relocatable Over The Horizon Radar (ROTHR)	Basis for at least three DoD radar systems in operation, 1960s—[3, 21]	Navy AF	2
88. Retirement for Cause (RFC)	Combined nondestructive testing, probabilistic fracture mechanics, logistics, and economics to predict failure—now used by DARPA's partner in the effort, the AF, 1980s—[21]	AF	2
89. Satellite Navigation System	Served Navy for 28 years, until replaced recently by GPS, 1960s—[21]	Navy	2
90. Schottky IR Imager For The B-52	Use of Schottky barriers on standard integrated circuit-grade silicon enabled practical fabrication of large 2D arrays of IR-sensitive detectors. Incorporated into B-52, 1990s—[21]	AF	2
91. Sea Shadow	Prototype of signature control technologies integrated into a surface ship, 1980s—[21]	Navy	2
92. SEI Capability Maturity Models (CMM)	CMM enables software development organization to determine its ability to develop software—used in many companies furnishing DoD with software, 1980—[21]	Multiple	2
93. SEMATECH	Associations of semiconductor industries to conduct precompetitive technology development—contributed greatly to DoD products, 1980s—[21]	Multiple	2
94. Sensor-Fuzed Weapon	Entered AF inventory, 1994—[21]	AF	2
95. Shaped Charge Warheads	Warheads for TOW, Javelin, 1990s—[21]	Army	2

96. Signal Processing Technologies For The OH-58D	OH-58D upgrade features DARPA-developed signal processing technology, 1990s—[21]	Army	1
97. Silicon Graphics, Inc.	Provider of systems for defense & Intelligence Formed around DARPA projects and has supported DoD computing contracts, since 1980s—[21]	Multiple	2
98. SIMNET	SIMNET spawned many variants of trainers for all services using distributed simulation, 1980s—[21]	Multiple	3
99. Simulators/Computer Graphics	DARPA developed graphics algorithms over a 20-year period—these graphics systems have been used extensively for DoD programs, 1970s—[21]	Multiple	2
100. Software for "Virtual Enterprises"	These software protocols enable globally competitive "Virtual Enterprises" used on DoD programs by Electric Boat Corp. and Lockheed Martin to save $20.5 million per ship and $700,000 per F-22 respectively. Projected life cycle costs on the Joint Strike Fighter program would amount to $3 billion, 1990s—[19]	Multiple	2
101. Soldier 911	An emergency notification system for soldiers who have been injured—monitors soldier's position and emits a warning upon entering a prohibited area. Used in Macedonia and Korea to avoid U.S. intrusion across sensitive borders, 1990s—[21]	Army	2
102. SONET OC-192 and ATM Self-Healing Ring	Leased from commercial sector by DoD (NSA and DISA) for high traffic route data flow transmission, 1990s—[19]	Multiple	2
103. SPEAKeasy Advanced Technology Tactical Radio	Developed the architecture for the ongoing Joint Tactical Radio System Developmental Program and DARPA's Airborne Communications Node (ACN) program, 1990s—[1991 CS, 21]	Multiple	1
104. Sprint	DARPA's HIBEX program developed high specific impulse solid propellants that made this and follow-on terminal intercept missiles possible, 1960s—[21]	Army	2
105. Stealth	Tacit Blue led to B-2 Bomber, Have Blue led to F-117, 1980s—[21]	AF	3
106. Sun Microsystems, Inc.	Workstations, etc. ($950 million in 1996 in DoD), 1990s—[21]	Multiple	2
107. Superconducting Electronics Consortium/HTS	Consortium was in early stage of a successful 15-year materials technology R&D to fielded product cycle, 1990s—[1991 CS]	Multiple	1
108. Surveillance Aircraft	DARPA supported the development of the Lockheed X-26B surveillance aircraft, used in Vietnam. Later, this provided the baseline for the YO-3A, also used in Vietnam, 1960s—[3]		1
109. Surveillance Towed Array Sensor System	Towed undersea surveillance capability has been in service with the Navy, 1980s—[10]	Navy	2
110. Synthetic Forces Development	The ModSAF program to produce computer generated forces (CGF). ModSAF and its derivatives are being used in hundreds of laboratories and form the basis for several Service battle experiment enterprises—four conferences are devoted to CGF per year, 1990s	Multiple	2
111. Taurus Launch Vehicle	A four stage small standard launch vehicle (SSLV) launched payloads, 1990s—[10]	AF	2
112. TCP/IP	Interoperability across networks, 1980s—[10]	Multiple	2

113. Teal Dawn Cruise Missile	Precursor to AF Advanced Cruise Missile, 1980s—[10, 21]	AF	2
114. Tethered Aerostat Radar System	Used for several MTI and communications systems operated by the AF, 1970s—[10]	AF	1
115. Tomahawk Cruise Missile Engines	Adapted DARPA's Rocket Belt engine to the power the Tomahawk, 1960s—[10]	Navy	2
116. Transit Navigation Satellite	The world's first global satellite navigation system. Transit provided positioning for the Navy's Polaris strategic submarines and other ships, since the mid-1960s—[3]	Navy	2
117. Uncooled IR Sensors	Affordable, effective IR sensors without cryogenics for driving ISR, 1990s—[10]	Army	2
118. UNIX	An operating system used extensively by the military, 1970s—[10]	Multiple	2
119. Unmanned Undersea Vehicle (UUV)	Part of the Navy Joint Mine Countermeasures ACTD, 1990s—[10]	Navy	1
120. Vela Satellites	Early satellites, late 1950s—[3, 10]	Multiple	2
121. Very Large-Scale Integration (VLSI) Fabrication	Virtual prototyping techniques, and Metal Oxide Semiconductor Implementation Service, 1980s—[10]	Multiple	2
122. Voice Recognition Systems (Dragon)	Used in Bosnia, 1990s—[10]	Multiple	1
123. X-31 Aircraft	Demonstration aircraft to demonstrate feasibility of post stallflight and used in Joint Strike Fighter Program, 1990s—[10]	AF	1
124. X-ROD	Guided armor penetrator rod, 1990s—[10]	Army	1

TABLE A-2 DARPA 1990S TRANSITIONS

	DARPA PRODUCT			FINAL PRODUCT		
Product or Program Name	**Scale of Program**	**Maturity** (See definitions in Chapter I.E.2)	**Transition Path/Strategies** (See definitions in Chapter II.A and E)	**Disposition** (See definitions in Chapter I.E.4)	**Impact** (See definitions in Chapter I.E.5)	**Remarks**
	Small (<$100M) or Large (>$100 M)	1-5, or 6-9	DSA, DIS, or DS&T/ TP, CP, DU	Fielded System, Sub-system, Component, or Technology or Major Developmental Program System, Sub-System, Component, or Technology	Significant (1), Very Significant (2), or Disruptive (3)	
1. Advanced Pictorial Archiving Communications System	Small	6-9	DIS/TP, DU	Fielded System	1	Biomedical
2. Affordable Short Takeoff Vertical Landing (STOVL)	Large	1-5	DS&T/CP	Developmental Program System	1	AF
3. Affordable Tooling For Rapid Prototyping	Small	6-9	DIS/TP	Fielded System	2	Materials
4. Analog Optoelectronic Module	Small	6-9	DIS/TP, DU	Fielded Component(s)	2	IT
5. ARPA/Rome Planning Initiative (ARPI)	Small	6-9	DSA/CP	Fielded Component(s)	1	Software
6. Battery Technology	Small	6-9	DIS/CP, DU	Fielded Component(s)	2	Materials
7. Bearings; Precision, High Performance Ceramic (ATIP)	Small	6-9	DSA/CP	Fielded Component(s)	1	Materials
8. Body Armor	Small	6-9	DSA/CP	Fielded Component(s)	1	Materials
9. Bosnia C3 Augmentation System	Small	6-9	DSA/CP	Fielded System	1	IT
10. Brilliant Anti-Tank (BAT) Munition	Large	6-9	DSA/CP	Fielded System	2	Army
11. Cermet Materials For Armor (LAST® and Aircraft)	Small	6-9	DSA/CP	Fielded Component(s)	1	Materials

12. Comanche Ann-Based ATR	Small	6-9	DSA/CP	Fielded Component(s)	2	software/Army
13. Composite Materials for Aircraft	Large	6-9	DSA/CP	Fielded Component(s)	1	Materials
14. Consortia for All Optical Network Technology	Small	6-9	DIS/TP, DU	Fielded Component(s)	2	IT
15. Consortia for Optoelectronic Interconnection	Small	6-9	DIS/TP, DU	Fielded Component(s)	2	IT
16. Diffractive Optics	Small	6-9	DSA/TP	Fielded Component(s)	2	Materials
17. Endurance Unmanned Air Vehicles	Large	6-9	DSA/CP	Fielded System	2	AF system
18. Engine Ceramic Parts (Advanced Ceramic Technology Insertion)	Small	6-9	DSA/CP	Fielded Component(s)	1	Materials
19. Enhanced Survivability For HMMWV	Large	6-9	DSA/CP	Fielded Component(s)	1	Materials/Army
20. Federal High Performance Computing and Communication (HPCC)	Large	6-9	DIS/TP, DU	Fielded Component(s)	2	IT
21. Hand-Emplaced Wide Area Munition	Small	6-9	DS&T/CP	Fielded Component(s)	1	Army
22. Head Mounted Displays	Small	6-9	DSA/CP	Fielded Component(s)	2	Display
23. High Definition Systems	Small	6-9	DIS/CP	Fielded Component(s)	2	Display
24. HiPer-D: Processor interconnection	Small	6-9	DS&T/CP	Major Developmental System	1	Software
25. Hydrodynamic/Hydroacoustic Technology Center	Large	6-9	DS&T/CP	Fielded System (Facility)	1	Navy
26. Infrared Materials Producibility (Crystal Growth)	Small	6-9	DSA/CP	Fielded Component(s)	1	Electronic Materials
27. Integrated Optoelectronic Modules	Small	6-9	DIS/TP, DU	Fielded Component(s)	2	IT
28. LEGOS: Object-based Software Components for Mission-Critical Systems	Small	6-9	DIS/CP, DU	Fielded Component(s)	2	Software
29. MELIOS Improvement	Small	6-9	DSA/CP	Fielded System	1	Display
30. Metal Matrix Composites	Small	1-5	DSA/TP	Fielded Component(s)	1	Materials/Army
31. Microelectronic Mechanical Systems (MEMS)	Small	1-5	DIS/TP, DU	Fielded Component(s)	2	Micro-Electronics

32. Non-Penetrating Periscope	Large	6-9	DSA/CP	Fielded Component	1	Navy
33. Pegasus-Air-Launched Vehicle Program	Large	6-9	DSA/CP	Fielded System	2	AF
34. Predator Missile	Large	6-9	DSA/CP	Fielded System	2	USMC
35. Pyrotechnic Devices and Laser Igniter	Small	6-9	DIS/CP, DU	Fielded Component(s)	1	Materials/Army
36. Schottky IR Imager (B-52)	Small	6-9	DSA/CP	Fielded Component(s)	2	AF
37. Sensor-Fuzed Weapon	Large	6-9	DSA/CP	Fielded System	2	AF
38. Shaped Charge Warheads	Small	6-9	DSA/CP	Fielded Component(s)	2	Materials/Army
39. Signal Processing Technologies For The OH-58D	Small	6-9	DSA/CP	Fielded Component(s)	1	Software/Army
40. Software for "Virtual Enterprises"	Small	6-9	DIS/TP, DU	Fielded Component(s)	2	Software
41. Soldier 911	Small	6-9	DSA/CP	Fielded System	2	Display/Army
42. SONET OC-192 and ATM Self-Healing Ring	Small	6-9	DIS/CP, DU	Fielded Component(s)	2	IT
43. SPEAKeasy Advanced Tactical Radio	Small	1-5	DS&T/CP	Major Developmental Program system	1	IT
44. Superconducting Electronics Consortium/HTS	Large	6-9	DSA/TP	Fielded Components	1	Super-conducting Components
45. Synthetic Forces Development	Small	6-9	DSA/CP	Fielded Component(s)	2	Software, Simulation
46. Taurus Launch Vehicle	Large	6-9	DSA/CP	Fielded System	2	AF
47. Uncooled IR Sensors	Large	6-9	DIS/CP, DU	Fielded System	2	Multiple Service
48. Unmanned Undersea Vehicle (UUV)	Large	6-9	DSA/CP	Major Developmental Program system	1	Navy
49. Voice Recognition Systems (Dragon)	Small	6-9	DSA/CP	Fielded Component(s)	1	Software
50. X-31 Aircraft	Large	1-5	DSA/TP	Major Developmental Program system	1	AF

TABLE A-2A SUMMARY OF CHARACTERISTICS OF 1990S TRANSITIONS

	DARPA PRODUCT				FINAL PRODUCT			
TRANSITION	SCALE		MATURITY		DISPOSITION		IMPACT	
PATHS	Small	Large	1-5: POP-to-Breadboard Validation	6-9: Prototype-to-Mission Validation	System	Technology, Component, or Subsystem	Significant	Very Significant
DSA—30 (60%)	18 (60%)	12 (40%)	3 (10%)	27 (90%)	8 (27%)	22 (73%)	17 (57%)	13 (43%)
DIS—15 (30%)	13 (87%)	2 (13%)	1 (7%)	14 (93%)	3 (20%)	12 (80%)	2 (13%)	13 (87%)
DS&T—5 (10%)	3 (60%)	2 (40%)	2 (40%)	3 (60%)	2 (40%)	3 (60%)	5 (100%)	0
TOTAL—50	34 (68%)	16 (32%)	6 (12%)	44 (88%)	13 (26%)	37 (74%)	24 (48%)	26 (52%)

TABLE A-3 DARPA FY 1991 NEW START TRANSITIONS (SEE APPENDIX E FOR CASE STUDIES)

	DARPA Product			FINAL PRODUCT		
Product	**Scale of Program**	**Maturity**	**Transition Path/ Strategies**	**Final Product**	**Impact**	**Remarks**
1. Advanced Biochemical Technology						Three small efforts initiated within larger program. Lacked Service support.
2. Advanced Ceramic Technology Insertion Program (ACTIP) (Insertion)	Small	6-9	DSA/CP	Fielded Component(s)	1	Goal was to speed up transition of materials into fielded systems. Three of 14 fielded to date.
3. Advanced SRAM Consortium Technology (Consortia)						Fifty/fifty cost share program in which the technology, which is now obsolete, transitioned to the commercial sector, but not the Services.
4. (D)ARPA/Rome Planning Initiative (ARPI)/Planning & Decision Aids Program (Insertion)	Small	6-9	DSA/CP	Fielded Component(s)	1	Goal to accelerate transition—first three efforts resulted in two leave behind proto-types to customer and one insertion into system program.
5. Bearings, Ceramics Technology (Insertion)	Small	6-9	DSA/CP	Fielded Component(s)	1	Success partly based on relationship to ACTIP.
6. Consortia for All-Optical Network Technology (Consortia)	Small	6-9	DIS/TP, DU	Fielded Component(s)	2	DARPA/Industry Consortium.
7. Consortia for Optoelectronic Interconnection (Consortia)	Small	6-9	DIS/TP, DU	Fielded Component(s)	2	DARPA/Industry Consortium—Services are continuing to pursue advanced technology.
8. Diamond Manufacturing Pilot Line (Insertion)						Insertion program to improve process and lower cost of sub-components. Problems included sponsorship, attention span to new technologies, marketing.

9. Federal HPCC: Networking	Large	6-9	DIS/TP, DU	Fielded Component(s)	2	The Networking Systems program within the Federal HPCC initiative at DARPA was one of four HPC programs. The technology is pervasive throughout industry and used by the military in commercial applications.
10. Fuel Cell Power System for UUV						Searching for system to replace existing batteries. Aluminum oxide approach terminated after six years.
11. High Definition System	Small	6-9	DIS/CP	Fielded Component(s)	2	The DARPA High Definition Systems program has the overall goal to meet the diverse, but specific DoD needs for information display.
12. HiPer-D (Insertion)	Small	6-9	DS&T/CP	Major Developmental Program Component(s)	1	The high performance computing demonstrated in HiPer-D is being incorporated into naval shipboard platforms, and is having significant impact on next generation AEGIS Weapons System.
13. Infrared Materials Producibility-Crystal Growth	Small	6-9	DSA/CP	Fielded Component(s)	1	Service Labs tested/evaluated Industry components and carried thru to production.
14. Laser Verification						Feasibility Study done at four national labs. Study proved technology wouldn't work.
15. LAST® Ceramic Armor	Small	6-9	DSA/CP	Fielded Component(s)	1	DARPA initiated, developed, and fielded within 90 days of SecDef request.
16. RF Vacuum Microelectronics						Transitioned to Service Labs in 1994/95. Difficult problem still being worked on by NRL.
17. Speakeasy Advanced Tactical Radio System	Small	1-5	DS&T/CP	Fielded Component(s)	1	Services were reluctant to do prototype—too costly. Industry pushed. OSD mandated use via 1997 Mgmt Implementation Plan for JTRS.
18. Superconducting Electronics Consortium/HTS (Consortia)	Large	6-9	DSA/TP	Fielded Component(s)	1	Consortium was in early stage of a successful 15-year materials technology R&D to fielded product cycle.

TABLE A-3A SUMMARY OF CHARACTERISTICS OF 1991 NEW START TRANSITIONS

	DARPA PRODUCT				FINAL PRODUCT			
TRANSITION	**SCALE**		**MATURITY**		**DISPOSITION**		**IMPACT**	
PATHS	**Small**	**Large**	**1-5: POP-to-Breadboard Validation**	**6-9: Mission-to-Mission Validation**	**System**	**Technology, Component, or Subsystem**	**Significant**	**Very Significant**
DSA—6 (50%)	5 (83%)	1 (17%)	0	6 (100%)	0	6 (100%)	6 (100%)	0
DIS—4 (33%)	3 (75%)	1 (25%)	0	4 (100%)	0	4 (100%)	0	4 (100%)
DS&T—2 (17%)	2 (100%)	0	1 (50%)	1 (50%)	0	2 (100%)	2 (100%)	0
TOTAL—12	10 (83%)	2 (17%)	1 (8%)	11 (92%)	0	12 (100%)	8 (67%)	4 (33%)

Appendix B. 1991 New Start Case Studies

(1) ADVANCED BIOCHEMICAL TECHNOLOGY

Background: In 1991, as part of an on-going program in Advanced Biochemical Technology, DARPA initiated three technology efforts in the far forward casualty care area. They were titled: Ultrasonic Immunomodulation with Georgetown University; Genetic Targeting with Gilead Sciences, Inc. and the Naval Medical Research Institute (NMRI); and Structure Based Drug Design with University of California-San Francisco. The combined expenditure for these three efforts was approximately $6 million over a two-year period.

Program Objectives: The objective of these three initiatives was to exploit innovative ways of approaching the development of generalizable methodologies that could be broadly applied to the prevention or treatment of diverse diseases of significant importance to the warfighter. This work did not focus on the disease state itself. In the Ultrasonic Immunomodulation area, DARPA hoped to elaborate a general strategy for identification of protective antigens and their large-scale production. Genetic Targeting focused on addressing infectious, disease-bearing micro-organisms directly on the genetic level. The Structure-Based Drug Design effort was aimed at the development of a cost-effective strategy for the discovery of lead compounds for protease inhibition.

Transition Status: None of the efforts received follow-on support by any Service. Reportedly, the Services indicated that if they decided to pursue any of the areas, they would do it themselves and not rely on DARPA. It's unknown if any of the Services did eventually pursue any of the issues. At the conclusion of the efforts, DARPA discontinued any further research in these areas.

Transition Plan/Path: No transitions plans were developed for these efforts.

General Comments: Although many attempts were made to obtain additional information on these efforts, we were not successful. This is a very abbreviated case study for that reason. We did substantiate that they did not successfully transition products.

(2) ADVANCED CERAMICS TECHNOLOGY INSERTION

Background: The Advanced Ceramics Technology Insertion Program (ACTIP) was initiated in the DARPA Defense Sciences Office/Materials Sciences Division (DSO/MSD) in 1991, and ran for approximately six years. Ceramics offer advantages in strength, elastic modulus, wear and corrosion resistance, reduced weight, and durability under extreme environments. Although work had begun in ceramic materials in the early 1970s and "ceramic fever" had spread throughout the world, by the late 1980s advanced ceramics were still not being inserted into fielded military systems. A former MSD Director, stated that it typically takes anywhere from 15 to 20 years to introduce a new material into a military system. In an attempt to accelerate the transition process for advanced ceramics, DARPA created ACTIP whereby they would help the Services take existing advanced ceramics technology from commercial off-the-shelf (COTS) and additionally help sponsor ways to get the technology inserted into their systems. The concept was patterned after the successful Gallium Arsenide (GaAs) Insertion Program that had been initiated in DSO/Electronic Sciences Division. ACTIP was not a normal DARPA program in that it was not designed as a research effort. Some research did occur, but it was primarily in the area of improvements to the existing ceramic material to provide form, fit, and function for successful system insertion. The Army, Navy, and Air Force supported the idea and in conjunction with DARPA, funded a number of advanced ceramics projects.

Program Goal and Objectives: The goal of the program was to demonstrate the system-level benefits that accrue from the reliability, durability, and performance of state-of-the-art structural ceramic components in order to increase the insertion rate of these materials into production military systems. The objectives were to: (a) improve performance and/or reduce repair and maintenance costs; (b) establish markets for domestic materials suppliers; and (c) stimulate the transition of technology to dual use and commercial applications. Projects were designed so that the relevant Service program offices could then undertake necessary qualification, additional testing, and procurement of the ceramics upgrade.

Transition Status: DARPA issued a BAA in 1991 and selected 16 projects from 65 proposals; however, of these, only ten received funding. An additional six projects were selected in 1994/95 timeframe, and four were funded. Fourteen projects, at a DARPA cost share of $17 million (the Services supplied over $5 million for testing, etc.), resulted from the solicitations (two Army, six each Navy and Air Force). Table B-1 describes the current status of the 14 projects. Projections indicate this program should end up with a 50 percent transition rate.

Project – Company	Sponsor Ofc	Status
Ceramic Hybrid Bearings for Navy Pumps - General Dynamics	NAVSEA	Being implemented in Seawolfs & 688 LA Class
Ceramic Hybrid Bearings for Air Cooling Turbines – AlliedSignal Aerospace	AFMC ACC	Preferred spare insertion underway F-15, C-130, F-111
Ceramic Bearings for IR Seekers - Raytheon	NAWC-CL	In production for Sparrow
Ceramic Wear Parts for Constant Drive - Sundstrand Aerospace	Navy, Pax River	Inserted commercially Pax River still testing
CMC Flameholder for F-110 Engine - GE Aircraft Engines	Norfolk NADEP, VA	Insertion planned F-110, F-100, F-129 F-400
Nozzle for Ground Power Cart Turbine - Garrett APD	ASC, Luke AFB	Insertion planned 4500 Ground Power Carts - APUs
Ceramic Diesel Engine Components - Detroit Diesel	TACOM, Paladin Program Office	After successful tests, Army stated they had no insertion opportunity
CMC Divergent Flap/Seal for F-110 - General Electric	OC-ALC, Hill AFB	Operational fleet tests F-110, F-100, F-129
Ceramic Hybrid Bearings for Harrier Roll Reaction Valves – MTI/ITB Bearings	Cherry Point NADEP, NC	Successful tests but Navy dropped project
Ceramic Face Seal for Engine Starter - Pratt & Whitney	OC-ALC, Hill AFB	Implemented in Commercial aircraft
Ceramic Hybrid Bearings for F-117 Engine - Pratt & Whitney	ASC, Luke AFB	Tests ongoing, FAA approved, P&W not pursuing
Ceramic 02 Generator - 5 Design Contractors	NAWC Warminster, PA & OC-ALC Hill AFB	Original prog. term. alternative ceramic oxygen generating system
CMC Fin for Missile - Loral/Vought	MICOM Huntsville, AL	Technical problems No insertion planned
Ceramic Piston Insulator, C-130 Landing Gear	OC-ALC, Hill AFB WL/FI WPAFB, OH	Flight tests completed promising candidates C-130, B-52, C-141

TABLE B-1

Transition Plan/Path: This program followed the DARPA-to-Service Acquisition (DSA) path. It was aimed at eliminating as many impediments as possible to ensure a timely transition. Among those impediments were the military specification requirements, the contracting process, and the budget process (dollars not available for production). The DARPA BAA required contractors to identify fielded systems or subsystems where insertion of ceramic components would improve mission effectiveness, reduce life cycle costs, or enhance overall mission readiness. In addition the BAA required the field activity, program office, or repair depot responsible for acquisition or support of the weapons system, be involved as both the contracting and technical agent for DARPA thereby ensuring endorsement of the proposal. And lastly, the contractors had to identify ceramic material suppliers who would participate as team members to address the design and manufacturing issues early on. DARPA funded the design, construction, and demonstration of the ACTIP component in the fielded system or subsystem. As identified above, the Military Services have funded testing and implementation (where noted), either as a preferred spare insertion or part of a block upgrade.

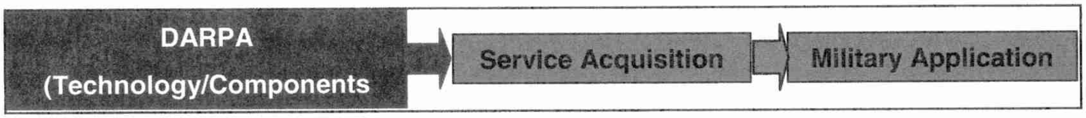

FIGURE B-1

General Comments: A paper entitled "Insertion of Ceramic Matrix Composites Into Future Military Systems—Lessons Learned" was presented in 1997 by Dr. Larry Fehrenbacher at the *Composites: Design for Performance* conference in Lake Louise, Canada, and published in the conference proceedings. Dr. Fahrenbacher is an expert in ceramics and was the DARPA technical advisor throughout the program. His paper provides background, approach, and recommendations based on lessons learned from the ACTIP program. His recommendations include doing an analysis of the contractor's incentive and asking the following questions: What is his defense market? Is he interested in new business or is he just interested in future R&D business? What is his commercial market, size of the spinoff market? Is he a market leader or a follower? What is his previous track record? All of these are good questions that should be asked when contemplating the transition path for any program. Although the paper is specific to the ACTIP, the lessons learned could be applicable to most other programs. While the paper does discuss and provide recommendations from the contractors end, unfortunately, it does not address problems encountered within the Military Services.

One of our interviewees stated that transition is an extremely intensive pursuit that takes a lot of extra effort and time on the part of the program manager. However, for a relatively low cost a champion can be to ensure that momentum continues both in the Services and in industry. ACTIP had a champion in the form of Dr. Fehrenbacher who offered to continue tracking and pushing the projects after DARPA completed their technology funding. But, DARPA believed that they had successfully transitioned the program to the Services, since the promising projects were already in testing phase, and that it was now up to the Services to ensure insertion.

This program seems to closely mirror a later insertion program. The Commercial Operations Support and Savings Initiative (COSSI) began at DARPA in 1997 as a joint-Service program. In 1999 it was transitioned to the Services for execution and implementation with OSD in an administrative oversight position. The Service-run portion of the COSSI program survived for only two years. This fall, all of the Services zeroed out their COSSI budgets for fiscal year 2001 and beyond. While an insertion approach to technology transition has many benefits, it appears to be too costly and time prohibitive for the Services to maintain momentum. The problems endemic to the ACTIP are still very much in existence today. There are many reasons, including timing (the technology readiness is not lined up with the budget availability), and priorities (many programs vie for the same dollars and priorities change).

(3) ADVANCED SRAM CONSORTIUM TECHNOLOGY

Background: SRAM (static random access memory) is memory that retains data bits as long as power is being supplied. Unlike dynamic RAM (DRAM), which stores bits in cells consisting of a capacitor and transistor, SRAM does not have to be periodically refreshed. SRAM provides faster access to data, but is more expensive than DRAM. SRAM is used for a computer's cache memory and as part of the RAM digital-to-analog converter on a video card.

Program Objectives: The objective of this program was to develop advanced SRAM for defense as well as commercial needs. The impetus came from the general need for microelectronics technology. This was a 50/50 cost share program.

Transition Status: Based on an interview with the DARPA program manager, the technology was successful, but has not transitioned into the military. Micron Technology transitioned the product that it developed into the commercial sector, but the program manager assumes the technology has now become obsolete. The program manager noted that a space satellite company intended to pick-up the technology for radiation hardened microcircuits for satellites, but is not sure whether the transition took place.

Transition Plan/Path: No transition plan was formulated for this program.

General Comments: The program manager believes that this program was successful, despite the lack of transition to the Services. He noted that the 50/50 cost share of the consortium worked well. There was an initial development product that worked, then a second product that the company did not want to pursue, and then a third product.

(4) PLANNING AND DECISION AIDS PROGRAM
also known as
(D)ARPA/ROME PLANNING INITIATIVE (ARPI)

Background: The Planning and Decision Aids Program was DARPA's portion of the (D)ARPA/Rome Planning Initiative (ARPI), a jointly sponsored initiative between DARPA and the Air Force Research Laboratory. The joint initiative began in February 1991 with a goal of fostering the creation of new tools and technology, managing the research process, and transitioning new technology from the research environment into operational practice in support of military crisis action planning. A dynamic and rapidly changing operational environment, exemplified by Desert Shield and Desert Storm, demanded maximum flexibility and reactivity from plans and planners at all levels. Those events underscored the complexity of the crisis action planning problem faced by the military. Deliberate plans were not flexible and adaptive enough to cope with a rapidly changing situation. New approaches and technology were needed to replace current systems and procedures. ARPI was created to address those challenges in an innovative, cooperative effort. DARPA expended approximately $90 million over a nine-year period on this program. The Air Force contributed less funding but provided considerable contractual and technical support over the life of the program.

Program Objectives: The objectives of this initiative were to develop, demonstrate, and transition advanced technology for automatic and interactive planning, scheduling, and decision making to allow better, faster planning in complex, stressed situations. Under normal circumstances, the transition of promising logistics and planning technologies from the laboratory to the field has taken years. A goal of ARPI was to accelerate the process from basic research to fielded planning and scheduling systems.

Transition Status: This program resulted in a number of planning tools that followed the DARPA-to-Service Acquisition (DSA) path model. Below are descriptions of five major planning tools developed via the ARPI program. In addition, research results from the Planning Decision Aids Program were spun off to many other DARPA programs including Joint Force Air Component Commander (JFACC), the Advanced Logistics Project (ALP), the Joint Task Force Advanced Technology Demonstration (JTF ATD), the Adaptive Courses of Action Advanced Concept Technology Demonstration (ACOA ACTD), and Control of Agent-Based Systems (CABS).

The first ARPI effort, the Dynamic Analysis and Replanning Tool (DART), could plan troop deployments substantially faster than prior operational systems. DART was built on-site and used by U.S. TRANSCOM during the first weeks of Operation Desert Storm. Using DART, U.S. EUCOM logistics planners transported tanks and heavy artillery from Europe into Saudi Arabia at least three weeks faster than would otherwise have been possible. After the Gulf War, DART was deployed to 14 different sites including all theater CINCs and TRANSCOM components. DART was transitioned from DARPA to the Defense Information Systems Agency (DISA) for insertion into TP Edit and Global Command and Control System (GCCS). The development of DART contributed to the Analysis of Mobility Platform (AMP) tool currently in use by the U.S. TRANSCOM.

DARPA's TARGET planning system was a precursor to today's distributed collaboration tools (e.g., NetMeeting which is used extensively both by the military and commercial world), and was the primary planning tool used by PACOM for over five years ending in 1997, when a new product was introduced. It is credited with reducing crisis action planning time by 50 percent as measured in a large U.S./Australia exercise.

The Air Campaign Planning Tool (ACPT) aids users in decomposing national goals and executable tasks (i.e., specific targets). This is now the Joint Planning Tool (JPT), and it is operational in the U.S. Air Force Air Combat Command.

The Air Mobility Command Scheduler, also known as CAMPS, focuses on the scheduling and rescheduling of airlift. This tool is operational in the Air Mobility Command.

The In-Theater Airlift Scheduler (ITAS) is in operational use with PACAF and has been used in an exercise by the Air National Guard.

Transition Plan/Path: This initiative relied on application prototyping cycles and regular workshops for technical exchange among program participants. It introduced a software/knowledge infrastructure, roles, tools, and a defined process aimed at accelerating the development, evaluation, maturation, and insertion of new technologies (categorized as evolutionary "tiers") in crisis action planning applications by connecting the tiers of development. The current ARPI research community spans more than 25 educational and industrial research sites all working on advanced technologies related to planning and scheduling, and addressing the domain and operational problems identified by the initiative.

FIGURE B-2

General Comments: This program proved to be a very successful model for transitioning software to the military in record time. This was achieved by having the Services, universities, and industry all focusing as a team. The DARPA program manager stated that it was vital to ensure that the very rapidly maturing technology fits into the users needs. He stated that it is a balance that must be maintained. If upgrades are integrated too quickly, the user may become confused and discouraged trying to understand and keep up with the changes. On the other hand, if software is not upgraded in a timely manner, systems become obsolete and maximum capability is not achieved. Although the DARPA office that sponsored this program would have liked to continue aiding transitions in this area, DARPA's philosophy is that there is a beginning and an end to every program. DARPA management concluded this program after nine years.

(5) CERAMIC BEARINGS

Background: The Ceramic Bearings Program was a $10 million technology program funded out of the DARPA Defense Sciences Office/Materials Sciences Division (DSO/MSD). Individual projects began in 1991 and ran for an average 36 months. In an advantageous move, DARPA decided to leverage this program with the Advanced Ceramics Technology Initiative Program (ACTIP) that was also just beginning. Using Non-Destructive Evaluation (NDE) techniques for ceramic bearings originated during this effort. A company, called CERBEC (later merged with Norton Advanced Ceramics), commercialized this process and continues to manufacture ceramic bearing components. Norton Advanced Ceramics is a leader in high volume manufacturing of silicon nitride balls. CERBEC bearing components are currently supplied to bearing companies worldwide.

Program Objectives: Enhance the processing technology base for high quality ceramic rolling elements and ceramic bearings. Ceramic bearings offer significant improvements in performance and durability for a wide variety of military applications ranging from inertial guidance instruments and precision sensor gimbals to turbine engine exhaust nozzle actuator and submarine pumps. Two principal barriers to the greater use of ceramic bearings by DoD have been their high cost and poor operational reliability. The overall goal of this program was to enhance the industrial technology base capabilities for ceramic-hybrid and all ceramic bearings to be used in advanced DoD systems, and to reduce costs. This was to be done through innovative research efforts for developing and introducing advanced processing and process control technologies to ceramic fabricators and bearing manufacturers, including using NDE in their manufacturing process.

Transition Status: The following products have transitioned from the DARPA Ceramic Bearings Program. Ceramic hybrid bearings for Navy Pumps are being implemented in Seawolf Class and the 688 LA Class Submarines under a contract with General Dynamics. In addition, under an AlliedSignal Aerospace contract, ceramic hybrid bearings for air cooling turbines are on the preferred spare insertion underway on the F-15, C-130, and F-111 Air Force systems.

A 1998 Tribology Systems, Inc. (TSI) press release states, "TSI's recent application to flywheels of solid-lubricated hybrid ceramic bearings and sliding surfaces greatly reduced flywheel cost in comparison to designs which use magnetic bearings. This breakthrough evolved from TSI technology and products developed over three decades. These bearings are used not only in TSI's own flywheels, but as primary or backup bearings in wheels made by United Technologies Corporation, including units in BMW and Air Force demonstration and test vehicles."

A February 1999 AFOSR Research Highlights release states, "The Air Force, DoD, and NASA will benefit from more powerful and efficient mechanical and propulsion systems based on the use of more reliable ceramic ball bearings. The advance is based on experimental techniques developed under AFOSR support that aided in detecting early fatigue failures in bearing tests. The Air Force recently introduced ceramic bearings into F-16 auxiliary power units and a variety of devices used for attitude control. The Air Force also plans to use the ceramic ball bearings in air-breathing and rocket engines. NASA uses the bearings for space shuttle fuel pumps. In addition, a testing methodology derived from the research was transitioned to Pratt and Whitney from a DARPA-sponsored program." The paper goes on to say, "The Aerospace Corporation is developing standards for NDE techniques for industry use. Use of the new standards will result in improved quality control during ceramic (silicon nitride) ball bearing productions."

Transition Plan/Path: Separate BAAs were issued for the ACTIP and Ceramic Bearings programs. However, many of the bearings efforts were implemented under the ACTIP insertion model. As stated in the ACTIP case study, in an attempt to accelerate the transition process for advanced ceramics, DARPA created ACTIP whereby they would help the Services take existing COTS advanced ceramics technology and help sponsor ways to get it inserted into their military systems. The ceramics bearings program benefited greatly from this dual approach. It allowed DARPA to work closely with the Services and help insert technology much more quickly that would have happened otherwise. This was a DARPA-to-Service Program Office (DSA) transition.

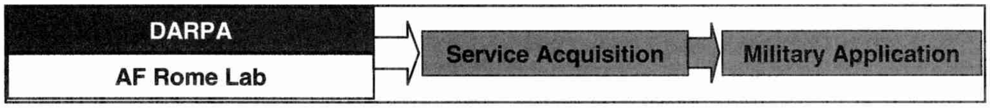

FIGURE B-3

General Comments: This coupling of the Bearings Program with the ACTIP provided an avenue of opportunity that otherwise would not have been available and most likely would have resulted in significantly different success results for the Bearings Program.

Although this program was deemed by us as a DSA-type transition, one of the individuals interviewed for this program, stated that the real path to transition is always via the contractors. If the contractors are not on-board, if they do not have the incentive or market, then the technology will go nowhere.

(6) CONSORTIA FOR ALL-OPTICAL NETWORK TECHNOLOGY

Background: This program began in 1991 as a solicitation for proposals for the formation of a Pre-Competitive Consortia for All-Optical Network Technology with one-time funding from DARPA. According to the BAA, the only requirements for the consortia were that it be vertically coordinated with expertise ranging from devices to applications, and address a broad range of tasks. The tasks included the design of technically and commercially viable network architecture, the development of devices needed to implement the architecture, the development of a suitable host computer environment, and the integration of these elements into a demonstration system. Also the consortia had to address manufacturing S&T issues to insure producibility and reliability. The bidders were also asked to identify the specific goals and approaches that promise to have significant utility to national defense.

DARPA accepted three proposals under this BAA. The first consortium was the All-Optical Network (AON), which was led by MIT's Lincoln Lab with AT&T and Digital Equipment Corporation as their partners. Bellcore (now Telcordia Technologies) led the second consortium—the Optical Network Technology Consortium (ONTC). Other ONTC members included: Case Western Reserve University, Columbia University, Hughes Research Laboratories, Northern Telecom, Bell Northern Research, Lawrence Livermore National Laboratory, Rockwell Science Center, United Technologies. The third consortium consisted of IBM and its various departments. DARPA funding for the Consortia was approximately $7.7 million and $6.7 million in FY 1991 and FY 1992 respectively.

Program Objectives: The objective of the consortia was to develop the technology for an all-optical communications network capable of terabit-per-second throughput. In an all-optical network, the signal will remain in the form of light from source to destination. According to the BAA, the goal was to eliminate electronic bottlenecks that exist in networks. In the DoD, networks based on all-optical technology are essential for transferring high bit-rate information such as data and high-resolution images from multiple sources. ONTC focused on networks for large corporations. AON focused on large area networks for medium-sized businesses, and IBM concentrated on small enterprise systems. In particular, AON studied a three-level wavelength division multiplexing (WDM) network that gives optical access to the desktop. ONTC researched a transport network using wavelength add/drop multiplexers and cross-connects and electronic Asynchronous Transfer Mode (ATM) switching. An economic study of a 70 node large MAN showed that 40 percent savings could be obtained using these types of electronic equipment.

ONTC was followed by the Multiwavelength Optical Networking (MONET) project in 1993, a consortium of five organizations—Bell Atlantic, BellSouth, Pacific Telesis, Southwestern Bell Technology Resources Inc., and Bell Labs, in cooperation with NSA and NRL. MONET set out to define, demonstrate and reach an industry consensus of the best national scale multiwavelength optical network for serving commercial and government application. MONET sought to expand the commercial viability of optical networks and to fit DoD needs. The optical network would support virtually any future telecommunications standard, enabling graceful growth. Its support of a large variety of format-independent, bit-rate-independent and protocol-independent service could offer increased flexibility and economic advantages in commercial networks, and also is of particular interest to the U.S. defense establishment.

Transition Status: The technology developed under these DARPA-sponsored consortia is the basis for today's telecommunications revolution. The ONTC testbed delivered the world's first live field demonstration of a reconfigurable, multiwavelength, all-optical network. The solicitation called for a demonstration system (both architecture and components), which was accomplished. The components developed under this BAA are being produced by JDS Uniform and Bellcore (Telcordia), and are integral to the Internet. The technology has also benefited NSA, allowing them to complete coast-to-coast link-up of their systems. MONET's Washington Area Network connects NRL, NSA, DARPA, the Defense Intelligence Agency (DIA), DISA, and NASA. "The technologies demonstrated by the MONET long-distance and local-exchange testbeds will be the foundation of the next-generation Internet, where the demands for quality of service, bandwidth, configurability and scalability will far exceed the capability of today's network infrastructure," said Bert Hui, a former program manager in DARPA's Information Technology Office. "We envision that the Department of Defense will continue to rely heavily on the Internet for a lot of our day-to-day communication needs." The military also benefits from the high-capacity networks that have been built and are in place. The technology has also been integrated into the Next Generation Internet Initiative and the Global Grid program

Transition Plan/Path: This program followed the DARPA-to-Industry-to-Service Acquisition (DIS) path. This program began as a proposal in response to an agency-wide competition. A non-traditional approach was taken by establishing a precompetitive industrial consortium. In this way, R&D was focused on creating generic technology in the optoelectronics area.

According to the program manager, the DARPA solicitation is the reason for the revitalization of the U.S. optoelectronics industry. In the 1980s, this industry was waning with the Japanese taking the lead. The U.S. device market share, then about 10 percent, has since increased to 40 percent. Prior to the DARPA investment, the industry was without direction. DARPA's involvement inspired the organizations to form consortia and to further research in this area. The consortia approach focused their efforts, accelerated the technology, and allowed the companies to work together without the fear of a violating the anti-trust laws.

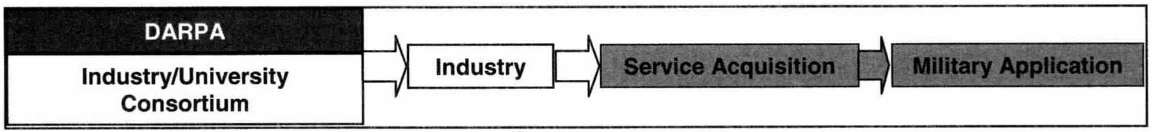

FIGURE B-4

General Comments: The program manager noted that there is no magic formula to transition. He stated that program managers need to continuously look for paths, and suggest where the technology/research can be transitioned. One hindrance to transitioning technology from DARPA is the slow pace of the contractual and procurement processes. He remarked that it could take up to a year to solicit and select a proposal, and negotiate a contract, which can impact market timelines and small start-up companies.

(7) OPTOELECTRONIC INTERCONNECTION CONSORTIA

Background: The U.S. optoelectronics industry was languishing in the late 1980s, while Japan had cornered the commercial market. According to the program manager, about this time U.S. industries were looking for direction and this effort presented that opportunity. DARPA was seeking to advance manufacturing science and technology issues to allow producibility and reliability. In addition, they were looking for interconnection that was scalable and flexible to accommodate and promote new computer architectures. The packaging of optoelectronic integrated circuits and the use of optoelectronic components in electronic packaging were key tasks for investigation. This program was established in 1991 as a three-year cost-sharing project for the formation of a Pre-Competitive Consortia for Optoelectronic Interconnection Technology. DARPA's share of the agreement with the consortium was $5.7 million. As an aside, DARPA has contributed more than $100 million in the optoelectronics interconnect thrust area since the 1980s. This consortium effort was just one relatively small initiative within the thrust area.

Program Objectives: DARPA's goal for the consortia was to reduce technical uncertainties and permit realistic assessment of potential applications of optoelectronic interconnections. Using optoelectronic technology, this cooperative project provided integrated components for optical interconnections to achieve significant performance improvements and relieve communication bottlenecks in computers. An intra-processor interconnect with proper interfaces compatible with silicon chip and packaging technology was sought.

Transition Status: The program has been an unmitigated success. DARPA selected a consortium with GE as the lead and AT&T, IBM and Honeywell as partners. Honeywell's research resulted in a breakthrough technology of a new type of laser emitter device called the Vertical Cavity Surface Emitting Laser (VCSEL). Regarded as the "transistors" of optoelectronics, VCSELs are currently the smallest coherent light sources and the most efficient light converters, with an efficiency of 50 percent conversion from electrical to optical power. This device has revolutionized the interconnect industry.

As a result of this technological breakthrough, the U.S. has surged ahead of Japan and the European Community markets in the production of VCSELs. In 1996, Honeywell was the first company to commercialize VCSEL technology, and today it is the world's largest VCSEL component supplier. VCSEL technology is now utilized as the gigabit Internet industry standard and is a $10 billion a year industry. Other leading production companies include Cisco Systems Inc, Ciena Corp., Sycamore Networks Inc., Tellium Inc., and Lucent Technologies.

Boeing Company has selected VCSEL technology for their 777 avionics, and they have received the FAA approval required for commercial application. Due to stringent requirements placed on commercial airplanes, once a technology such as VCSEL is used in a commercial avionics application, transition into military systems is essentially assured.

Boeing selected Honeywell VCSELs embedded in Finisar Corporation transceivers as part of the electronics suite for the Joint Strike Fighter (JSF). The Navy F/A-18 E&F Super Hornet, currently in production, is utilizing VCSEL technology developed by the Harris Corporation for integration into the fiber channel switch. VCSEL technology is also embedded in the computer optical backplane of the latest Israeli F-16 aircraft. There is no doubt that there are many other systems throughout the Military Services where VCSEL technology is or soon will be integrated. However, due to time constraints and the difficulty in tracking down this relatively small (albeit important) part of major systems, for this case study, we are limiting our search and did not continue tracking information beyond those identified above.

Because there are many applications for VCSEL technology, NASA, NIST, and Sandia National Labs, as well as DARPA and the Services, continue to aggressively pursue advances in this technology. DARPA has had successive optical interconnect programs in which VCSEL technology plays a key role: the Broadband Information Technology (BIT) Program; the Optical Micro-NETworks Program; and the VLSI Photonics Program. In addition, many multi-million dollar spin-off companies have been formed. Some include: Cortak (recently acquired by Nortel); Calient Networks, Inc.; and Bandwidth 9. Also, Sanders/Lockheed Martin (now part of BAE) recently signed an agreement with three leading venture capital firms to create a new company (TeraConnect Inc) based on Sanders-developed optical communications technology.

One example of how VCSEL technology continues to impact both commercial and military applications is a BMDO SBIR project to investigate high-speed optoelectronics for more responsive missile guidance systems. In the spring of 2000, it was announced that New Dimension Research, Inc. (NDR), a small business out of Woburn, MA, had developed a multilaser technology that should enable future computer disc drives to read data at much faster speeds than today's models. Given time, it's anticipated that this technology will simplify optical disc drive design. VCSELs are at the center of NDR's technology breakthrough.

Transition Plan/Path: We considered this program to fall into the DARPA-to-Industry-to Service Acquisition (DIS) path primarily because after the breakthrough, industry supplied much of the investment needed to drive the development. When DARPA issued their BAA, they mandated that the consortia be led by industry and be vertically integrated with users, system integrators, components suppliers and researchers as members. Bidders were asked to identify specific goals and approaches that promised to have significant utility to the national defense. The DARPA program manager was aware that optoelectronics interconnection was an industry-led technology, and that the path into military systems was via industry. The Services were eager to take advantage of this new and innovative technology and, as noted above, quickly began developing programs and upgrading systems to apply VCSEL technology.

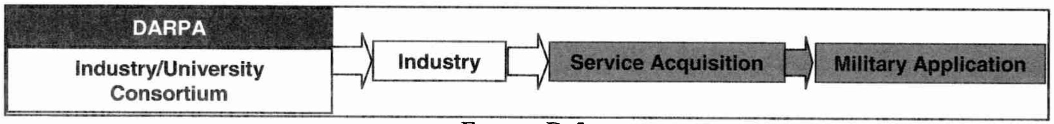

FIGURE B-5

General Comments: At the time DARPA initiated this program, entering into a cost-shared effort with a consortia was still a fairly innovative technique within DoD. While this was a research effort, DARPA pursued the non-traditional approach to enable a more rapid transition of technology. The program centered on a cost-shared agreement between DARPA and an industrial consortium based on the new "other transactions" agreement authority. The DARPA program manager noted that this program would probably not have been initiated if not for the $50 million Congressional add to the DARPA budget that included language providing authority to enter into precompetitive technology development cooperative projects. The DARPA program manager also stressed that timing was an important aspect in this breakthrough. He told us that the technology was on the verge of a breakthrough and this program pushed it through. But, had the program been initiated one or two years sooner or later, VCSEL technology may not be a current reality. Could he have predicted the right timing? No. Unfortunately, many technological advances rely not only on the research but luck of timing.

(8) THERMAL MANAGEMENT DIAMOND
(Diamond Substrate Pilot Line)

Background: In 1991, DARPA began a new initiative in low-cost Chemical Vapor Deposition (CVD) free-standing, diamond substrate manufacturing technology. The performance and reliability of high-power defense electronics were limited by the inability of the associated microelectronics packages to dissipate heat. As DoD moved toward more solid-state power devices, this limitation became increasingly significant. Because thin-film diamond substrates have more than five times the thermal conductivity of the alternative thermal management substrates (beryllium oxide), they can provide a significant advantage to many devices and thus were considered a viable alternative—if the price could be sufficiently reduced to incentivize the commercial market. DARPA funding for the Thermal Management Diamond Program from 1991 through 1998 was approximately $68.6 million. Norton Diamond, a material fabrication company, was selected as the prime contractor for this effort.

Program Objectives: The objectives of the program were to demonstrate (a) the feasibility of a cost effective free-standing diamond substrate manufacturing process, (b) diamond substrate compatibility with standard microelectronic packaging equipment and processes, and (c) effectiveness of diamond substrates in accommodating the thermal loads of high speed, high density multichip modules.

Transition Status: Although planned as an effort that would transition into industry and back to the military, the commercial market did not support the defense requirements. Former DARPA and NRL program managers for this program told us that this technology failed to transition from industry to the military. Further investigation found no evidence to disprove their statements. After DARPA discontinued their program, most companies pursuing this aspect of diamond technology turned their endeavors in a different direction. Companies did continue to pursue diamond technology for many commercial applications but none directed toward the DARPA program objectives. According to those interviewed, a number of factors contributed to this failure.

Problem—military readiness. In a few insertion test cases, it was quickly learned that while the diamond substrate material was a viable low-cost alternative, it did not "fit" into existing systems. In order to insert the material, the systems would have to be completely re-engineered. The Services were not ready to make a commitment of this magnitude (many millions of dollars) on a system that they knew worked within reasonable boundaries with existing technology and would continue to do so for awhile yet. Only systems still on the drawing board would be considered for this technology. That means that no military market would be available for many years. This factor alone indicates a hard "lessons learned." Even the best-managed program, however technologically successful, will fail if something is left out of the equation. In this instance, had some attention been focused on the eventual impact to the military systems the product was directed towards, it may have provided the ability to project early-on when the military market would surface, thus precluding premature commercial marketing. The insertion failure may have been averted.

Problem—sponsorship. A comparison was made between the Gallium Arsenide (GaAs) industry and the CVD thermal diamond substrate for MCM. Due to the vital importance of GaAs for high frequency communications, a singularly important application, sponsors maintained continuous interest for 30 years. But, diamond technology has many applications most of which are more lucrative to the commercial market. Based on a comment from an interview, the result is that everyone thinks that the other guy will do this work then in actuality it ends up no one does the work.

Problem—attention span. Industrial sponsors tend to have about a five-year attention span to a new technology. They do not have the patience required to see a new technology through especially if it tough and takes significant time. If a near-term profit is not forthcoming, they re-focus their efforts to one that will produce the desired profit. As important as this technology had been to DARPA in 1991, even they made the decision in 1997 to cease funding the program. There were no champions to take up the march—the total opposite of what happened with the Optoelectronics Interconnection Program.

Problem—marketing. U.S. companies blew their lead in production. Europe, Japan, and China currently are the world leaders in the production of CVD diamond substrates. Many companies at the forefront of this technology in the early 1990s, have collapsed or been bought by other companies. Statements from two individuals indicated that Norton Diamond Films, now a division of Compagnie de Saint-Gobain and once DARPA's prime facility contractor on this effort, suffered from poor marketing skills. Soon after they were acquired by Saint-Gobain, their facility in Massachusetts was redirected to other more promising commercial activities. It was surmised that this was due primarily to profit loss and missing projection sales goals. In addition there was competition from GE in the area of high-pressure high temperature diamond compact/composite powder.

So, although industry managed to get the cost of the diamond substrate down from $1,000/karat to less than $1/karat, this program was a commercial failure. This project is typical of U.S. R&D where industry does not have the staying power to complete the transition of top notch technology to an industrial reality. The Japanese, Chinese, and Koreans are not so linked to an immediate gratification (profit) in their pursuit of new business and technology.

Transition Plan/Path: It was acknowledged that a successful military transition demanded a robust commercial market, so the transition plan followed the DIS path. But, when the commercial market was not forthcoming, military transition also failed. Contracts were executed through NRL, the primary agent, and DARPA's contracts office. Teaming approaches, with product suppliers prime (Norton), included significant participation by component and system integrators to set product requirements. Also included were universities and national/defense laboratories for development of scientific understanding to underpin the technology development. Venders were strongly encouraged to develop business plans incorporating commercialization strategies.

It had been envisioned that transfer to the Military Services would occur by establishing the functionality of diamond substrate MCM technology in defense systems. Industrial transfer of the technology was expected to occur initially through demonstrations of specific modules such as the Ross SPARC module that was the primary component of a laptop workstation.

Although working diligently with NRL and funding them for some of the research, this technology never got out of industry. It was acknowledged that typically a successful military transition demands a robust commercial market as well. However, there was no commercial market for this DARPA-specific technology.

General Comments: The vision of effortless production, as insignificant cost, has vanished, but much remains. A handful of the companies started during the stampede have survived, and have identified opportunities that may enable them to prosper. Enhancements to the basic diamond deposition process, including plasmas, electric fields, radio frequency and microwave energy, and new reactive chemistry, ranging from halogens to fullerenes, have appeared. Also the field of diamond-like coatings (DLCs) has emerged. DLCs are usually based on the same carbon chemistry used to produce diamond films, but can be processed at lower energy levels and at a more affordable cost. DLCs do not equal diamonds in overall properties, but numerous applications have been found where they exceed conventional coating chemistry by a significant margin.

There are currently two near term markets being pursued: (1) laser diodes for repeater station on fiber optic communications (undersea) that would significantly extend the life of cables, and (2) tool bits for machining.

An aside comment from one of our interviewees was that since moving to industry, he has found that it is extremely hard to displace an entrenched technology or business. Getting to market involves a much broader issue than just producing a better technology. A sound business strategy, along with luck and timing, are key ingredients.

(9) FEDERAL HIGH PERFORMANCE COMPUTING AND COMMUNICATIONS (HPCC): NETWORKING SYSTEMS PROGRAM

Background: The High Performance Computing Act of 1991 (Public Law 102-194) formally authorized the HPCC program. The Networking System Program was a sub-component of HPCC at DARPA. The HPCC initiative grew out of successful ongoing computer and communications research programs at participating agencies, including DARPA. High Performance Computers (HPCs) are important in designing and operating many military systems and essential for some. DARPA's mission statement regarding their involvement in the Concurrent Super Computing Consortium (CSC) notes that the size and complexity of DoD problems such as weather prediction, air defenses, polar aircraft design, submarine defenses, as well as basic technical problems such as turbulence, combustion, and electronics require large amounts of computational power. Building and efficiently engineering high-speed networks remains a critical DoD need. Affordable communications for Defense require that DoD derive the bulk of its communications services from the commercial sector, which in turn requires DARPA to seed the commercial technology base.

The HPCC program developed critical technologies necessary for the Department of Defense to carry out its mission, including the capability to communicate on a global scale, across an extremely diverse set of communication systems, and with the highest reliability and performance in an affordable manner. The Networking Systems Program, one of four HPCC programs initiated at DARPA, focused on high performance networking technologies as enablers of a worldwide, ubiquitous, and reliable information infrastructure. Network communications is utilized in day-to-day operation, training, mission planning, logistics, and command, control, communication, and intelligence activities. The driving forces are the need to provide enabling technology in support of global simulation, high-resolution remote imagery exploitation, and telemedicine as well as the National Information Infrastructure and other requirements for integrated information and communication systems. Specific challenges are the need to provide communication services across a wide range of heterogeneous network types, the need to connect billions of host systems, and the need to join together high performance distributed computing and information resources working on a common set of problems.

Program Objectives: The goal of the program is to develop high-speed network components and protocols to operate in multigigabit systems to enable new DoD services such as virtual situation rooms, collaborative environments and real-time multicasting. Networking services will deliver data for these applications at high rates and within timeliness constraints that are measurable and discernible to the end users.

The program addressed these needs by developing specific technologies in the context of ubiquitous information infrastructure architecture. The program is organized into three subprograms:

- Internetworking—The Internetworking subprogram develops protocols and technologies to provide the integrating glue between network technologies of differing capabilities and reach. The technology focus areas within this subprogram are: Internet protocols, communication services, and networks.

- High Performance Networking—The High Performance Networking subprogram is concerned with increasing the performance of underlying network technologies and developing innovative ways of delivering bits to the customer. The technology focus areas within the subprogram are: transmission systems, switching systems, architectures, and software tools.
- Advanced Developmental Networking—The Advanced Developing Networking subprogram is an initiative for the development and demonstration of a gigabit-per-second data rate optical fiber network that connects critical DoD operational and intelligence centers in direct support of DoD's Science and Technology Global Surveillance and Communications activity. The leading components of the program now are focused on high-speed packet handling devices and network analysis and engineering.

Transition Status: The Networking Systems program has been responsible for a chain of major developments, including the new Internet protocols (IPv6), advanced protocols for large-scale video multicasting, gigabit network testbeds which accelerated the availability of broadband services for the DoD by at least one half a decade, the development of the technology for DISA's DISN Leading Edge Service, and for fostering the revolutionary concepts for new programs, such as Active Networks. Networking Systems has also been the crucible for the design of high-speed network hardware that is tightly bound to efficient Internet work processing. The program, which began in the early 1990s as a significantly larger effort, has spun off several major parts into separate programs (Active Nets, SuperNet, GloMo, and High-Confidence Nets).

Transition Plan/Path: Due to the various components of the program, several approaches to transition have been used. However, ultimately, it followed the DARPA-to-Industry-to-Service Acquisition (DIS) path. One approach was to identify key defense requirements by working with DoD network planners from DISA, NRL, NSA and several other agencies who represent leading edge defense users. These same agencies have been engaged through the testbed elements of the program to employ and transfer technology from the testbeds directly to their agencies. In some cases such as the AAI system, ATDNet, and ACTS, these test beds have been cofunded with the other agencies.

The second approach works with industry and commercial service providers to investigate long term research questions and to build advanced prototypes of switches, algorithms and systems. The gigabit testbeds is a leading example of this approach. Not only did it involve joint vendor and DARPA research groups in demonstrations of high-speed devices but also the provision of circuits and equipment by telephone companies and equipment vendors to test these devices in very advanced systems.

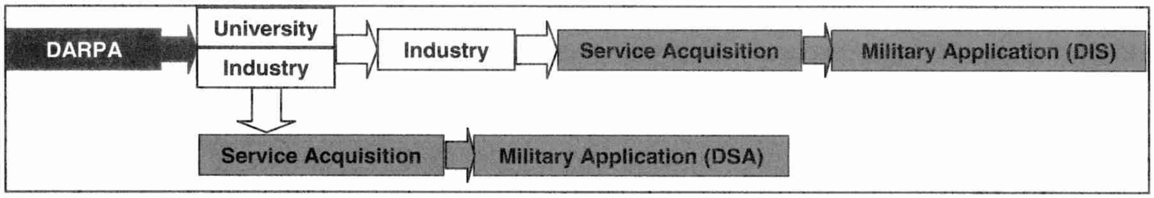

FIGURE B-6

General Comments: As noted, the Networking Systems program within the Federal HPCC initiative at DARPA was one of four HPCC programs. The technology has been, and is being, used by industry. The information for this case study was collected from various sources, including: the DARPA website for the program, the Federal HPCC website, and telephone interviews with past DARPA program managers and a NRL program manager.

(10) FUEL CELL POWER SYSTEM FOR UUV

Background: In 1991 DARPA issued an RFP in search of an alternative power source for existing batteries to eventually be used on the planned DARPA/Navy Unmanned Undersea Vehicle (UUV). The UUV program was initiated in 1989. The International Fuel Cells Corporation (IFC) was already under a UUV contract to develop Proton Exchange Membrane (PEM) fuel cells for undersea use. DARPA wanted to ascertain if other equally or more qualified, less expensive technologies could be developed for the same application. It was noted in the RFP that the Phase I part of this effort would be conducted in parallel to the IFC effort and it was expected that only one of the two efforts would be down-selected for continuation to Phase II. Loral won the RFP competition based on their proposal to develop a promising aluminum oxide semi-fuel cell. Although Phase I was estimated to run for two and a half years, the fuel cell project never reached Phase II. Even though Loral's effort appeared to be a workable idea, it did not reach the developmental stage. One major obstacle that plagued both the IFC and Loral efforts was the need to purchase cryogenic storage tanks. There was only one supplier (Ball Aerospace) and the cost of the tanks was prohibitive to the program budget. By this time, an even greater disincentive had emerged. There was no near-term DARPA UUV available in which to install the technology even if a successful solution was found. After a contribution of approximately $28 million toward this research in UUV fuel cells ($14 million each for IFC PEM and Loral Aluminum Oxide technologies), DARPA discontinued pursuing the effort in 1997.

Program Objectives: The objective was to develop a Fuel Cell Power System (FCPS) to replace existing batteries that would eventually be used in the planned UUV. During Phase I the contractor was to design the FCPS and design, construct, and test a Power Plan Demonstration Unit (PPDU). The PPDU was to demonstrate in an integrated power system the operation of components and processes that would otherwise entail risk during Phase II. In Phase II the contractor would construct the FCPS, install it in the UUV and provide support for sea trials. The requirements for the FCPS were 15 kW of power, at least 1000 kWh of energy, fit within the existing battery hull section of the UUV, be reliable and very safe, and have minimum impact on the operation of the vehicle other than providing total energy to the UUV.

Transition Status: In the end, the UUV program itself never developed sufficiently that this technology could be inserted even if it did eventually prove successful so the program was cancelled. For a while after DARPA ended the program, Loral continued to pursue the aluminum oxide fuel cell technology but was never successful. They were basically squeezed out of the market by the other fuel cell technologies and chose to turn to more profitable areas of research. No one else pursued this approach.

A lesson might be learned from this program. If viable alternatives already exist or are being pursued, a short-term feasibility study may eliminate costly long-term research. Although the aluminum oxide fuel cell technology may have one day proven beneficial, competition from the PEM and other fuel cell technologies would be tough to overcome. It's unknown if a risk analysis was performed on the chances of this particular fuel cell gaining entrance into the market, but if it wasn't, it probably should have been.

Transition Plan/Path: The strategy was to work with the Navy (ONR) via the UUV Program in investigating a longer lasting, reliable alternative power source for the battery-powered unmanned submersible.

The program had some strange twists however. As part of the FY94 Appropriations Act, the Senate Appropriations Committee requested Navy assign the Director of Navy's Expeditionary Warfare Division (N85) the responsibility for establishing the Navy's UUV program priorities. Further, DARPA (then ARPA) was requested not to obligate funds provided for its autonomous mine countermeasures project until the USD(AT&L) and ASN(RD&A) certified that the DARPA effort was part of the overall plan and met the priorities established for UUVs. The DARPA project continued for another two years because they considered propulsion (fuel cells) an important issue for a UUV. But in 1997, because the Navy was aggressively pursuing research in this area, DARPA made the decision to terminate their effort. Navy continues to fund research and development efforts in this area. In July 2000, ONR issued a BAA soliciting white papers for new S&T concepts supporting UUV. One of the major focuses of the solicitation is propulsion, targeting fuel cells and semi-fuel cells. Their budget for effort in FY 2001 is in the range of $4 million.

General Comments:

As an aside, IFC (now a subsidiary of United Technologies) continued working PEM fuel cell technology. They, and other commercial companies such as Ballard of Canada, have invested well over $100 million each in PEM fuel cells, the primary potential commercial market being the automobile. So, while the DARPA UUV/fuel cell program was not successful, it did contribute to improving the state-of-the-art. According to the DARPA program manager, the funding that DARPA provided to IFC under the UUV program accounts for at least two versions of improvement in their early PEM technology.

(11) HIGH DEFINITION SYSTEM (HDS)

Background: Based on previous studies, CBD announcements, and Congressional descriptive summaries describing the program, we believed this program to be a FY 1991 new start. Later we learned that the first BAA was actually issued in April 1989. The program started out with the name High Definition Television (HDTV) and garnered about $30 million in initial funding from three other programs. The name was changed soon after to High Definition Display Technology (HDDT), because of backlash from commercial industry. The name was then changed to High Definition System (HDS). The first funding line identified for HDS at DARPA began in FY91.

The program was initiated as a DARPA vision to create smaller displays without a large surrounding equipment infrastructure similar to commercial high definition televisions. ONR and the Air Force Wright Patterson Laboratory were both involved in the project working on projection systems and cockpit displays. In addition, at the time, DoD was concerned with ensuring they had a provider of high definition displays. Five years ago, only the Japanese were high volume producers of this technology, and would not work on military-unique programs. Today, the number of companies that will work with the Defense Department has grown, not only in the U.S., but also in Korea and Taiwan. In fact, the Koreans and Taiwanese dominate the market now, with the leading technology, Active Matrix Liquid Crystal Displays (AMLCDs).

Program Objectives: The DARPA HDS program had the overall goal to meet the diverse, but specific DoD needs for information display. Displays are important to the Department of Defense because high performance displays will provide improved performance for the warfighter. Displays often control information assimilation, impacting the speed and effectiveness of decision-making. The center of future command posts will be large, very high information content displays.

The specific display related goals of the HDS program include increasing power efficiency, reducing weight, lower power, higher resolution, improving user interface, and improving the overall ruggedness of display systems. These goals are to be met while pushing the state-of-the-art in display performance and the ability to improve information assimilation

Transition Status: Besides major technology developments and transitions, other DARPA programs are also a direct spinout of the HDS program with the initial research being conducted under the High Definition System program. Several companies were also formed or strengthened by this initiative including: Candescent, Qualcom (compression technology), TI, Planar, Kent Display Systems, and dpiX (flat panel display for cockpits).

Most projection systems in use today use the Digital Micromirror Device™ (DMD™)—the "crown jewel" of the HDS program developed under the DARPA program by Texas Instruments (now Raytheon TI). The first RGB (full-color) HDTV format video projection display based on micromechanical light modulators was demonstrated by TI, who has commercialized the technology with several OEM partners aimed at consumer, business, and professional markets. TI is also utilizing the rear projection DMD™ technology to produce a 21-inch diagonal (1280 x 1024) resolution display for the USAF Common Large-Area Display Set (CLADS) program. The CLADS program will replace the 19-inch CRT in mission crewstations in several C4ISR aircraft—AWACS, JSTARS, and Airborne Command, Control, and Communications ABCCC)—with common display hardware. Raytheon TI's DMD™ and Digital Light Processing™ (DLP™) were also incorporated into a Tiled Command and Control Display System at Ft. Belvoir, VA. It is a seamless display using constellation tiling units.

Planar Systems developed a 12μm pixel Active Matrix Electroluminescent (EL) (640x480) display that is currently being evaluated for the Land Warrior program. Planar Systems (in cooperation with Computing Devices) has also demonstrated a 1316x480 thin-film EL glass device, which met the 1995 Abrams (M1 tank) Systems Enhancement Program (SEP) requirements developments by General Dynamics (the prime contractor). Operational trials proved successful and in March 1999, Computing Devices delivered the first high-resolution video capable of EL display to the Abrams SEP—three hundred CTV units have been delivered and continue. Without DARPA support the EL glass development would not have been possible. This EL technology can also address commercial market demands. It has been incorporated into

Mack Trucks, Inc.'s Vision by Mack™ highway tractor, which includes an integrated driver information display, designed and manufactured by Planar Systems.

Some additional HDS successful technology development programs include (from the HDS website at DARPA):

- The world's highest resolution active matrix liquid crystal display (AMLCD) with 6.3 million pixels (3072 horizontal x 2048 vertical) on a 13-inch diagonal screen was demonstrated by Xerox Corporation. Xerox launched a new company, dpiX, in March 1996 to bring this technology to a wide range of markets—dpiX 21. The Eagle-5M displays from Planar and dpiX will be incorporated into the U.S. Army AH-64 Target Acquisition Designation System and Pilot Night Vision System (TADS/PNVS) Program. Each AH-64 Apache attack helicopter will use an Eagle-5M display at the gunner/co-pilot seat, where the displays will provide superior situational awareness for weapons targeting and night vision system imagery. The technologies to produce these displays and the facility where the displays will be produced have been supported under several past HDS programs.
- Micron Display Technology (MDT) has developed a small, full color, field emission display. This miniature display is 0.7 inches in diagonal and is suitable for head mounted displays, as well as commercial applications. Monochrome field emission displays from MDT are being inserted into thermal imaging systems for evaluation in the Army.

Kent State University and Kent Display Systems demonstrated a 120 dpi resolution 8.5 x 11 inch reflective LCD that can maintain static images without consuming power. This type of display is especially useful for low power portable applications. Kent State is currently working on a color version of the cholesteric bistable display, as well as a displays fabricated on flexible plastic substrates. These displays are capable of reflecting images in the visible and infrared spectral regions. The technology is being incorporated into the military eBook (MIL eBook) for the soldier of the future. The technology has implications for the Land Warrior program, combat vehicles, as well as commercial applications.

Transition Plan/Path: This program followed the DARPA-to-Industry-to-Services (DIS) transition path. In 1996 Raytheon TI (who was one of the larger performers) created a business plan and transitioned the technology into both DoD and commercial applications. The technology was being driven by the needs of the Services, who set the vision. The current strategy for High Definition Systems within DoD is to make use of the global industrial capability, with DoD contractors buying most display components in the highly competitive and rapidly evolving market within acquisition guidelines. In addition, DoD is focusing R&D investments on those needs that industry is not meeting and where a military advantage is needed.

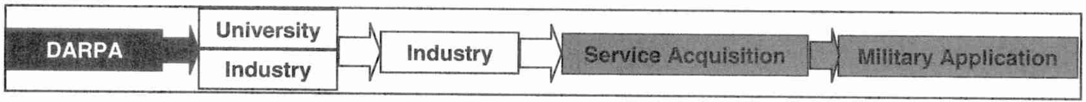

FIGURE B-7

General Comments: The former program manager stated that a large problem that he encountered was the bureaucratic requirements. He said that the process needs to be streamlined and aligned with the planned length of the program manager's tenure at DARPA (three to four years on average).[42] In other words, the proposal process needs to be shortened to respect the time period that the program managers are there. He noted that it takes at least one year to get underway with your program, including half a year for a CBD announcement and review process. Another obstacle was that a program manager is unable to change directions quickly. Funding has to be obligated by mid-summer or it can be lost; however, he noted that good ideas don't come in based on a fiscal year. If an idea was proposed after the summer that he wanted to use it would take another year to get underway, which is a lifetime for a start-up company.

The program manager also said that they were expected to fail sometimes. The DARPA director (at the time) told them that it was their job to take risk, and if they didn't fail they weren't doing their job—they weren't walking close enough to the edge.

(12) HIGH PERFORMANCE DISTRIBUTED EXPERIMENT (HiPer-D)

Background: Since the early 1970s, DARPA has engaged in the development of high performance distributed computing including, parallel processors, distributed computing, portable secure operating systems, and high speed networks. However, the technologies developed prior to 1991 had had very limited success transferring directly to military weapons systems and their applications. The High Performance Distributed Experiment (HiPer-D) was to demonstrate that a weapons system, AEGIS, could be implemented using state-of-the-art operating systems and distributed systems tools. AEGIS, the Navy's pre-eminent computer-controlled weapons system, was chosen because it suffered from limited resistance to catastrophic failure, under- powered computer, and difficult to maintain software systems. The program was initiated in 1991 in the Computer Science and Technology Office of DARPA, and is still ongoing at the Naval Surface Weapons Center (NSWC) Dahlgren and parts at DARPA. General Electric (now Lockheed in N.J. as a prime contractor to AEGIS) worked on advanced targeting, NSWC Dahlgren worked on the distributed tracking system, and Johns Hopkins University/Applied Physics Laboratory (JHU/APL) worked on tracking control.

Program Objectives: HiPer-D was mainly a technology insertion program, with the primary programmatic goal of validating distributed computing in the context of a real-time weapons system. HiPer-D technology sought to improve real-time performance and reduce cost while maintaining positive system control for mission critical combat system applications. Its supporting objectives included:

- validating the scalability of computational capacity to meet growing mission requirements;
- dynamic fault tolerance for survivability and availability, flexible "hardware independent" design to accommodate future growth and technology capture; and

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[42] We recommend in the body of this report, that negotiations with prospective program managers ensure that their tenure matches estimated life span of their project.

- validating test and integration approaches, and demonstrating compatibility with Ada requirements.

HiPer-D demonstrated real-time weapons systems operation on a high performance distributed computational platform, using a distributed operating system, and distributed system management toolkit. It also demonstrated that the software developed on this technology was not bound to a particular computer or display architecture—this was an essential element of the program. The new computing architecture enabled the use of COTS products, engineered from both DARPA and commercial computing components, and validated in the context of the AEGIS Weapon System performance timeline.

Transition Status: HiPer- D made advances in defining COTS-based shipboard computing architectures, in creating a framework for evaluation, in integrating new computing technologies, and in transitioning computing technology into the AEGIS program. The effort has shown that mainstream COTS hardware computing products can meet most DoD requirements, given the proper software architecture. The high performance computing demonstrated in HiPer-D is being incorporated into naval shipboard platforms, and is having significant impact on next generation AEGIS Weapons System (Baseline-7). The 1998 guidance document for Baseline 7 (Phase I) captured the technologies and architecture demonstrated in HiPer-D. This document, based on the HiPer-D distributed system and architecture, incorporates everything needed to know to build COTS architecture for AEGIS. The architecture will be incorporated into the new Baseline, and will be back-fitted on two-thirds of the AEGIS fleet (approximately 50 ships). Another transition from the HiPer-D program is a component called Dynamic Resource Management. It is a tool that allows the crew to control what systems and what areas of the ship are running specific programs. This technology is about to be patented by NSWCDD and the Navy Chief Technology Officer is looking into investing funds in the tool for the Baseline 7 architecture.

Another result from HiPer-D is the COEA (cost and operation evaluation assessment) for the 21st century combatant—DD-21. The HiPer-D team was asked to lead the COEA team that deals with the computer architecture of the next generation ship. They developed a Total Ship Computing concept that described the resource management at the complete shop level. Their recommendations will be incorporated into the Operations Requirements Document (ORD) for DD-21. In summary, HiPer-D impacted two major surface combatants and created the Dynamic Resource Management technology.

Transition Plan/Path: This program followed the DARPA-to-Service S&T-to-Acquisition (DS&T) path. This program was designed to fit into a critical window of opportunity. The technologies involved in HiPer-D were sufficiently mature for integration into major systems and the AEGIS program was approaching a key decision point. The next AEGIS Command System Baseline architecture was getting ready to be defined, and the HiPer-D team wanted to impact AEGIS Baseline 7 (the next system). The DARPA program manager worked with the Navy and the prime contractor to AEGIS to first demonstrate the technologies and system, and then to incorporate the architecture into future Baselines of the system. When the program began the Navy was building Baseline 5 and designing Baseline 6—the program goal was always to transition into AEGIS Baseline 7. This was accomplished.

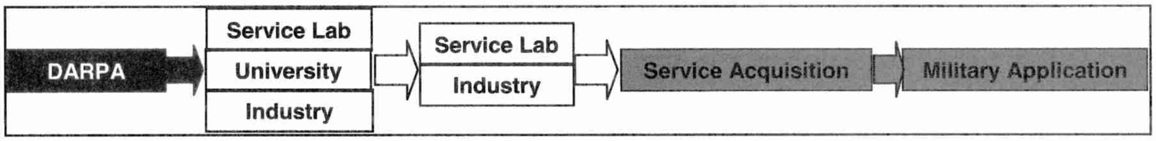

FIGURE B-8

General Comments: The DARPA program manager commented that timing has a lot to do with whether or not a program is successful. As he pointed out, the HiPer-D program owes a great deal of its success due to the AEGIS being available as a major test facility and the Navy's agreement to allow DARPA access to it.

(13) IR MATERIALS PRODUCIBILITY (CRYSTAL GROWTH)

Background: This program was a $10 million effort in 1991 to address the growth of infrared material for the production of advanced infrared focal plane arrays (IRFPAs) required for missile seekers, navigation, target acquisition, and search and track systems. Areas of interest included: improvements in the manufacture of infrared substrate materials; non-destructive characterization of infrared materials; and expanded application of infrared materials in military and industrial process control applications. The program was conducted in two phases. The first phase tested the feasibility of the improved IR substrate materials growth techniques and non-destructive characterization of infrared materials in a prototype reactor. The second phase developed techniques for the manufacture of improved infrared materials and a pilot run of the improved infrared materials.

There were two teams selected to participate in this program. The first team was composed of Johnson Mathey (lead), Texas Instruments, II-VI Incorporated (Two-Six, Incorporated), and Loral (now BAE Systems). The second team was Santa Barbara Research Center.

Program Objectives: The objective of the program is to develop source(s) of IR substrate material qualified for insertion into IRFPA fabrication lines. The program sought to address the advanced manufacturing techniques necessary to improve material properties, including an increase in the single crystal substrate size, reduction of the material defect density, elimination of inhomogeneities in the material, and reduction of material impurities. The program manager noted that this was a basic materials program—materials were developed. DARPA hoped to reduce the cost of the substrate arrays, a component in IR detectors.

Transition Status: The materials that were developed out of this program have been incorporated into the 240x2 FPA of the Javelin Command Launch Units (CLU), as well as the first production of Long Wave Infrared Camera (LWIR) staring arrays for its missile seekers. Over 1500 CLU FPA modules have been produced and 5,000 FPA modules have been produced. The material has also been used in the 420x4 IRFPA that was incorporated into the upgrade for the Light Airborne Multipurpose System (LAMPS) Helicopter Forward Looking Infrared Systems (FLIRS)—thesehelicopters were used in search and rescue in missions in Kosovo. The AC140 gunship also uses the detector. The developed substrate has been utilized in the standard array used in a family of combat systems to dramatically increase the target acquisition range. One such example is the target acquisition system in the Army Horizontal Technology

Integration/Improved Target Acquisition System (HTI/ITAS). Over 1,150 FPA modules of this kind have been produced. The substrate material was integrated into the large staring arrays for the Navy Ball Joint Gimball Program, an ACTD, eliminating the need for step-stare mechanism and simplifies Gimball. This is the largest LWIR FPA operating at near theoretical limits, and has been produced in prototype quantities. The autonomous guided munitions program demonstrated process control required to produce large sensors arrays in LWIR material. There is no commercial application for the high-end substrate materials.

Transition Plan/Path: This was a Direct-to-Service Acquisition (DSA) transition into the Services. While DARPA worked with industry in developing these substrate materials, the Services contributed money to make the arrays since they were the only consumer. When DARPA issued the BAA it was clear that the transition plan was to incorporate the developed materials into the ongoing fabrication lines for IRFPAs that were in use by the Services and more detectors than the Services needed to implement.

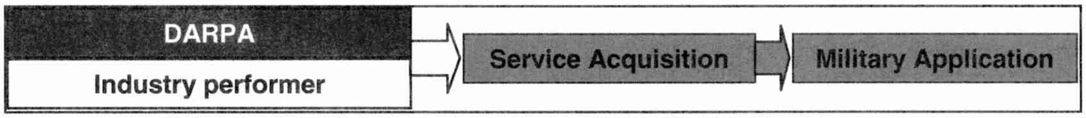

FIGURE B-9

General Comments: The DARPA program manager believes that DARPA should fund its programs for a longer period, entering the early production stage. This would ensure that the product (in this case a material) could be produced at a procurable price. It would enable the industrial manufacturers to go beyond the "gee whiz" phase and bridge the gap between producing one versus one thousand products.

Another problem discussed was program manager turnover. The program manager noted that with DARPA program manager turnover, the program advocate goes away, which hampers the transition link between the Services and DARPA. This weak link also affects industry. They want to be assured of a long-term commitment on behalf of the government prior to investing their own funds.

(14) LASER BRIGHTNESS VERIFICATION PROGRAM

Background: During fiscal years 1990 and 1991, Congress appropriated a total of $10 million to DARPA for the specified purpose of beginning a program in laser brightness verification. Due to the uncertainties of this technology, in FY91, a feasibility study was initiated by DARPA. This study was led by Lawrence Livermore National Laboratory (LLNL) and done in collaboration with Los Alamos National Laboratory (LANL), Sandia National Laboratory (SNL), and Argonne National Laboratory (ANL). The effort was divided so that each laboratory was working in an area of specialized expertise and existing technologies. LLNL pursued the development of a solid state imaging device (camera) and associated software. LANL was the lead for lidar work. SNL focused on radiometer development and ANL on nephelometer[43] instrumentation.

Program Objectives: The purpose of the Laser Brightness Verification Program was to design, fabricate, and test a model suite of sensor hardware suitable to measure the brightness of ground-based lasers capable of anti-satellite missions. It was expected that the knowledge and experience gained from the program would be useful to the U.S. in understanding the feasibility of verifying limits on the brightness of ground-based high-power laser systems.

Transition Status: Based on an interview with the DARPA program manager, the final outcome of the feasibility study was that in principle, the measurement could be accomplished but only under very favorable conditions. This coupled with the end of the Cold War, determined the fate of the program. DARPA decided not to follow through with a verification demonstration, terminating the program

Transition Plan/Path: The program was never formulated to the point of identifying a transition plan.

General Comments: Midway through the program, the JASON, a prestigious academic defense program review panel undertook a review of this program. Their recommendations included: an admonition that the overall goal of the program should be the development of a suite of infrared (IR) instruments suitable for carrying out a verification demonstration; team efforts should be encouraged; an arms control framework was needed to provide a context for technical planning and decision making; and an investigation of secondary observables and cooperative measures was needed. We tried numerous sources to retrieve a copy of the final report prepared by the National Laboratories but have been unsuccessful. The DARPA program manager no longer holds a copy of the report and we could not locate one via the Defense Technical Information Center (DTIC).

(15) LIGHT APPLIQUÉ SYSTEM TECHNOLOGY (LAST®)

Background: In the fall of 1990 as the Gulf War was escalating, there was concern about Iraqi artillery and the insufficient protection for Marine Corps Light Armored Vehicles (LAVs). The SecDef contacted DARPA and asked if they had any technology available that could be rapidly prototyped and quickly manufactured to protect the light armored forces. The DARPA Materials Program had already developed the Lanxide cermet material, a ceramic metallic composite produced by a unique material manufacturing process. But they had not yet determined how to apply this technology to the vehicles. The Armor/Anti-Armor Joint Program had developed a technology that was a rugged fabric with hooks and loops similar to Velcro. When the call came in from the SecDef, DARPA brainstormed and realized that these two technologies could probably be combined to produce a tile that would be strong enough, lightweight enough, and easily and quickly applied. The result was the Light Appliqué System Technology (LAST®). In less than 90 days, DARPA had LAST® kits available and mounted on 75 Marine Corps LAVs. They were ready for deployment but, because the Gulf War ended quickly, the vehicles were too

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[43] An apparatus used to measure the size and concentration of particles in a liquid by analysis of light scattered by the liquid.

late to enter combat. For the LAST® armor project only, it's estimated that DARPA expended approximately $2 million. This figure excludes the Lanxide and Velcro technologies.

Program Objectives: To quickly identify, prototype, and produce a material that would provide the top of the Marine Corps LAV with sufficient protection from fragments at very low aerial density that might be delivered by Iraq's large arsenal of artillery.

Transition Status: Despite the fact that the 75 Marine Corps LAVs were never deployed, the technology was tested and field proven with the USMC LAV-25 in Pacific, South West Asia and Mediterranean theaters. Canadian forces adapted the LAST® system to their vehicles (similar to the LAV, but called the "Grizzly"). Their vehicles served in Bosnia and Croatia. LAST® Armor a subsidiary of Foster Miller, continues to market and produce LAST® technology. It is currently being applied to C130s and C141s in the following areas: flight station walls; flight station floors, flight station seats; crew bunk; crew LOX bottle; troop LOX bottle; loadmaster seats/paratroop doors; nose wheel compartment; and galley floor. LAST® has also been applied on the USMC Dragoon and Chrysler Peacekeeper and the French VAB. In addition, LAST® Armor is producing a civil application called the Frag Bag. This is a unique bomb box that dissipates and deflects blast up and away from personnel and public. It's man portable, highly deployable and fits in the trunk of a cruiser. It has been successfully tested by Los Alamos National Lab and New Mexico State Police bomb technicians.

Transition Plan/Path: This program followed the DSA path. It was a direct transition into the Marine Corps and eventually the other Military Services as LAST® Armor developed and proved additional applications.

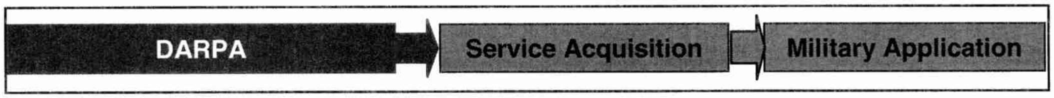

FIGURE B-10

General Comments: This is a sterling example of DARPA's unique abilities. In less than three months time, DARPA was able to meet a serious military threat with a unique highly successful technology that continues to grow and provide increasing uses for other applications. This is certainly not the norm for DARPA but most likely, few other military organizations would have had the capability or ability to come close to the quick response that DARPA highly successfully met.

(16) RF VACUUM MICROELECTRONICS

Background: Vacuum microelectronics describes a device technology based on arrays of sub-micron-size field emission sources. Presently, gated field emitter arrays have achieved values of normalized transconductance (97 Siemens/cm2) and average electron current density (1 kA/cm2) that exceed the limits of gridded thermionic cathodes by orders of magnitude. The advent of practical high-performance gated emitters would have particular impact on microwave and mm-wave source technology. Such emitters, which combine the advantages of solid-state microfabrication with those of electron transport in vacuum, would enable the development of new classes of emission-gated amplifiers. This type of amplifier offers distinct advantages to the system designer in terms of increased specific power, i.e., power per unit weight, and efficiency, leading to substantial reduction in size weight, and ease of thermal management. In FY 1991, DARPA initiated an early phase effort in design and concept validation for which the suitability of vacuum microelectronics technology for radio frequency (RF) power amplification was to be demonstrated.

Program Objectives: The goal of the program was to expand low frequency, high power to high frequency high power outputs to enable high power 94 Ghz radars to find "stealthy" objects. It was both a DARPA vision and a DoD need. Unless the technology can be advanced far enough, the radars will not be working at the level needed for signature reduction capabilities likely to be in the hands of our adversaries.

Transition Status: The former DARPA program manager interviewed for this project stated that this is a very difficult problem and transition into a radar system has not yet occurred. He also indicated that it may take many more years before any results warrant transition into a fielded military system. DARPA transitioned the program in the 1994/95 time period to ONR and NRL. NRL had been the technical and contractual agent for DARPA throughout the DARPA program. To illustrate the likelihood that this research will continue, we cite ONR sponsored BAAs from 1999 and 2000 that state: "...the Naval Research Laboratory is seeking proposals for innovative technology base development in the broad area of RF vacuum electronics. Areas of interest include, but are not limited to: (1) advanced high power millimeter-wave amplifiers suitable for radar and electronic warfare applications; ... (5) supporting technology to advance RF vacuum electronics..." The Army also issued a BAA in 2000: "The Army requires study and development in the areas of the following high-power vacuum electronics RF sources for electronic warfare, countermeasures, communications, and radar systems..."

Transition Plan/Path: This program is following the DS&T transition path, from DARPA to NRL. At the outset of this program, the DARPA program manager viewed this technology as extremely difficult and high-risk. But, since high-risk is inherent in the DARPA mission, it was a technology he felt that DARPA should invest in. With the knowledge that he was pursuing long-term research in a difficult area his transition plan did not go beyond transitioning the technology into the Services S&T for additional research. From that standpoint, his program was a success. However, for our purposes, since this technology is not yet fielded, we have not counted it in the "success" column.

General Comments: This program falls into the category of an early technology base project where DARPA does not expect any near-term transition success. They undertook the pursuit of this technology because they had the foresight and understanding of the importance that this technology would have to the military. DARPA's budget permitted an initial program that generated sufficient results and interest so that the Services S&T organizations were able to justify continuing the research.

(17) SPEAKEASY ADVANCED TACTICAL RADIO SYSTEM

Background: SPEAKeasy introduced a revolution in the prevailing architectural infrastructure of radio communications systems. SPEAKeasy presented a well-defined standardization of interfaces and functions that allows interoperability and flexibility of radio systems not previously attained. It promulgated "open systems" architecture, focused on modularity by function (not waveform). SPEAKeasy was a program to develop and demonstrate an affordable, highly advanced, programmable RF communications resource featuring simultaneous, multiband, multimode operations and networking across the frequency band of 2 MHz to 44.5 GHz. Its premise was that software wave forming would enable one radio to simultaneously perform functions that previously required separate radios. The ultimate goal was the achievement of a framework that all DoD tactical communication systems could evolve to, thus creating a seamless environment that is flexible, reliable and cost effective.

The SPEAKeasy program appeared on two sources as a FY 1991 start. It wasn't until further investigation that we discovered the program started in the Air Force (Rome Labs) and then transferred to DARPA in FY 1993. However, since SPEAKeasy has not been addressed in previous transition studies and we collected very good data about the transition of this program, we determined that it was worthwhile to continue the case study.

SPEAKeasy was initiated by the Air Force (and in concert with the Army) as a Balanced Technology Initiative (BTI). When the BTI program dissolved, the Air Force asked DARPA to continue the research in this innovative area. DARPA agreed and set up a five year research program. Phase I, completed in 1995, developed a feasibility model (brassboard) for laboratory evaluation. This reprogrammable, two-channel model was built by Hazeltine Corporation and included HF, VHF, and UHF operation. Phase II commenced in June 1995 with a contract to Motorola to produce a smaller, compact model that would be more useful and compatible with field needs. Although six channels were the goal, due to a funding shortage, only four channels were completed. This advanced software reprogrammable modem was tested during the Task Force XXI exercise in April 1996. It exceeded expectations and proved immensely successful in allowing ground to air communications. However, six months after the start of Phase II, the new DARPA Director determined that DARPA should not continue research in this area and directed that the program be transitioned immediately. The final 30 months of the program funding was swept.

When DARPA approached the Air Force and Army to accept the SPEAKeasy technology that had been developed to date, but both Services were hesitant. The Army said they had no dollars in the POM to cover this and the Air Force said they wanted a product, not just a technology. Eventually they did agree to carry on the technology development for a while, but at a low level of funding. As all of this was happening, a quirk of fate stepped in. The SPEAKeasy program manager was attending a government retirement seminar and during a break happened to converse with an OSD staff person. This person became very excited about the concept and shortly thereafter formed a working group to investigate the technology. This study led to a Management Implementation Plan on the Joint Tactical Radio Systems (JTRS) signed by Dr. Jacques Gansler, the USD(AT&L), on December 19, 1997. This memorandum in essence directed all the Services to integrate the JTRS open architecture and incorporate hardware and software modules into all their weapons and communications systems (past, present, and future).

Program Objectives: The purpose of the SPEAKeasy program was to develop and demonstrate an affordable, highly advanced, programmable RF communications resource featuring simultaneous, multiband, multimode operations and networking across the frequency band of 2 MHz to 44.5 GHz. This would enable one radio to simultaneously perform functions that previously required separate radios. The ultimate goal was the achievement of a framework that all DoD tactical communication systems could evolve to, thus creating a seamless environment that is flexible, reliable and cost effective.

Transition Status: While the Navy had not contributed financially to the SPEAKeasy program, they maintained a keen interest in the technology throughout the developmental years. In 1997, they decided to leverage SPEAKeasy technology for their Digital Maritime Radio (DMR) and have been buying production quantities from Motorola. Although when SPEAKeasy began, it was dedicated to military radio usage, current commercial cell phones have adopted and are using SPEAKeasy technology. As stated before, the OSD study led to the Management Implementation Plan on JTRS on December 19, 1997. This memorandum in essence directed all the Services to integrate the JTRS open architecture (SPEAKeasy architecture) and incorporate hardware and software modules into all their weapons and communications systems (past, present, and future). This technology is also central to the DARPA Airborne Communications Node (ACN) program.

Transition Plan/Path: This program followed the DS&T transition path. Under DARPA management, a joint Service development office was established with Rome Laboratory as the executive agent. Integrated Air Force, Army, Navy and National Security Agency agreements that had been initiated between Rome Laboratory and the participating agencies continued. A consortia was formed, the Multi Band Multi Mode Radio (MBMMR) Forum, in late 1995. This was dedicated to adopting interface standards, specifications, and protocols that the developers voluntarily would build to. The Forum, open to Industry and Government, allowed for the exchange of ideas between developers and users, engendered an enlarged market base, and created new market opportunities. This Forum continues under a new name, the Modular Multifunction Information Transfer System (MMITS). Recognizing that SPEAKeasy-type technology has global application, MMITS Forum members are participating in discussions with International Telecommunications Union (ITU) and the European Union (EU) groups that are planning for the development of global deployment of 3rd generation wireless systems.

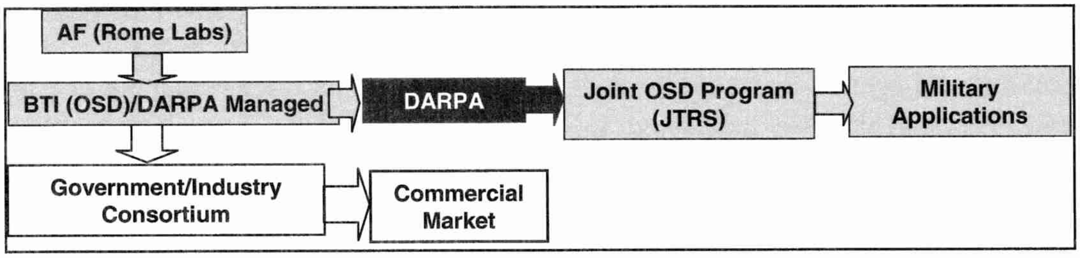

FIGURE B-11

General Comments: The program manager we interviewed felt that from the beginning SPEAKeasy labored under a misunderstanding of what the technology was really about. Many individuals assumed this was a new kind of radio and failed to understand that it was a computer architecture that allowed the other radios to communicate. He also noted that there was no structured way to accomplish transition, and that DARPA's actions needed to be more consistent. He commented that the Services and other partners are gun-shy when it comes to working with the Agency, because DARPA might not carry the program to completion. As noted in this case, DARPA eliminated the funding with very little notice two and one half years before the project was scheduled for completion.

(18) SUPERCONDUCTING ELECTRONICS CONSORTIUM

Background: This 1991 new initiative was a three-year cost-sharing project for the formation of a Pre-Competitive Consortia for superconducting electronics. The U.S. Consortium for Superconducting Electronics (CSE) was composed of MIT Lincoln Laboratory, Boston University, Cornell University, and State University of New York (SUNY) at Stony Brook. There was no industry involvement in the consortium. DARPA's share of the agreement with the consortium was $15 million. Superconducting electronics was reinvigorated by the 1986 discovery of high-temperature oxide superconductors, an event that globally changed the entire field of superconductivity. The CSE effort was begun during the early stages of DARPA's involvement in HTS and was aimed at base level development.

As an aside, since 1987 DARPA has contributed approximately $200 million (inclusive of the consortium funding) in high temperature superconducting (HTS). A DARPA program in HTS continues today carrying technology to a higher stage, e.g., tunable filters with a higher level of sophistication. Of the $200 million, between $20-$40 million was expended on development and the remainder on applications—form, fit, and function. Much of the material and device development in the U.S. was funded by DARPA where most of the devices and subsystems were targeted at RF and microwave applications. Japan has been the closest foreign competitor in this technology but the U.S. achievements in RF and microwave HTS technology are substantially beyond those of Japan.

Program Objectives: The primary goal for the consortia was to develop basic technology components out of HTS films and an understanding of HTS component RF filter phase shifters. The problem facing the industry at that time was the difficulty in making films that had uniformity and were patterned.

Transition Status: As the consortium ended (1994/95) the technology was still in development; however, significant progress had been gained. Consistent films could now be made of high temperature superconductors, patterned in framework for components. The film had been bench-tested and found to work well but it was not yet field-ready for components.

It took an additional five years before the first HTS components were fielded. DARPA, the Office of Naval Research, and the Air Force Office of Scientific Research funded programs at a large number of laboratories predominantly in the areas of HTS RF and microwave passive components and systems, lower cost refrigerators, and HTS digital junctions and circuits. They have pursued a robust technology infrastructure for design, manufacturing, and cryopackaging. The results are the manufacture of large numbers of films of increasing area (at least 5 cm in diameter) to the sale of commercial (wireless) systems.

Military applications include signals intelligence (SIGINT), and communications intelligence (comint). The 1996 Air Force decision to re-fit the Rivet Joint Aircraft (RC 135) used the latest technology, including HTS. The Navy has taken advantage of HTS technology in their signals intelligence activities at Whidby Island, WA. DARPA also worked closely with the CIA, FBI, and NSA in fielding HTS technology into ground radar activities. The CIA has exploited HTS in many devices that allows increased reliance on the interception of radio frequency information.

Interests of DOD and industry in RF and microwave manufacturing have converged. There is currently a commercially viable HTS microwave filter system technology that is rapidly expanding the wireless communications market in cellular phone bay stations. Primary venders identified by the DARPA program manager are SuperConducting Technologies Inc of Santa Barbara, CA and Conductus, Inc of Sunnyvale, CA.

Transition Plan/Path: This was a Direct-to-Service Acquisition (DSA) transition. The program manager for this program said that at the time the Consortium was formed, there was not a transition plan in mind. The technology was still relatively immature and too early in the process to know what applications would ultimately be viable. As the program progressed however, much energy was devoted into maintaining working relationships with universities and forming new ones with both the Service S&T community and industry. It was this combined effort that ultimately allowed the technology to be fielded. The path shown below reveals that there were many players in the transition from the beginning of the technology. However, DARPA didn't "transition" the technology to these other entities, they worked with them. DARPA sponsored the technology from the beginning and throughout the many phases. They were ultimately instrumental in transitioning the final product into the Services.

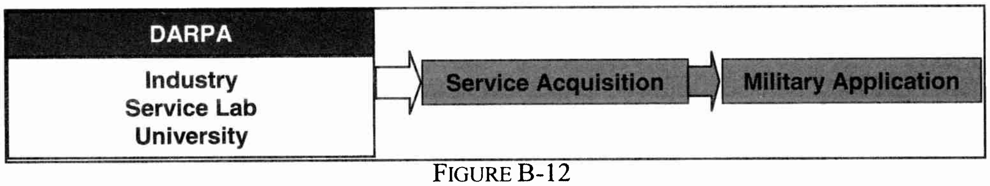

FIGURE B-12

General Comments: An important aspect of transitioning technology to the military is to figure out the role of the commercial sector. Dual applications are extremely important in today's market. Small companies must run a profit, especially those who receive money from venture capitalists (VCs). VCs do not want to just sustain a company, they expect and want to see a profit.

As our other case studies suggest, it often takes at least 15 years to get a new technology to the maturity level necessary for transition. In addition, it is extremely difficult to predict a new technology. Again, it seems efficacious for DARPA to engage a program manager for the duration of a program versus their current rotation policy of approximately 4-year tours. An extended tour would allow a champion to see a new technology from beginning to end thus perhaps precluding a lot of effort from being expended on a new technology that could ultimately be lost (sometimes completely) by having multiple program managers. New program managers do not always have the same interests as those they are replacing and the possibility of having a program shelved or completely redirected is very great. Fortunately, this was not the case for the HTS program.

Appendix C. Definitions and Acronyms

1. Definitions

It is important that we adopt acceptable and consistent definitions of the components of this study. We must be able to measure the subjects of this project as well as the parameters that affect them. In the following, we have defined several of these in the context of this project.

Development Effort. The effort that DARPA undertakes to produce a product may be conducted on a "program" or "project" level. No distinction is made between the two levels of effort. An effort is active as long as someone continues to fund it—that is until it is transitioned into use or the program or project is terminated.

Products. Two kinds of products are defined for the purposes of this study: 1) The DARPA Product is the item delivered by a DARPA effort and may be a system, component, or a Technology; and 2) the Final Product is the final form of the DARPA Product as it is integrated into a fielded system as a system, subsystem or component. The movement from DARPA Product to Final Product is essentially the transition.

New Start. A new project or program at DARPA, defined by one or more of the following indicators in the year of interest:

- Reference as a new start in the Director's testimony to Congress
- Reference as a new start in the Congressional Descriptive Summary
- Reference as a new start in DARPA files
- Reference as a new start in the Completion Briefings
- An initiation or major increase in funding

Transition. For purposes of this study, transition is the insertion of a DARPA Product (in the form of a Final Product) into a fielded *military* system. Evidence of a transition is an expenditure of funds by the adopting service to employ the DARPA Product. In some instances we gave credit for transition into a large developmental program.

Transition Rate. This is the number of transitions per program or per funding dollar. The definition of a successful rate of transition depends on several factors, which are referenced in Stevens and Burley [27] according to:

- Kind of development effort (technology or system)
- Size of development effort (funding level)

Performer. This is the organization actually performing the effort sponsored by DARPA. Performers may be: commercial industry, academia, defense industry, or a government laboratory.

Transition Plan. This is the plan for accomplishing transition adopted by the DARPA program manager.

2. Acronyms

AAI	ACTS ATM International
ABCCC	Airborne Command, Control, and Communications
ACC	Air Combat Command
ACCAT	Advanced Command and Control Architectural Testbed
ACN	Airborne Communications Node
ACOA	Adaptive Courses of Action
ACPT	Air Campaign Planning Tool
ACTD	Advanced Concept Technology Demonstration
ACTIP	Advanced Ceramic Technology Insertion Program
ACTS	Advanced Computational Testing and Simulation
AFB	Air Force Base
AFMC	Air Force Materiel Command
AFOSR	Air Force Office of Scientific Research
AI	Artificial Intelligence
ALP	Advanced Logistics Project
AMCOM	Aviation and Missile Command (Army)
AMLCD	Active Matrix Liquid Crystal Display
AMP	Analysis of Mobility Platform
ANL	Argonne National Laboratory
AON	All-Optical Network
ARPA	Advanced Research Projects Agency
ARPI	ARPA/Rome Planning Initiative
ASC	Airborne Strike Control
ASN(RD&A)	Assistant Secretary of the Navy (Research, Development & Acquisition)
ATACMS	Army TACtical Munitions System
ATD	Advanced Technology Demonstration
ATM	Asynchronous Transfer Mode
ATR	Automatic Target Recognition
AWAC	Airborne Warning and Control System (E-3A Aircraft)
BAA	Broad Agency Announcement
BAT	Brilliant Anti-Tank
BDS	Battlefield Distributed Simulation
BFVS	Bradley Fight Vehicle System
BIT	Broadband Information Technology
BMDO	Ballistic Missile Defense Office
BTI	Balanced Technology Initiative
C4I	Command, Control, Communications, Computers, and Intelligence
CoABS	Control of Agent-Based Systems
CAD	Computer Aided Design
CAMPS	Combined Air Mobility Planning System
CBD	Commerce Business Daily
CCT	Close Combat Training
CCTT	Close Combat Tactical Trainer
CGF	Computer Generated Forces
CIA	Central Intelligence Agency
CINC	Command in Chief
CLADS	Common Large-Area Display System
CLGP	Cannon Launched Guided Projectile
CLU	Command Launcher Unit

COEA	Cost and Operation Evaluation Assessment
COSSI	Commercial Operations Savings and Support Initiative
COTS	Commercial Off-the-Shelf
CSC	Concurrent Super Computing Consortium
CSE	Consortium for Superconducting Electronics
CTO	Chief Technology Officer
CVD	Chemical Vapor Deposition
DARPA	Defense Advanced Research Projects Agency
DART	Dynamic Analysis and Replanning Tool
DIA	Defense Intelligence Agency
DIS	Distributed Interactive Simulation
DIS	DARPA-to-Industry-to-Service acquisition path (Institute abbreviation)
DISA	Defense Information Systems Agency
DISN	Defense Information System Network
DLC	Diamond-like Coating
DLP™	Digital Light Processing™
DMD™	Digital Micromirror Device™
DMR	Digital Maritime Radio
DoD	Department of Defense
DRAM	Dynamic Random Access Memory
DSA	DARPA-to-Service acquisition path (Institute abbreviation)
DSB	Defense Science Board
DSO	Defense Sciences Office
DSP	Digital Signal Processors
DSRC	Defense Science Research Council
DS&T	DARPA-to-Service Science and Technology Organization (Institute abbreviation)
DTIC	Defense Technical Information Center
DUS&T	Dual Use Science and Technology
DVE	Driver's Vision Enhancement
EHF	Extremely High Frequency
EL	Electroluminescent
ELITE	Extended Long-range Integrated Technology Experiment
EU	European Union
EUCOM	U.S. European Command
FAA	Federal Aviation Administration
FBI	Federal Bureau of Investigation
FCPS	Fuel Cell Power System
FIST-V	Fire Support Team Vehicle
FLIR	Forward-looking Infrared
FOG	Fiber Optic Gyroscope
FPA	Focal Plane Arrays
FTTH	Fiber-to-the-Home
FY	Fiscal Year
GaAs	Gallium Arsenide
GAO	Government Accounting Office
GCCS	Global Command and Control System
GE	General Electric
GPS	Global Positioning System
HDDT	High Definition Display Technology
HDS	High Definition System

HDTV	High Definition Television
HiPer-D	High Performance Distributed Experiment
HMMWV	High Mobility Multi-Wheeled Vehicle
HPC	High Performance Computers
HPCC	High Performance Computing and Communications
HTI	Horizontal Technology Integration
HTS	High Temperature Superconducting
IDA	Institute for Defense Analysis
IEMS	Integrated EletroMechanical Systems
IFC	International Fuel Cells Corporation
IMU	Inertial Measurement Units
IOEM	Integrated OptoElectronic Modules
IOEMs	Integrated OptoElectronic Modules
IPA	Inter-governmental Personal Act
IR	Infrared
IRFPA	Infrared Focal Plane Arrays
IRI	Industrial Research Institute
ISO	Information Systems Office
IT	Information Technology
ITAS	In-Theater Airlift Scheduler
ITO	Information Technology Office
ITU	International Telecommunications Union
JFACC	Joint Force Air Component Commander
JHU/APL	Johns Hopkins University/Applied Physics Laboratory
JPT	Joint Planning Tool
JSF	Joint Strike Fighter
JSTARS	Joint Surveillance Target Attack Radar System
JTF	Joint Task Force
JTRS	Joint Tactical Radio System
LAMPS	Light Airborne Multipurpose System
LANL	Los Alamos National Laboratory
LAST®	Light Appliqué System Technology
LAV	Light Armored Vehicle
LBR	Laser Beam Rider
LCD	Liquid Crystal Display
LLNL	Lawrence Livermore National Laboratory
LOCUSP	Low Cost Uncooled System Program
LOX	Liquid Oxygen
LWIR	Long Wave Infrared Camera
MAN	Metropolitan Area Network
MBMMR	Multi-band Multi-mode Radio
MCM	Multi-Chip Module
MCT	Mercury Cadmium Telluride
MDT	Micron Display Technology
MEMs	Microelectronic Mechanical Systems
MICOM	Missile Command
MIMIC	Microwave and millimeter wave monolithic integrated circuits
MMITS	Modular Multifunction Information Transfer System
ModSAF	Modern Semi-Automated Forces
MONET	Multi-wavelength Optical NETworking
MSD	Materials Science Division

NADEP	Naval Aviation Depot
NASA	National Aeronautics and Space Administration
NATO	North Atlantic Treaty Organization
NAVSEA	Naval Sea Systems Command
NAWC	Naval Air Warfare Command
NAWC-CL	Naval Air Warfare Command—China Lake
NDE	Non-Destructive Evaluation
NDR	New Dimension Research, Inc.
NIH	National Institutes of Health
NIST	National Institute of Standards and Technology
NMRI	Naval Medical Research Institute
NRL	Naval Research Laboratory
NSA	National Security Agency
NSF	National Science Foundation
NSIA	National Security Industrial Association
NSWC	Naval Surface Weapons Center
NSWCDD	Naval Surface Weapons Center Dalhgren Division
NVOEL	Night Vision OptoElectronics Laboratory
NVR	Night Vision and Reconnaissance
OC-ALC	Oklahoma City Air Logistics Center
OEM	Original Equipment Manufacturer
ONR	Office of Naval Research
ONTC	Optical Network Technology Consortium
ORD	Operations Requirement Document
OSD	Office of the Secretary of Defense
OTA	Office of Technology Assessment
P&W	Pratt & Whitney
PACAF	Pacific Command Air Force
PACOM	Pacific Command
PDA	Planning and Decision Aid
PDU	Protocol Data Units
PEM	Proton Exchange Membrane
PM	Program Manager
PNVS	Pilot Night Vision System
POM	Program Objective Memorandum
POP	Proof Of Principal
PPBS	Planning, Programming, and Budgeting System
PPDU	Power Plan Demonstration Unit
R&D	Research and Development
RAM	Random Access Memory
RDT&E	Research, Development, Testing and Evaluation
RF	Radio Frequency
RFC	Retirement for Cause
RFP	Request for Proposal
ROC	Required Operation Concepts
ROTHR	Relocatable Over the Horizon Radar
RTIS	Raytheon TI Systems, Inc. (RTIS, formerly Texas Instruments Defense Systems & Electronics (TI DS&E))
S&T	Science and Technology
SATCOM	Satellite Communications
SBIR	Small Business Innovation Research

SCP	Strategic Computing Program
SDI	Strategic Defense Initiative
SecDef	Secretary of Defense
SEP	Systems Enhancement Program
SIGINT	Signal Intelligence
SIMNET	SIMulation NETwork
SNL	Sandia National Laboratory
SOCOM	Special Operations Command
SPARC	Scalable Process Architecture
SRAM	Static Random Access Memory
SSA	Source Select Authority
STARS	Surveillance Target Attack Radar System
STICOM	Simulation, Training and Instrumentation Command
STOVL	Short Takeoff Vertical Landing
STOW	Synthetic Theater of War
SUNY	State University of New York
T4	Technology Transfer/Technology Transition
TAB	Technical Advisory Board
TACMS	TACtical Missile System
TACOM	Tank-automotive and Armaments Command
TADS	Target Acquisition Designation System
TARDEC	Tank Automotive Research, Development, and Engineering Center
TCP/IP	Transmission Control Protocol/Internet Protocol
TI	Texas Instruments
TOW	Tube-launched Optically-tracked Wire-guided
TRANSCOM	U.S. Transportation Command
TRL	Technology Readiness Level
TRP	Technology Reinvestment Project
TSI	Tribology Systems, Inc.
TWT	Traveling Wave Tubes
UAV	Unmanned Air Vehicle
UC	University of California
UFPA	Uncooled Focal Plane Array
USA	United States Army
USAF	Unites States Air Force
USD(AT&L)	Under Secretary of Defense (Acquisition, Technology and Logistics)
USMC	United States Marine Corps
UUV	Unmanned Underwater Vehicle
VC	Venture Capitalist
VCSEL	Vertical Cavity Surface Emitting Laser
VLSI	Very Large Scale Integration
WAM	Wide Area Mine
WDM	Wavelength Division Mulitplexing
WL/FI	Wright Laboratory Flight Dynamics Directorate
WPAFB	Wright-Patterson Air Force Base (Ohio)

Appendix D. References

F. Previous Studies

The principal difficulty in conducting a retrospective study of any issue that demands insight into the Agency's past programs lies in data collection. As discussed later, the records of programs and program funding are often contradictory or nonexistent. Interviews with past DARPA and industry program managers' help, but time tends to polarize perceptions of what happened and why, so there is also disagreement among players. One growing source of information is the studies and reports funded by DARPA over the years. Although these are episodic chronicles and leave significant gaps in our knowledge, they afford the best insight into the trends in DARPA's program history. Noting the lack of a survey article on these publications, we felt it worthwhile to list those we thought presented the best coverage of DARPA's program history. Although we were interested primarily in transition, we believe this Appendix represents a fairly complete list of references. We feel the ten references cited below offer the most comprehensive coverage of various program areas or historical eras.

1. *Technology Transition* [21] is the best publication for general information about DARPA programs, which transitioned products to the military. This document, written in 1997, also provides the most up-to-date listing of programs. There are about 90 programs described.
2. *DARPA Technical Accomplishments: An Historical Review of Selected DARPA Projects, Volumes I-III* [3] covers major programs up to around 1990. It contains case studies on about 45 programs.
3. *Technology Reinvestment Project (TRP) Review Project Study Report* [19], published in 1999, offers 113 case studies of nearly all of the programs conducted under the TRP program and offers aggregated statistics on its history, transition, commercial usage, and DARPA's unique management practices.
4. *MARITECH Program Impacts on Global Competitiveness of the U.S. Shipbuilding Industry and Navy Ship Construction* [12] reports on DARPA's MARIECH program, with data and conclusions gained from visits to 13 shipyards. This study was conducted in 1998.
5. *Uses of DARPA Materials Sciences Technologies in DoD Systems* [24], written in 1996, provides insights into 19 materials programs with information about the conduct of the programs and their application.
6. *History of the Information Processing Techniques Office of the Defense Advanced Research Projects Agency* [11] discusses DARPA's experience in Information processing up to 1992. This report is organized by technology thrust rather than programs, but presents an excellent summary of the Agency's history in one of its premier areas of involvement.
7. *Study: The Defense Advanced Research Projects Agency's Technology Transfer Process* [18], a study of DARPA's transition and transfer methodology, was written in 1985, but many of the observations and recommendations ring true today.

8. *Technology Transfer at the Defense Advanced Research Projects Agency: A Diagnostic Analysis* [20], also written in 1985, is an analysis of DARPA's transition processes by a prestigious panel, led by a researcher who studied the Agency over a period of years.

9. *DSRC Study on Technology Transfer/Technology Transition* [6] is the most recent study on transition at DARPA (except for this one). It is the result of interviews and briefings by numerous DARPA alumni, industrial participants in DARPA programs and academics.

10. *Investment Strategy for DARPA* [10] is a report of a Defense Science Board examination of DARPA conducted in 1999. The report does not focus on transition, but presents helpful data and conclusions on associated issues.

There is excellent information in these reports but, they concentrate on the large, well-publicized successes of the Agency and lack information on many important aspects on even those programs (e.g., funding). There are also gaps of time and technology area that have received little attention. These flaws in DARPA's database can only be corrected by a real-time effort to collect and analyze transitions as they occur. The feedback from such an effort would be instantaneous and much more helpful to the Agency's program managers.

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