Calhoun: The NPS Institutional Archive

DSpace Repository

Theses and Dissertations	1. Thesis and Dissertation Collection, all items

1990-12

Impact of the defense Critical Technologies Plan on weapon systems Test and Evaluation

Romero, Edward Charles

Monterey, California: Naval Postgraduate School

https://hdl.handle.net/10945/27656

This publication is a work of the U.S. Government as defined in Title 17, United States Code, Section 101. Copyright protection is not available for this work in the United States.

Downloaded from NPS Archive: Calhoun

http://www.nps.edu/library

Calhoun is the Naval Postgraduate School's public access digital repository for research materials and institutional publications created by the NPS community. Calhoun is named for Professor of Mathematics Guy K. Calhoun, NPS's first appointed -- and published -- scholarly author.

Dudley Knox Library / Naval Postgraduate School
411 Dyer Road / 1 University Circle
Monterey, California USA 93943

NAVAL POSTGRADUATE SCHOOL
Monterey, California

AD-A242 952

DTIC
ELECTE
DEC 5 1991
S D
C

THESIS

IMPACT OF THE DEFENSE CRITICAL TECHNOLOGIES PLAN ON WEAPON SYSTEMS TEST AND EVALUATION

by

Edward Charles Romero

DECEMBER 1990

Advisor: Dick Doyle

Approved for public release: Distribution is unlimited

91-17028

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved OMB No 0704-0188

1a REPORT SECURITY CLASSIFICATION: Unclassified	1b RESTRICTIVE MARKINGS
2a SECURITY CLASSIFICATION AUTHORITY	3 DISTRIBUTION / AVAILABILITY OF REPORT: Approved for public release: Distribution is unlimited
2b DECLASSIFICATION / DOWNGRADING SCHEDULE	
4 PERFORMING ORGANIZATION REPORT NUMBER(S)	5 MONITORING ORGANIZATION REPORT NUMBER(S)
6a NAME OF PERFORMING ORGANIZATION: Naval Postgraduate School; 6b OFFICE SYMBOL (If applicable): AS	7a NAME OF MONITORING ORGANIZATION: Naval Postgraduate School
6c ADDRESS (City, State, and ZIP Code): Monterey, CA 93943-5000	7b ADDRESS (City, State, and ZIP Code): Monterey, CA 93943-5000
8a NAME OF FUNDING / SPONSORING ORGANIZATION; 8b OFFICE SYMBOL (If applicable)	9 PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER
8c ADDRESS (City, State, and ZIP Code)	10 SOURCE OF FUNDING NUMBERS: PROGRAM ELEMENT NO; PROJECT NO; TASK NO; WORK UNIT ACCESSION NO

11 TITLE (Include Security Classification)
IMPACT OF THE DEFENSE CRITICAL TECHNOLOGIES PLAN ON WEAPON SYSTEMS TEST AND EVALUATION

12 PERSONAL AUTHOR(S)
EDWARD CHARLES ROMERO

13a TYPE OF REPORT	13b TIME COVERED	14 DATE OF REPORT (Year, Month, Day)	15 PAGE COUNT
Master's Thesis	FROM _____ TO _____	DECEMBER 1990	145

16 SUPPLEMENTARY NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government

17 COSATI CODES			18 SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
FIELD	GROUP	SUB-GROUP	test and evaluation, critical technologies plan, technology

19 ABSTRACT (Continue on reverse if necessary and identify by block number)

This thesis analyzes the impact of the Critical Technologies Plan (CTP) on planning and budgeting activities associated with weapons systems Test and Evaluation (T&E). It discusses the intent and purpose of the CTP. It develops the role and functional areas of T&E. Lastly, it analyzes the relationship between the objectives and processes involved in weapon systems T&E and the purpose of the CTP.

The CTP is deemed to have a significant impact on T&E. Thirteen out of 20 critical technologies are concluded to be capable of making major contributions in 11 of the 13 T&E functional areas.

It is recommended that personnel from the Deputy Director, Defense Research and Engineering (Test and Evaluation) be placed on the working group responsible for developing the CTP. Further, it is recommended that the T&E community view the CTP not only as a method of anticipating future weapons, but as a process to acquire and advance T&E technologies.

20 DISTRIBUTION / AVAILABILITY OF ABSTRACT	21 ABSTRACT SECURITY CLASSIFICATION	
☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT ☐ DTIC USERS	unclassified	
22a NAME OF RESPONSIBLE INDIVIDUAL: Dick Doyle	22b TELEPHONE (Include Area Code): (408) 646-3302	22c OFFICE SYMBOL: AS

DD Form 1473, JUN 86 — Previous editions are obsolete — SECURITY CLASSIFICATION OF THIS PAGE

S/N 0102-LF-014-6603

UNCLASSIFIED

Approved for public release: Distribution is unlimited

Impact of the Defense Critical Technologies Plan on Weapon Systems Test and Evaluation

by

Edward Charles Romero
B.S., Engineering,
California State University, Northridge, 1985

Submitted in partial fulfillment of the
requirements for the degree of

MASTERS OF SCIENCE
IN MANAGEMENT

from the

NAVAL POSTGRADUATE SCHOOL

DECEMBER 1990

Author: [redacted]
Edward Charles Romero

Approved by: [redacted]
Dick Doyle, Thesis Advisor

[redacted]
Lyle K. Hochberger, Second Reader

[redacted]
David R. Whipple, Chairman
Administrative Science

ABSTRACT

This thesis analyzes the impact of the Critical Technologies Plan (CTP) on planning and budgeting activities associated with weapons systems Test and Evaluation (T&E). It discusses the intent and purpose of the CTP. It develops the role and functional areas of T&E. Lastly, it analyzes the relationship between the objectives and processes involved in weapon systems T&E and the purpose of the CTP.

The CTP is deemed to have a significant impact on T&E. Thirteen out of 20 critical technologies are concluded to be capable of making major contributions in 11 of the 13 T&E functional areas.

It is recommended that personnel from the Deputy Director, Defense Research and Engineering (Test and Evaluation) be placed on the working group responsible for developing the CTP. Further, it is recommended that the T&E community view the CTP not only as a method of anticipating future weapons, but as a process to acquire and advance T&E technologies.

Accession For
NTIS GRA&I
DTIC TAB
Unannounced
Justification
By
Distribution/
Availability Codes
Dist | Avail and/or Special
A-1

TABLE OF CONTENTS

I. INTRODUCATION 1

A. BACKGROUND 1

B. OBJECTIVES 2

C. RESEARCH QUESTION 3

D. SCOPE, LIMITATIONS AND ASSUMPTIONS 4

E. METHODOLOGY 7

F. ORGANIZATION OF STUDY 8

II. CRITICAL TECHNOLOGIES PLAN 10

A. ORIGINATION 10

B. LEGISLATIVE INTENT 12

C. THE 1989 CRITICAL TECHNOLOGIES PLAN 13

D. 1990 CRITICAL TECHNOLOGIES PLAN 21

E. 1991 CRITICAL TECHNOLOGIES PLAN 31

III. WEAPON SYSTEM TEST AND EVALUATION 33

A. PURPOSE AND ROLES 33

B. CATEGORIES OF TEST AND EVALUATION 35

C. IMPORTANCE/CONTRIBUTIONS 40

D. TEST AND EVALUATION RESOURCES AND PLANNING . 45

E. NEEDED TEST AND EVALUATION RESOURCES 51

IV. IMPACT OF THE CRITICAL TECHNOLOGIES ON THE TEST AND EVALUATION FUNCTIONS 66

A. REACTIVE IMPACT 66

B. PROACTIVE IMPACT 70

V. CONCLUSIONS AND RECOMMENDATIONS 87

A. CONCLUSIONS 87

B. RECOMMENDATIONS 91

APPENDIX A. PUBLIC LAW 100-456, SECTION 823 93

APPENDIX B. PUBLIC LAW 101-189, SECTION 605 95

APPENDIX C. BILL S.2884, SECTION 801 99

APPENDIX D. SUMMARY OF CRITICAL TECHNOLOGIES 103

BIBLIOGRAPHY 133

INITIAL DISTRIBUTION LIST 137

I. INTRODUCTION

This introduction provides the background and objectives for this thesis. It includes a list of research questions answered throughout the description and analysis. The scope, limitations and assumptions made during the formulation of the framework is described. The next section discusses the methodology employed during the collection and analysis of data. Finally, the organization of this thesis is provided.

A. BACKGROUND

Growing challenges to U.S. dominance of fields such as computing, superconductivity, and semiconductor manufacturing have led some in Congress to advocate a more aggressive role in spurring developmental technologies. This opinion was reaffirmed in a recent report from the Senate Armed Services Committee:

> The recent dramatic events in Eastern Europe and the Soviet Union only reinforce the need for a comprehensive science and technology policy.[1]

Because U.S. defense depends upon state of the art technology, and DoD funds a significant share of total U.S.

---

[1] Senate Armed Services Committee, *Acquisition Policy and Management Report,* 1990 p. 179.

support for research and development, DoD technology policy can be seen as both part of the problem and solution.

Public Law 100-456, and subsequent legislation requiring the DoD to submit an annual Critical Technologies Plan (CTP) for identifying and developing technologies, is one important response to this problem. These technologies are to be those which are critical to the superiority of American weapon systems.

Another approach to insuring the superiority of weapon systems is Test and Evaluation (T&E). The fundamental purpose of T&E is to identify the areas of risk to be reduced or eliminated. Test and evaluation is conducted to demonstrate and determine the feasibility of conceptual approaches, to minimize design risk, to identify design alternatives, to compare and analyze tradeoffs, and to estimate operational effectiveness and suitability.

B. OBJECTIVES

This thesis explores these two aspects (CTP and T&E) of weapon systems development and discusses their potential inter-relationship. It discusses the relationship between the objectives and processes involved in test and evaluation of weapon systems and the purpose of the Critical Technologies Plan. It analyzes the impact of the CTP on planning and budgeting activities associated with weapons systems test and evaluation. Finally, it suggests inputs which the T&E

community might provide to future Critical Technology Plans and the manner in which T&E planners might benefit from the CTP approach.

Legislation requires the Secretary of Defense to submit an annual plan for identifying and developing technologies critical to the Department of Defense (DoD). The CTP is a new approach to allocating research and development resources within DoD. Two reports have been completed, and there is reason to believe that the new requirements associated with CTP may continue and, in fact, be expanded in the foreseeable future. Therefore the T&E community should understand what it may mean for them and how they might impact the CTP. Few have thought about the CTP from this perspective. Because the implementation of the CTP is still in the formative stages, it is possible to have some impact.

C. RESEARCH QUESTION

1. Primary Research Question

What are the major impacts on weapons systems testing and evaluation (T&E) of the requirement for a Department of Defense Critical Technologies Plan (CTP)?

2. Subsidiary Research Questions

What is the CTP?

What is the legislative origin and intent of the statute which established the CTP?

What are the legal requirements?

What did the 1989 and 1990 CTPs encompass?

What are the purposes and processes of testing weapons systems?

Why is testing important?

What are its contributions to national security?

What are the major categories of testing?

What technological resources are needed to evaluate weapons systems?

What are the purposes and processes of evaluating weapons systems?

Why is evaluation significant?

What are its contributions to national security?

What are the major categories of evaluation?

What technological resources are needed to evaluate weapons systems?

How might the CTP influence T&E?

What are the potential advantages, from a T&E perspective, of the CTP and the goals it seeks to achieve?

Given the requirements for weapons systems testing, what inputs to the CTP would the T&E community recommend?

What might the T&E community learn from the CTP?

D. SCOPE, LIMITATIONS AND ASSUMPTIONS

1. Scope

This thesis is divided into four sections. These sections include an examination of the CTP, the role of T&E,

potential impacts of the CTP on T&E, and recommendations and conclusions.

First, the purpose of the CTP is discussed. Specific issues consider the problem it addresses, how it intends to solve this problem, and its requirements for DoD. Additionally, a description of the two CTPs which DoD has completed is included in Appendix D. However, insight is limited because this is a new and very demanding requirement, and implementation is still in a formative stage. Gaining information about implementation was difficult for this same reason.

Second, the role of T&E - its processes, purposes, importance and major categories - is described. The question of how T&E initiates new technology into weapon systems is emphasized. Potential impacts of the CTP on T&E is highlighted in the third section. This includes the manner in which T&E needs and processes might be factored into the CTP process.

Finally, the analysis generated some recommendations regarding the manner in which the CTP process might be improved to address T&E requirements. It also suggests how the T&E community might take advantage of the CTP process.

2. Limitations and Assumptions

a. General Limitation

This thesis is not advocating that advanced technology is the only method in which the T&E community should further its capability. A systems engineering approach is appropriate for designing new T&E systems. Reliability, maintainability, availability, supportabilty, manability, cost, and schedule should be considered when designing and procuring the system. Advanced technology is only one factor in maintaining the capability of T&E systems.

b. Test and Evaluation Functions

In Chapter III, where the functions needed to perform T&E are developed, a generic test facility is analyzed. Individual facilities within the Major Range and Test Facility Base (MTRFB) may have specialized needs. Therefore, the T&E functions identified and used to evaluate the impact of the CTP may not apply or cover all activities at individual facilities.

Also, it is assumed that proper pre-test planning has occurred in identifying the T&E functions. The discussion focuses on technologies needed to perform T&E. Therefore, the planned test is assumed to provide the raw data necessary for the associated decision.

E. METHODOLOGY

Data was gathered through interviews with officials at White Sands Missile Range (WSMR), NM and the Pacific Missile Test Center (PMTC), Point Mugu, CA. The Technical Director was interviewed at White Sands. Other interviews conducted at WSMR included personnel from the Army Materiel Test and Evaluation Directorate, National Range Operations Directorate and Nuclear Effects Directorate. The Assistant Executive Director and personnel from the Weapons Evaluation Directorate were interviewed at PMTC. Strategic plans and mission statements were also used to describe the technological requirements of the T&E community.

Review of congressional testimony and discussion with a congressional staff member provided background and insight into the CTP. Personnel from the Office of Deputy of Defense Research and Advanced Technology and the Office of the Secretary of Defense (Legislative Affairs) were also interviewed. In addition, a professor of T&E Management, and supervisor personnel at the Defense Systems Management College contributed.

Current articles from defense policy journals, statutory law, committee reports and testimony, documents related to legislative intent, DoD T&E management guides and the two CTPs were used for background and analysis. This documentation is referenced in the bibliography.

A bibliography search was conducted through the Defense Logistics Studies Information Exchange. Further literature research was conducted through the Dudley Knox library at the Naval Postgraduate School and Defense Systems Management College.

Data analysis consisted of consolidating information and analyzing it in accordance with the framework described here. General public policy analysis techniques and management concepts aided in developing the relationship between the CTP and T&E. The author's personal work experience and contacts in the T&E community were used to assess the technological needs of the T&E community.

F. ORGANIZATION OF STUDY

1. Introduction

The introduction identifies the purpose and scope of the thesis. It includes the reasons for the study and a general description of the study.

2. Critical Technologies Plan

The background and the requirement for the CTP is explored. Insight to its legal requirements and legislative intent for DoD is provided. Congressional responses to the first two plans are examined.

3. Test and Evaluation

This chapter discusses the process, purpose, importance and major categories of T&E. The discussion

includes technology policy issues involving integration of new technology, resources, costs, and operational performance.

4. Impact of Critical Technologies Plan on Test and Evaluation

A discussion of the relationship between the CTP and weapons systems test and evaluation is presented. This relationship was found through analysis and interpretation of the facts and opinions coming from the research literature and interviews. Interpretation also relies on the author's personal T&E experiences and contacts within the T&E community.

5. Recommendations and Conclusions

This discussion focuses on what the CTP might mean to the T&E community, its impact and how the technological needs of the T&E community can be furthered within the framework of the CTP.

6. Appendices A, B, and C

These appendices contain reproductions of the 1988, 1989 and 1990 legislation requiring the submittal of the CTP.

7. Appendix D

This appendix summarizes the 1989 and 1990 CTPs. The differences between the two plans are identified and discussed.

II. CRITICAL TECHNOLOGIES PLAN

This chapter describes the two Critical Technologies Plans (CTPs) submitted by the Department of Defense (DoD) to Congress. It starts with a discussion of the origination and legislative intent of the Critical Technologies Plan (CTP). The origination section deals with the events leading up to the initial requirement for a joint DoD and Department of Energy (DoE) CTP. The legislative intent portion attempts to examine the purpose of the CTP. Subsequently, the legal requirements, planning process, selected critical technologies, and reactions to the 1989 and 1990 CTPs are addressed. In the segment on selected technologies in the 1990 plan, a discussion of the prioritizing process is included. Lastly, the 1991 anticipated legislation is reviewed.

A. ORIGINATION

The Subcommittee on Defense Industry and Technology of the Senate Armed Services Committee has the responsibility for ensuring that the United States technology and industrial base remains strong to support the national security strategy. In the spring of 1988 the subcommittee heard several reports that these foundations were deteriorating. The 1987 Defense Science Board study on Technology Base Management, chaired by

Massachusetts Institute of Technology Provost John Deutsch concluded that "our national technological advantage has eroded significantly in recent years."

Also, at a 1988 hearing, Dr. Cliff Duncan, Director of Defense Research and Engineering, testified that the DoD software producibility program was underfunded, despite the urgency addressing that problem.[2] In addition, there was concern that DoD and DoE were not taking advantage of all resources available. This situation led to the question of whether truly critical technologies were severely underfunded in the DoD request to the Congress and whether the DoD had a prioritized science and technology (S&T) program.

Senator Jeff Bingaman, Chairman of the Subcommittee on Defense Industry and Technology, originated the idea of requesting the DoD and the DoE to jointly submit a CTP. This plan was originally expected to identify ten technologies that were considered to be the most significant to the long-term superiority of US weapons systems. After some discussion, the requirement for ten technologies was thought to be too restrictive and the number was increased to twenty.

The first and second CTPs were required by Public Laws 100-456 September 29, 1988 and 101-189 November 29, 1989 respectively. Senate bill S.2884 was introduced July 10, 1990

---

[2] Senator Jeff Bingaman, *Hearings before the Committee on Armed Services, United States Senate, Part 7 Defense Industry and Technology*, March 17, 1989, p. 2.

to renew the requirement for the CTP. Each year these laws have changed slightly in scope and conditions. However, the basic purposes and intent of this policy have not changed.

B. LEGISLATIVE INTENT

The requirement for the CTP has several prominent and implied purposes. First, the most obvious purpose is to identify, prioritize, consolidate and focus critical technologies requirements and milestones within DoD and DoE. Second, with these technologies identified, the list can be used to allocate resources in the budgeting process. Third, it provides an avenue for the Congress and DoD to scrutinize and manage programs that employ these critical technologies. The plan can serve as a roadmap for both the Congress and DoD to follow in the oversight of the technology base programs. Lastly, the policy requires that we compare the US with foreign countries on the progress in each critical technology area. This last condition allows for monitoring of foreign progress and possibly enhanced cooperation between allies by describing their relative strengths and weaknesses.

Underlying these goals are others, starting with the requirement for DoE and DoD to submit a joint plan. This condition was meant to strengthen the coordination between the two agencies. This requirement would also facilitate the contribution of DoE's weapons laboratories in meeting the DoD critical technology needs. The plan can also be used as a

"report card," identifying advances and deficits in the pursuit of critical technologies. It should be mentioned here that these critical technologies should not be confused with the Military Critical Technologies List which is used to control the export of technologies.

C. THE 1989 CRITICAL TECHNOLOGIES PLAN

1. Legal Requirements

Public Law 100-456, the National Defense Authorization Act, Fiscal Year 1989 of September 29, 1988 required that the Under Secretary of Defense for Acquisition, in consultation with the Assistant Secretary of Energy for Defense Programs, submit a plan, not later than March 15 of each year, for developing the 20 technologies considered to be the most essential to ensure the long-term qualitative superiority of US weapons systems. The plan was to consider both product and process technologies.

The content of the plan was to consist of:

1. The reasons for technology selection.
2. Milestone goals for development.
3. Amount contained in the budgets of DoD, DoE and other departments and agencies for support and development.
4. A comparison of the positions of the US and other industrialized nations, specifically the Soviet Union, in the development of such technology.
5. Extent the US should depend on other countries to develop technologies.

6. Potential contributions that allies of the US can make.

7. Potential contributions the private sector can make.

The law required that the first plan be submitted in 1989. The full statement of Section 823, PL 100-456, is reproduced in Appendix A.

2. Planning Process

The development of the CTP was based on the investment strategy planning process that is part of the S&T program in the DoD. An overview of this process is shown in Figure 1. The process begins with planning factors, which change with threat conditions. These planning factors are national priorities that are set by the President. The defense objectives, policy and strategy follow, as established by the Secretary of Defense. Then the Joint Chiefs of Staff and the three services perform mission area analyses. With this information the office of Director, Defense Research and Engineering (Research and Advanced Technology) [DDR&E(AT)] working closely with the three services, develops the technology investment strategy. The Secretary of Defense issues, for each budget cycle, defense guidance detailing what should be done to accomplish the investment strategy.

The DoD planning process makes S&T investment activities more visible to both planners and users. The CTP has the same basic objectives as the investment strategy, and

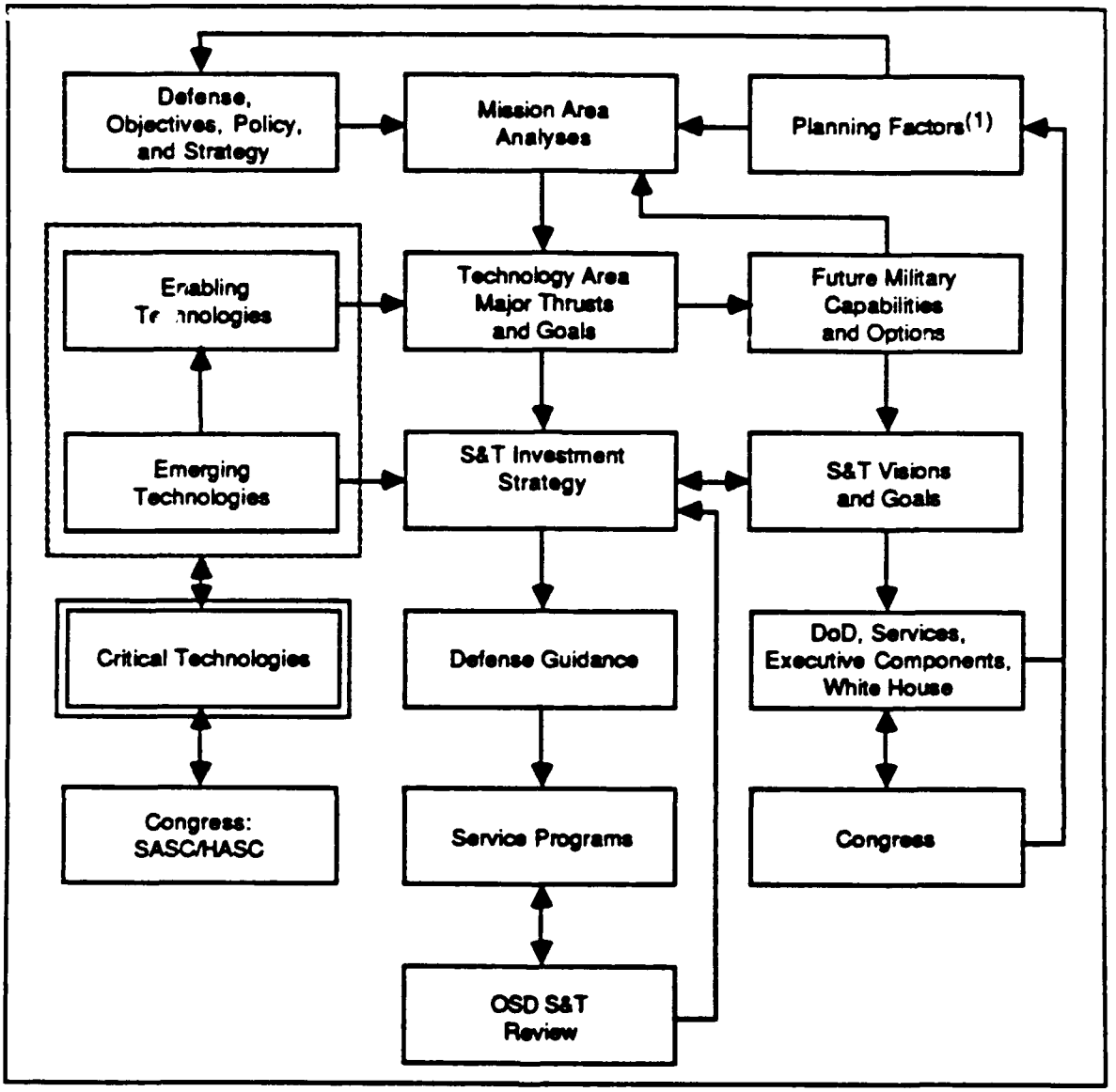


Figure 1. DoD Science and Technology (S&T) Strategic Planning Process(2)

Notes with Figure 1:

(1) Planning Factors include the world situation, budget constraints, Presidential guidance, Congressional mandates, etc.

(2) This block diagram cannot show all the many interactions that take place informally.

Source: Department of Defense Critical Technologies Plan, Revised, May 5, 1989, p 4.

is a natural output of the existing process.[3] An important distinction between the CTP and the investment strategy is that the former focuses only on the star performers, those technologies that make the most notable difference, while the latter takes into account all considerations.[4]

3. Selection Criteria

Critical technologies were selected on the basis of one or more of the Performance and Quality Design criteria listed below:

PERFORMANCE CRITERIA

1. Technologies that enhance performance of conventional weapon systems.
2. Technologies that provide new military capabilities.

QUALITY DESIGN CRITERIA

1. Technologies that improve weapon systems' availability and dependability.
2. Technologies that improve weapon systems' affordability.[5]

To qualify as "critical", the technology would have to improve one or more of these criteria by a factor of about three.

---

[3] Department of Defense, *Critical Technologies Plan, Revised,* May 5, 1989, p. 3.

[4] *Ibid.*

[5] *Ibid.*, p. 5.

4. Selected Critical Technologies

The following critical technologies were selected:

1. Microelectronic Circuits and Their Fabrication
2. Preparation of Gallim Arsenide (GaAs) and Other Compound Semi-Conductors
3. Software Producibility
4. Parallel Computer Architectures
5. Machine Intelligence/Robotics
6. Simulation and Modeling
7. Integrated Optics
8. Fiber Optics
9. Sensitive Radars
10. Passive Sensors
11. Automatic Target Recognition
12. Phased Arrays
13. Data Fusion
14. Signature Control
15. Computational Fluid Dynamics
16. Air Breathing Propulsion
17. High Power Microwaves
18. Pulsed Power
19. Hypervelocity Projectiles
20. High-Temperature/High-Strength/Light-Weight Composite Materials
21. Superconductivity
22. Biotechnology Material Processing

It is important to note that the CTP list of critical technologies "should not be regarded as a closed list. Technologies related to nuclear weapons and their effects, because of their special nature, are not included in this plan."

These 22 technologies are summarized in Appendix B. This summary includes an overview explanation, impact on weapons systems and comparison with other countries. Table 1 is a summary of foreign technological capabilities in each of the areas identified in the first CTP.

5. Reaction to 1989 CTP

It is generally accepted that the 1989 CTP was a good if not excellent first effort. This evaluation is given in light of the stringent time constraints - six months - under which it was developed (the law was enacted on September 29, 1988 and the plan was due March 15, 1989). When one realizes that the plan had to be revised and was reissued on May 5, 1989, one can truly estimate the time needed to put together such a comprehensive plan. This extra time was needed to refine the comparisons with other countries for each technology. There were, however, some criticisms about the 1989 plan.

In an article in *SIGNAL*, February 1990, four deficiencies were observed by Senator Jeff Bingaman. First, the plan followed the [Presidential] budget submission and

Table 1. Summary of Foreign Technological Capabilities

Critical Technologies	Warsaw Pact	NATO Allies	Japan	Others
1. Microelectronic Circuits and Their Fabrication	■	▨	▨	▨ Israel ▨ S Korea
2 Preparation of GaAs and Other Compound Semiconductors	■	▨	▨	
3 Software Producibility	■	▨	▨	▨ Many Nations
4 Parallel Computer Architectures	■	▨	▨	
5 Machine Intelligence/Robotics	■	▨	▨	▨ Finland Sweden
6 Simulation and Modeling	■	▨	▨	
7 Integrated Optics	■	▨	▨	▨ China Israel S Korea
8 Fiber Optics	■	▨	▨	▨ Various Sources
9 Sensitive Radars	■	▨	▨	▨ Sweden
10 Passive Sensors	■	▨	▨	▨ Israel
11 Automatic Target Recognition	■	▨	▨	▨ Israel Sweden
12 Phased Arrays	■	▨	▨	▨ Israel
13 Data Fusion	■	▨	▨	
14 Signature Control	■	▨	NA	
15 Computational Fluid Dynamics	■	▨	▨	▨ Sweden
16 Air-Breathing Propulsion	■	▨	▨	
17 High Power Microwaves	■	▨		
18 Pulsed Power	■	▨	▨	
19 Hypervelocity Projectiles	■	▨	▨	▨ Australia Israel
20 High-Temperature/High-Strength/Low-Weight Composite Materials	■	▨	▨	
21 Superconductivity	■	▨	▨	
22 Biotechnology Materials and Processing	■	▨	▨	▨ Many Nations

LEGEND

Position of Warsaw Pact relative to the United States

- ■ significant leads in some niches of technology
- ■ generally on a par with the United States
- ■ generally lagging except in some areas
- ■ lagging in all important aspects

Capability of allies to contribute to the technology

- ▨ significantly ahead in some niches of technology
- ▨ capable of making major contributions
- ▨ capable of making some contributions
- ▨ unlikely to make any immediate contribution

Source: Department of Defense Critical Technologies Plan, Revised, May 5, 1989, p 11.

therefore the correlation of funding estimates between the [approved] budget and the Presidential budget was weak.[6] Second, lead organizations and a development plan for the technology from this organization were not clear. Third, process technologies, seen as long neglected by DoD, were not given enough emphasis compared to product technologies. Finally, the international comparisons were viewed as having major gaps. These gaps were examined and a subsequent revised plan was produced as mentioned above.

From the congressional hearings held in May of 1989, other observations and comments on the 1989 CTP are worth noting. First, of the twenty-two critical technologies, 12 to 14 are what might be characterized as duel use technologies. Duel use indicates a possible exploitation in both the military and civilian sectors. Second, the plan must be reevaluated continuously because of the changing environment and pace within which technology changes. Third, the critical technologies must be integrated into the overall S&T plan along with other supportive technologies. Fourth, greater use of prior technology studies and reports would provide more inputs to meet congressional needs. Finally, missing areas of

---

[6] Senator Jeff Bingaman, *Signal*, February 1990, p. 59.

technology to be considered for future studies should include those more focused in undersea warfare such as sonar.[7]

D. 1990 CRITICAL TECHNOLOGIES PLAN

1. Legal Requirements

The primary conditions (identification of 20 critical technologies, DoE involvement and submission by March 15) of the CTP remained the same from the 1989 requirement. However, in an attempt to correct and deal with perceived deficiencies in the first submitted plan, Public Law 101-189 of November 29, 1988 added additional requirements and clarified others. The full statement of Section 605, PL 101-189 is reproduced in Appendix B. This law added a new paragraph titled "Priorities and Funding" and the content was expanded.

The major change from the 1988 law was to include the requirement to:

> designate priorities for development of the technologies identified in the plan and specify funding requirements of the Department of Defense, the Department of Energy and other appropriate departments and agencies for the development of the technologies identified in the plan for the five fiscal years following the year the plan is submitted.

This is in contrast to the 1988 requirement to report the amount contained in the budget for the support and development

---

[7] Electronic Industries Association, review of *Defense Department's Critical Technologies Plan*, May 5, 1989, p. 2.

of the technologies for the fiscal year the report was submitted.

The content of the plan was expanded by requiring the inclusion of two new segments. Both of these segments dealt with the technology selection process. The first of these sections was to be a discussion of the consideration of the most recent biennial report submitted to the President by the National Critical Technologies Panel under title IV of the National Science and Technology Policy, Organization, and Priorities Act of 1976. The second section was to address the relationship of the technology to the overall S&T program and the long-term funding strategy.

Additionally, the plan was to designate a lead organization responsible for the development of the technology, and a description of this organization's plan, including milestones and goals. Besides expanding the funding requirements description in the Priorities and Funding paragraph, the plan was to contain the amounts in the budget for the five preceding fiscal years, the current fiscal year, and each fiscal year that the Secretary of Defense has prepared a budget.

Under the requirement to compare the US, in the development of these technologies, to other industrial nations, language was added requiring a comparison to the degree of accessibility. This comparison was to contain the accessibility the US has to research conducted in allied

nations, the access allied countries have to US research and the effect of any imbalance in such access. Also, the plan was to describe the trends in the industrial base of such countries and the competitiveness of the industrial base in the US. Lastly, the plan was to discuss the extent of actions that the Federal Government should take to maintain and improve the industrial base and research efforts in the US.

2. Planning Process

The 1990 plan was developed by a working group chaired from the Office of the Secretary of Defense (OSD), with representatives from the Army, Navy, Air Force, the Strategic Defense Initiative Organization (SDIO), Defense Advanced Research Projects Agency (DARPA), Defense Nuclear Agency (DNA), OSD Offices, Department of Energy (DoE) Headquarters and National Laboratories (Los Alamos, Lawrence Livermore, and Sandia).[8] Several meetings were held with representatives of the Aerospace Industries Association, the Electronics Industries Associations and the National Security Industrial Association to discuss ongoing activities in strategic planning for science and technology. The technologies were selected as "critical" by a group of senior DoD officials with responsibility for the S&T program, based on the working group's recommendations.

---

[8] Department of Defense, *Critical Technologies Plan,* March 15, 1990, p. ES-1.

The critical technologies are contained in the technology areas of the S&T Investment Strategy. The development of this strategy was discussed previously under the planning process for the 1989 CTP, and was published in 1990 for the first time in a separate report. The investment strategy developed twelve major long-term goals from vision statements of needed military capabilities fifteen to twenty years in the future. Table 2 shows the linkage between the goals and the 20 critical technologies.

3. Selection Criteria

The four parameters in performance and quality design criteria remained the same as the previous year, with two criteria being added. These two are:

MULTIPLE USE CRITERIA

1. Pervasiveness in major weapon systems.
2. Strengthening the industrial base.

To be considered as "critical," major improvements in one or more selection criteria are sought. This definition of critical is consistent with the previous year's selection process.

4. Selected/Prioritized Critical Technologies

The priorities of the twenty critical technologies were assigned by a senior committee from DoD and DoE with management responsibility for the S&T program. Group A

Table 2. Major Linkages Between Critical Technologies and Major Long-Term Goals for the S&T Program

Critical Technology \ Goal	1. Strategically Relocatable Targets	2. Force Projection/Rapid Deployment	3. Defense Against Ballistic Missiles	4. On-Demand Space Asset Deployments	5. Antisubmarine Warfare	6. Worldwide, All Weather C3/Surveillance	7. Signature Management	8. Close Combat/Air Defense	9. Brilliant Weapons	10. Reduced Support Requirements	11. Personnel Reduction	12. Affordable/Producible Weapon Systems
1. Semiconductor Materials and Microelectronic Circuits	◄	─	─	─	─	─	─	─	─	─	─	►
2. Software Producibility	◄	─	─	─	─	─	─	─	─	─	─	►
3. Parallel Computer Architectures				X		X			X	X		
4. Machine Intelligence and Robotics				X				X	X	X	X	X
5. Simulation and Modeling		X				X		X		X	X	X
6. Photonics						X			X			X
7. Sensitive Radars	X		X		X	X		X	X			
8. Passive Sensors	X		X		X	X		X	X			
9. Signal Processing	X		X	X	X	X			X		X	
10. Signature Control	X		X		X		X					
11. Weapon System Environment	X	X	X		X			X	X			
12. Data Fusion	X		X	X	X	X				X	X	
13. Computational Fluid Dynamics				X	X			X				X
14. Air-Breathing Propulsion		X		X			X	X		X		X
15. Pulsed Power			X					X				X
16. Hypervelocity Projectiles			X					X	X			X
17. High Energy Density Materials			X	X				X		X	X	X
18. Composite Materials	◄	─	─	─	─	─	─	─	─	─	─	►
19. Superconductivity			X		X	X				X		
20. Biotechnology Materials and Processes										X	X	X

Source: Department of Defense Critical Technologies Plan, March 15, 1990, p 4.

contains the highest priority followed by Groups B and C. The order within each group, listed below, does not reflect the priority within that group. Group A technologies are the most pervasive; those in Group B are enabling technologies which can give the most immediate advances; and those in group C are technologies whose application is farthest in the future and are primarily enabling technologies.[9]

The following 20 critical technologies were selected and prioritized.

GROUP A

1. Composite Materials
2. Computational Fluid Dynamics
3. Data Fusion
4. Passive Sensors
5. Photonics
6. Semiconductor Materials and Microelectronics
7. Signal Processing
8. Software Producibility

GROUP B

9. Air-Breathing Propulsion
10. Machine Intelligence and Robotics
11. Parallel Computer Architectures
12. Sensitive Radars

---

[9] Department of Defense, *Critical Technologies Plan,* March 15, 1990, p. 7.

13. Signature Control

14. Simulation and Modeling

15. Weapon System Environment

GROUP C

16. Biotechnology Materials and Processes

17. High-Energy Density Materials

18. Hypervelocity Projectiles

19. Pulsed Power

20. Superconductivity

Fifteen titles remain the same as the previous year. Four major changes were made. First, segments of technologies titled Integrated Optics and Fiber Optics were redistributed into two titles, Semiconductor Materials and Microelectronic Circuits and Photonics. Photonics emphasizes optical information processing.

Second, Signal Processing replaced Automatic Target Recognition. Automatic Target Recognition is seen as a requirement included under Signal Processing.

Third, High Powered Microwaves and Phased Arrays were removed. However, features of these technologies are included in Pulsed Power, Signal Processing and Sensitive Radars.

Finally, two new technologies were introduced: High Energy Density Materials and Weapon System Environment. High Energy Density Materials is concerned with improved explosive

munitions, and with improved propellants for rockets.[10] Weapon System Environments influences weapon system design and is a factor in the "long-term qualitative superiority" of US weapon systems.[11]

The two new technologies are detailed in Appendix D along with the revised funding requirements for each technology. A summary assessment of foreign technological capabilities in the twenty critical technologies relative to the US is shown in Table 3.

5. Reaction to 1990 CTP

The DoD's second attempt at a critical technologies plan was almost twice the length of the first, 236 pages versus 124 pages respectively. Yet in Armed Services Committee discussions the committee stated that it was "deeply disappointed in the Defense Department's inability to provide a comprehensive plan addressing the development of technologies critical to the national defense." The committee clearly noted that the plan still lacks some key elements that they thought should be included.

The major criticism of the plan was its deficiency in planning for the future development of the critical technologies. In this planning the committee believed that the DoD should discuss how it was going to organize the resources

---

[10] *Ibid.*, p. 6.

[11] *Ibid.*

Table 3. Summary of Foreign Technological Capabilities

Critical Technologies	USSR	NATO Allies	Japan	Others
1. Semiconductor Materials and Microelectronic Circuits	▨	□□	□□□□	□□ Israel
2. Software Producibility	▨	□□	□□	□□ Various Countries
3. Parallel Computer Architectures	▨	□□	□□	□□ Switzerland, Israel, Hungary
4. Machine Intelligence and Robotics	▨	□□□	□□□□	□□ Finland, Israel, Sweden
5. Simulation and Modeling	▨	□□□	□□□	
6. Photonics	▨▨	□□	□□□□	□ Various Countries
7. Sensitive Radars	▨	□□	□□	□□ Sweden
8. Passive Sensors	▨▨	□□	□□	
9. Signal Processing	▨▨	□□	□□	□□ Sweden, Israel
10. Signature Control	▨▨	□□	□□	
11. Weapon System Environment	▨▨▨	□□□	□□	□ Various Countries
12. Data Fusion	▨▨	□□	□□	□□ Israel
13. Computational Fluid Dynamics	▨	□□	□□	□□ Sweden, Israel □ India, China, Australia
14. Air-Breathing Propulsion	▨▨	□□□	□□	
15. Pulsed Power	▨▨▨▨	□□	□□	□ Various Countries
16. Hypervelocity Projectiles	▨▨▨	□□	□□	
17. High Energy Density Materials	▨▨▨	□□□	□□□	
18. Composite Materials	▨▨	□□□	□□□	□□□ Israel
19. Superconductivity	▨▨	□□	□□□□	□□□ Switzerland
20. Biotechnology Materials and Processes	▨▨	□□□	□□□□	□□ Various Countries

LEGEND

Position of USSR relative to the United States

- ▨▨▨▨ significant leads in some niches of technology
- ▨▨▨ generally on a par with the United States
- ▨▨ generally lagging except in some areas
- ▨ lagging in all important aspects

Capability of others to contribute to the technology

- □□□□ significantly ahead in some niches of technology
- □□□ capable of making major contributions
- □□ capable of making some contributions
- □ unlikely to make any immediate contribution

Source: Department of Defense Critical Technologies Plan, March 15, 1990, p 11.

and assets available to achieve the technological objectives set out in the plan. These resources include DoD in-house laboratories, DoE national laboratories, universities and colleges and US and foreign industries. In addition, the committee urged the use of industry and association studies to help in planning the development of the critical technologies. Beyond this, the committee suggested, that in order to give industry a more meaningful involvement, they be allowed to prepare plans supplementing the strategic outlook.

Other areas identified as deficient included the designation of lead activities, international cooperation and identification of funding levels. The committee observed that no lead activities were designated for any technology. This requirement was directed by the 1990 law for inclusion in the CTP. The committee wanted lead organizations found in military service or Defense Agency technical organizations and laboratories. It suggested that these selections be made by the Director of Defense Research and Engineering from one of these organizations.[12]

Further, discussion of international cooperation as a means of achieving the desired goals was seen as not being addressed. Also, the committee suggested that the plan should not concentrate on the current status of the US relative to

---

[12] Senate Armed Services Committee, *Acquisition Policy and Management Report,* 1990, p. 179.

other nations, but deal with the dynamic environment affecting the position and prospects for each technology.[13]

Finally, the committee believed that to effectively manage the critical technologies DoD, should be able to "rapidly and accurately identify the levels of funding allocated to, or planned for, each critical technology."[14] From statements published by the committee it is clear that what they wanted was an identification of all the program elements which support the development of the critical technologies and the allocation of funds to technologies within those program elements. Careful reading of Public Law 101-189 reveals no such requirement; however this language is incorporated into proposed legislation for 1991.

E. 1991 CRITICAL TECHNOLOGIES PLAN

Bill S.2884, introduced July 10, 1990, specifically addresses the identification of program elements into the CTP. In fact, it is the only major change to Section 2508 of title 10, United States Code, requiring an annual CTP. A reproduction of the language finally adopted by Congress in 1990 is contained in Appendix C.

This new bill requires three parts relative to program elements. First, each program element contained in the

---

[13] *Ibid.*, p. 180.

[14] *Ibid.*

President's budget that has funds allocated for the support of any critical technology must be identified. Second, the amount for each critical technology included by the program element must be indicated. And third, this amount is to be compared with the prior fiscal year's allocation.

Another approach to insuring the superiority of US weapons systems is test and evaluation. The next chapter is devoted to investigating the test and evaluation process. Emphasis is placed on how the DoD plans for new technologies.

III. WEAPON SYSTEM TEST AND EVALUATION

This chapter describes weapon system Test and Evaluation (T&E) and how it relates to technology planning and resources. This chapter begins with a description of the purpose and functions of T&E, followed by an outline of the major categories within T&E. Then the importance and contributions of T&E are discussed. Contributions are explored within the DoD procurement and program milestone framework. The next section explores how DoD plans for the Major Range and Test Facility Base (MRTFB) T&E resources. Finally, an attempt to identify needed technical resources for T&E is introduced.

A. PURPOSE AND ROLES

The purpose of test and evaluation (T&E) is to provide a technical management tool used to reduce risk throughout the acquisition cycle. Testing involves the calculated and logical production of data for technical and managerial personnel who control development. The principal uses of this information are for development, acquisition milestone decisions, and operational utilization.

Although the terms "test" and "evaluation" are often found together, they describe two clearly distinguishable functions. "Testing" is the examination of hardware/software - models,

prototypes, production equipment, computer programs - to obtain data, necessary to develop new capabilities, manage the process, or make decisions on resource allocation.[15] The role of testing systems under development is to identify and resolve technical uncertainties and problems. While information on such problems is generated primarily through testing by the contractor, various government tests generate data that is basic to the development of systems.

Testing also provides information for many of the major milestone decisions. These decisions, such as initial development and full-scale development, are investment judgments. Selection makers are responsible for putting available resources to their most productive use. Data on how effective, reliable, maintainable and supportable a system is aid in making these decisions.

Test data are also used by the operational community. An output of the operational evaluation effort is the development of tactics for the most effective use of the system.

"Evaluation" is the process in which data are logically assembled and analyzed to aid in making systematic decisions.[16] Evaluation is the review and analysis of qualitative or quantitative data obtained from sources such as

---

[15] Department of the Navy, *RDT&E/Acquisition Management Guide*, 11th Edition, p. 7-1.

[16] *Ibid.*

design reviews, inspections, testing or operational use.[17] The process of evaluation begins with the identification of a deficiency or need and the documentation of an operational requirement. Next, critical issues need to be identified. These critical issues must determine if the system meets the requirement. Criteria must then be established to define required performance thresholds and to evaluate progress in reaching them. These issues are then broken down into measurable test elements. From these elements testing is conducted, test data are reviewed and analyzed, test results are weighed against the evaluation criteria, and the evaluation report is prepared.

B. CATEGORIES OF TEST AND EVALUATION

Tests are classified into three categories: Development Test and Evaluation (DT&E), Operational Test and Evaluation (OT&E) and Production Acceptance Test and Evaluation (PAT&E). The maturity of the equipment tested, prototype to production, determines the test category.

1. Development Test and Evaluation

Development Test and Evaluation is required for all acquisition programs. It is planned, conducted, and monitored by the developing agency or its designated organization. Objectives of each phase are developed and published in the

---

[17] Defense Systems Management College, *Test and Evaluation Management Guide,* March 1988, p. 4-1.

Test and Evaluation Master Plan (TEMP). Development Test and Evaluation is conducted in three major phases. If necessary, each phase may be divided into subphases.

Development Testing - I (DT-I) is conducted during the demonstration and validation (D&V) phase to support the Milestone II decision. A positive decision allows the program to proceed into Full-Scale Development (FSD). The principal purpose of DT-I is to demonstrate that all technical risks have been identified and reduced, that the best technical solutions have been selected, that engineering is now required and the required technology is available.[18]

Development Testing - II (DT-II) is conducted during FSD to support the Milestone III decision, which places the system into production. It demonstrates that the design meets specifications regarding performance, reliability, maintainability, supportability, interoperability, survivability, and vulnerability.[19] The final part to DT-II is a Technical Evaluation (TECHEVAL) of production hardware and software to determine if the system meets design specifications. In addition, the TECHEVAL assess whether the system is ready to undergo the Operational Evaluation (OPEVAL).

---

[18] *op. cit.*, Department of the Navy, p. 7-9.

[19] *Ibid.*

Development Testing - III (DT-III) is conducted after the production decision. Its purpose is to ensure that system improvements identified during TECHEVAL, OPEVAL and Follow-On Test and Evaluation (FOT&E) were performed and acceptable.

2. Operational Test and Evaluation

Operational Test and Evaluation determines the system's operational effectiveness and suitability, and provides information on tactics.[20] These tests are unique because they are conducted in a realistic environment, use operational personnel and are performed against a simulated enemy. Operational Test and Evaluation is divided into two major categories. Initial OT&E (IOT&E) is testing that is performed prior to the full production decision. Follow-On OT&E is testing which follows the production decision.

Operational Testing - I (OT-I) is IOT&E conducted during the validation phase to support the FSD decision. It is not required for most programs. Operational Testing - I is scheduled for systems using new operational concepts with high operational risks.

Operational Testing - II (OT-II) is IOT&E performed during the full-scale development phase to support the production and field introduction decisions. For major programs entering Low Rate Initial Production (LRIP), the director of OT&E must provide the Defense Acquisition

---

[20] *Ibid.*, p. 7-10.

Executive, the Defense Acquisition Board, the SECDEF and appropriate congressional committees a report of system effectiveness and suitability before Milestone III.[21] Operational Evaluation (OPEVAL) is the final part of OT-II and is conducted with a production representative system. This testing is to begin no sooner than one month after TECHEVAL testing.

Operational Testing - III (OT-III) is the first FOT&E performed after production and normally before field introduction. Usually, OT-III is conducted with the same pilot production system used in OPEVAL. Objectives include the testing of production fixes, tactics development, completing any deferred IOT&E and assessing operational availability.

Operational Testing - IV (OT-IV) is FOT&E performed on production systems. The initial objective of OT-IV is the demonstration of achievement of objectives for production system operational effectiveness and suitability. Other objectives may include OT&E of the system in other environments, applications, or against new threats.

3. Production Acceptance Test and Evaluation

Production Acceptance Test and Evaluation (PAT&E) is testing conducted on production items to demonstrate that they meet contract specifications. These production tests are

---

[21] *Ibid.*, p. 7-11.

usually performed on a sample of the actual number of systems manufactured. The objectives of PAT&E are described in the TEMP. Most PAT&E is the responsibility of the developing agency, but in some cases can be done by the manufacturing contractor.

4. Joint and Multiservice Test and Evaluation

The terms multiservice and joint testing are sometimes confused and used interchangeably. However, multiservice T&E is conducted on a system being acquired for use by one or more Service.[22] One Service is designated as the lead Service and is responsible for the management of the program. All Services procuring the system participate in the conception, performance, and evaluation of a multiservice test program. In contrast, joint test and evaluation is sponsored and funded by the Secretary of Defense (SECDEF). Joint T&E programs are not acquisition oriented. They are a means of examining joint Service tactics and doctrine. Past joint test programs have been conducted to provide information required by the Congress, by OSD, by the commanders of the Unified and Specified Commands and by the Services.[23]

---

[22] *op. cit.*, Defense Systems Management College, p. 3-7.

[23] *Ibid. p. 3-8.*

C. IMPORTANCE/CONTRIBUTIONS

Test and Evaluation is used as a risk management tool. Risk management balances system combinations/options such as improved performance versus maintainability, reliability or cost. Risk, which is usually minimized, requires pertinent data in order to make intelligent decisions. Pertinent and reliable data are the outcome of T&E endeavors. Test and Evaluation of parts and subsystems can also be used to reduce risk in a developmental and procurement effort of a new system. Thus, T&E may reduce cost, schedule and technical risks.

Test and Evaluation results play an important part in design and milestone decision reviews. The executive who has final decision responsibility must examine the critical issues and weigh the facts on hand. These facts, provided by the T&E process, may be unfavorable in some areas. This is where the balance of capabilities and shortcomings - risk management - is decided by the responsible executive.

Progress of T&E is monitored by the Office of the Secretary of Defense (OSD) throughout the procurement process. Their oversight extends to the major materiel acquisitions or designated acquisitions, which is about 5 percent of all the acquisitions being managed within DoD.[24] The Defense Acquisition Board, Defense Acquisition Executive, and the

[24] *Ibid.*, p. 2-5.

Secretary of Defense make procurement assessments based on the following T&E information:

1. The Test and Evaluation Master Plan (TEMP).
2. Service test agency reports and briefings.
3. Development T&E data from program managers, laboratories and contractors.
4. Detailed supporting documents developed by Service activities.

During the Concept Exploration/Definition Phase, prior to Milestone I, studies, analyses, simulation, and test data are used by the development agency to explore and evaluate designs proposed to satisfy the requirements.[25] The Operational Test and Evaluation Agency (OTA) monitors the T&E during this period to gather information for future T&E planning. At the end of this period the development agency puts together the DT&E System Concept Report to record and present T&E results of system designs compared to stated requirements. This report is incorporated into the Systems Concept Paper (SCP) and the status briefing for a Milestone I decision. The OSD evaluates the T&E of system alternatives based on requirements established in an approved TEMP.

During the Concept Demonstration/Validation Phase, prior to Milestone II, concepts that are demonstrated and validated provide a foundation for detailed test planning. The

---

[25] *Ibid.*

development agency conducts development test and evaluation on components, subsystems and prototypes to ensure that engineering is reasonably complete.

The operational T&E agency estimates the system's operational effectiveness, maintainability, supportability and suitability. These estimates are accomplished through testing performed by operational personnel in realistic field conditions. Information on tactics, organization and personnel requirements are identified along with recommended modifications. The results of demonstration and validation DT&E are prepared in a report by the development agency. This report is reviewed by the Service Headquarters and the Service acquisition review council prior to system acquisition review by DoD.[26] Concurrently, the OT&E agency prepares an independent report which presents the estimates of the system's operational effectiveness. Both of these reports are used to support the Decision Coordinating Paper (DCP). The DCP, prepared for Milestone II, is used to recommend proceeding to full-scale engineering development.

The Milestone III decision approves progress to the full-rate production/deployment phase. If the magnitude of the program is sufficiently large and/or the time between the beginning of low-rate initial production and full rate production is significantly long, there may be a need for a

---

[26] *Ibid.*, pp. 2-8.

Program Review or Milestone IIIA before the Milestone III decision point.[27] Test and Evaluation activities during this period yield much useful information. The data are used to assess the critical technical issues which are specified in program documents.

These technical issues include:

1. Satisfying specifications
2. Identifying deficiencies
3. Recommending corrective actions
4. Determining interoperability
5. Estimating reliability, maintainability, and availability
6. Determining whether the system is safe to undergo OT&E
7. Assessing technical risk and evaluating tradeoffs
8. Validating configuration changes
9. Assessing survivability, vulnerability and supportability
10. Determining system performance limitations
11. Verifying technical documentation concerning operation and maintenance

Operational T&E performed prior to the production decision achieves the following:

1. Estimating operational effectiveness and suitability

[27] Department of Defense, *Directive 5000.2, Defense Acquisition Program Procedures,* September 1, 1987, p. 3.

2. Recommending and evaluating changes in configuration
3. Developing logistic support, training, and tactics
4. Determining acceptable technical publications and support equipment
5. Estimating survivability in an operational environment

After the production decision has been made, Milestone III T&E activities continue to provide insights. Government representatives normally monitor or conduct Production Acceptance Test and Evaluation (PAT&E). Post production testing may lead to pre-planned product improvements, or what is known as "block upgrades."

The OT&E agency continues with OT&E in the form of FOT&E. Usually FOT&E is performed in two phases. The first phase consists of verifying the operational effectiveness and suitability of the production system which may have been accomplished earlier. The second phase is conducted by the user to refine tactics and training for the life of the system. The OT&E agency prepares a final report at the conclusion of FOT&E. This report records test results, relates evaluation to critical issues, and documents the assessments of deficiencies resolved.

Test and Evaluation is the primary means of predicting and/or assessing the performance of a weapon system. The results are important in making key decisions in the procurement process. This is especially true for the decision

to proceed from full-scale development to production. Operational Test and Evaluation provides an indication of how well the new system will work in the battlefield before it is produced.

D. TEST AND EVALUATION RESOURCES AND PLANNING

The Department of Defense defines test resources as a "collective term that encompasses all elements necessary to plan, conduct, collect and analyze data from a test event or program." These elements can include funding, personnel, test articles, models, simulations, instrumentation, targets, tracking and data gathering equipment and data reduction equipment. One place the Department of Defense manages these elements, to support the development and operation of weapon systems, is in the DoD T&E facilities.

1. Major Range and Test Facility Base

All of the Services operate ranges and test facilities for test, evaluation and training purposes. Twenty-one of these activities form the DoD Major Range and Test Facility Base (MRTFB). The MRTFB is a national asset which is to be sized, operated, and maintained primarily for DoD test and evaluation support missions, but is also available to all users having a valid requirement for its capabilities.[28] A list of MRTFB activities are in Table 4 and their locations

---

[28] Department of Defense, *Directive 3200.1, Major Range and Test Facility Base,* September 29. 1980, p. 1.

are shown in Figure 2. Summaries of the capabilities of each of these activities can be found in DoD Directive 3200.11-D.

The MRTFB facilities can be used by all the Services, other US Government agencies, and when authorized allied foreign governments and private organizations. Test resource scheduling is based on the existing Military Department priority and precedence rating system. However, DoD Directive 3200.11 does specify that time restrictions and equitable considerations be given to minimize delays in lower priority projects.

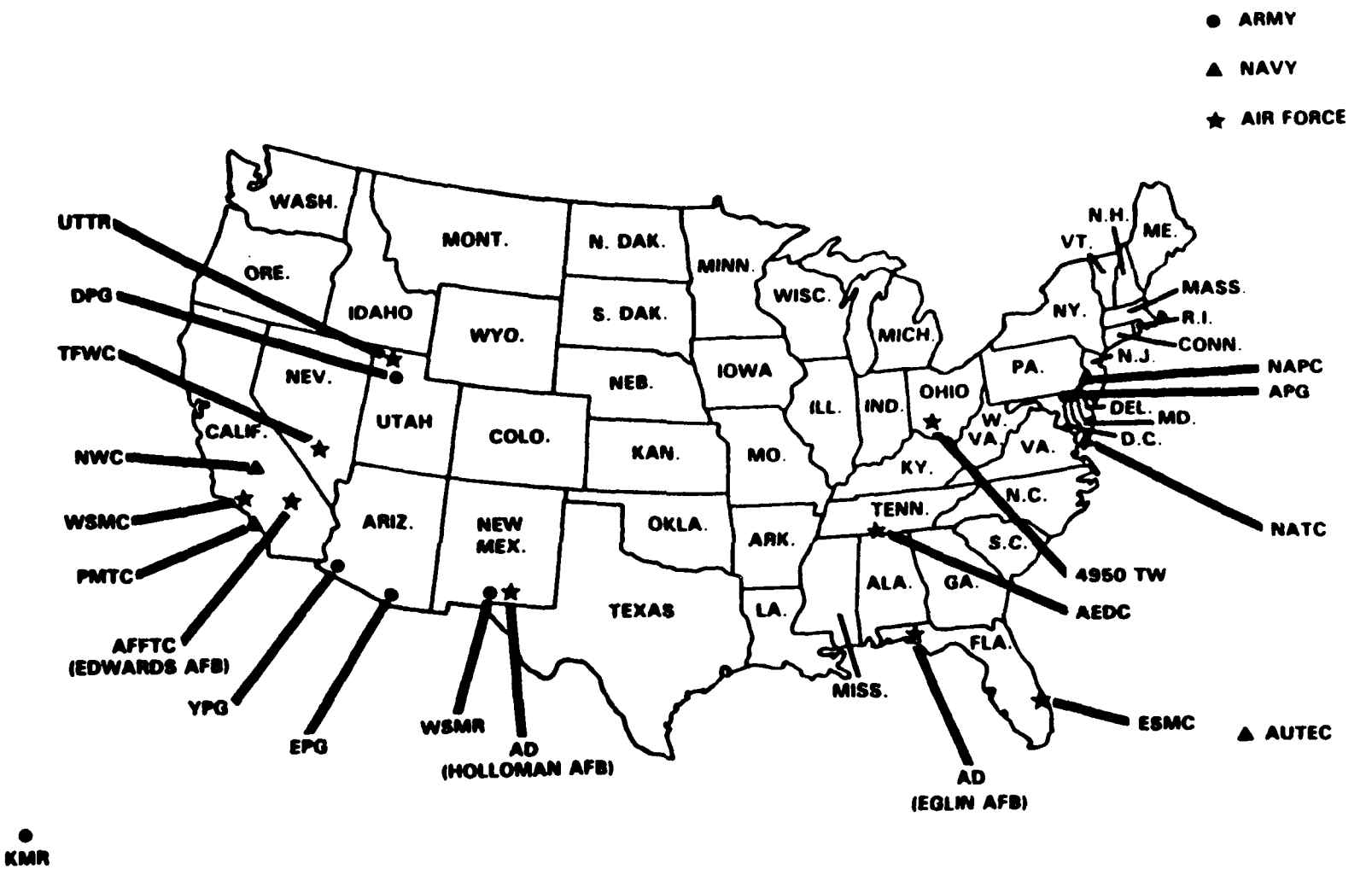
Funding is done on a reimbursable basis. For DoD component users, reimbursement is for direct costs which can be identified readily with the particular program. All other federal and nonfederal agencies are to pay for direct and indirect costs. The Deputy Director, Defense Research and Engineering (DDDR&E(T&E)) sets policy for the composition, use, and test program assignments of the MRTFB.[29]

2. Major Range and Test Facility Planning

Planning for the MRTFB can be categorized by the organizations responsible for that planning. Users provide funding and requirements for testing a weapon system. MRTFB activities support, manage and coordinate day-to-day operations of the activity. They are also tasked to develop

---

[29] *op. cit.*, Defense Systems Management College, chp. 18, p. 4.



DOD MAJOR RANGE AND TEST FACILITY BASE LOCATION OF ACTIVITIES

Figure 2. DOD MRTFB Location of Activities

Source: DOD 3200.11-D

Table 4.

MAJOR RANGE AND TEST FACILITY BASE SUMMARY

White Sands Missile Range

Kwajalein Missile Range

Yuma Proving Ground

Dugway Proving Ground

Electronic Proving Ground

Aberdeen Proving Ground

Pacific Missile Test Center

Naval Air Test Center

Naval Weapons Center

Naval Air Propulsion Center

Atlantic Undersea Test and Evaluation Center

Atlantic Fleet Weapons Training Facility

Eastern Space and Missile Center

Western Space and Missile Center

Arnold Engineering Development Center

Tactical Fighter Weapons Center

Utah Test and Training Range

Armament Division - 3246th Test Wing

Armament Division - 6585th Test Group

Aeronautical Systems Division - 4950th Test Wing

Source: DoD 3200.11-D

and maintain a master plan for developing and operating the MRTFB. Secretaries of the Military Departments plan, program and budget for development and are tasked with long-term management and operations of each MRTFB activity. In addition to setting policy the DDDR&E (T&E) monitors and evaluates the MRTFB for adequacy and duplication. The focus of this discussion will be on plans to develop the individual ranges and test facilities.

In the middle of the 1980's several factors led to the realization that DoD's T&E capabilities were approaching a crisis situation. These factors included congressional concerns for adequate weapon system testing, emerging technologies, very low average investment rate and projected long-term fiscal reductions.[30] Effective investment in modernization was to be obtained through better coordinated DoD wide management.

Several actions were taken in response to the T&E concerns. First, the Director of OT&E was established in 1984 and placed on what was then called the Defense Review Board (DRB). Second, in the summer of 1986 the Deputy Secretary of Defense established an OSD central funding line for OT&E. Third was the establishment of the Test and Evaluation Committee (TEC). Finally, in November of 1988, DoD established

---

[30] Mr. P. Horner, *Test Resources Master Plan Briefing, Pacific Missile Test Center,* May 17, 1989.

a central funding line for high priority T&E capability investments.[31] This funding was an OSD program element for the Central T&E Investment Program (CTEIP).

The Test and Evaluation Committee (TEC) is the single agent within the DoD responsible for the determination of corporate T&E planning, programming and budgeting and execution priorities and is responsible for reporting them to the DRB.[32] Among the responsibilities of TEC is to review planning guidance included in the Test Resource Master Plan (TRMP). The purpose of the TRMP is to define and guide investments in T&E capabilities needed to support the development, acquisition and operation of DoD weapon systems.[33] Specifically, prime goals are as follows:

1. Improve the ability to provide adequate evaluations of weapon concepts and equipment.
2. Institutionalize the National Test Capabilities Base (NTCB).
3. Ensure adequate, timely, cost effective test capabilities.

The major focus of this plan is on major investments at MRTFB activities.

---

[31] *Ibid.*

[32] Test and Evaluation Committee, *Draft Test Resources Master Plan,* April 24, 1989, p. A2-2.

[33] *Ibid.*

The services continue to have the responsibility to plan, budget and acquire needed test facilities. Subsequently, the MRTFB activities usually have, within their organization, a facilities planning department. Each Service and activity submits and performs this planning according to the requirements set by the chain of command. However, studies of shortfalls or capabilities can be performed in-house or by a contractor.

From these planning endeavors and the reports they produce, both at the OSD and activity levels, the basis for the next section of needed T&E resources is developed.

E. NEEDED TEST AND EVALUATION RESOURCES

The increasing battle space, complexity and interdependence of DoD weapon systems dictate improved, interrelated, highly efficient test capabilities.[34] To support and maintain these capabilities, long range planning is required to anticipate future technology requirements. These plans would identify activities associated with T&E and theorize possible future technical requirements. They would include an explanation of the problem, directional advice, and an investment strategy.

Two recent attempts at planning for required T&E resources have come from the TRMP and SRI International. First, the TRMP

---

[34] *Ibid.*, p. I-1.

Table 5. List of Test and Evaluation Functions

- 1.0 Collection Functions
  - 1.1 Instrumentation
    - 1.1.1 Tracking
    - 1.1.2 Scoring
    - 1.1.3 Sensing
    - 1.1.4 Communications/Telemetry
  - 1.2 Targets
  - 1.3 Simulation/Modeling
  - 1.4 Environmental Testing
  - 1.5 Range Safety
- 2.0 Processing Functions
  - 2.1 Data Recording
    - 2.1.1 Storage
    - 2.1.2 Retrieval
    - 2.1.3 Archiving
  - 2.2 Data Reduction
    - 2.2.1 Display
  - 2.3 Data Security

defines and guides investments in T&E capabilities needed to support the development, acquisition and operation of DoD weapon systems. Second, PMTC contracted SRI International to conduct two surveys designed to look at the problem. Results of these two efforts are discussed below.

1. The Test Resources Master Plan

The TRMP, drafted by the Test and Evaluation Committee, identifies seven functional areas to categorize and describe various planned and needed initiatives. These functional areas are:

1. Test mission command, control, communication and instrumentation. Encompasses instrumentation capabilities including scoring, tracking, target control, communications, telemetry, data collection and handling.

2. Electronic combat/threat/computational simulation capabilities. Concerned with disciplines necessary for electronic combat testing. Includes electronic hardware and digital simulation.

3. Space systems test capabilities. Related activities include test range capabilities, targets, threat simulators, telemetry, data processing, flight safety, launch processing and control.

4. Weapons effects test capabilities. Capabilities used for lethality or survivability testing, including nuclear and conventional threats.

5. Targets. Encompasses air, land, sea and underwater targets plus required support equipment.

6. Environmental/physical test capability. Facilities and capabilities needed to produce test environments such as wind tunnels, vibration stands, structural tests and weather chambers.

7. Management initiatives and other. Includes management issues, studies analyses, organizational and policy initiatives related to improving T&E capabilities.[35]

2. SRI International Report

The report performed by SRI International was in support of the US Navy T&E Technology Development Program. It documents the results of two surveys relating to T&E technology. The first survey developed T&E requirements based on projected needs; the second survey recorded current and recent technology research activities that might be exploitable for T&E applications.[36]

Separate procedures were used to develop both surveys. The requirements study consisted of interviews with individuals at the Pacific Missile Test Center, Naval Sea Systems Command and Defense Advanced Research Projects Agency. The interviews provided a supporting overview and projection of the character of T&E needs in the 1990's and potentially into succeeding years.[37]

Current and recent technology research activities were identified by searching existing documentation. This documentation was provided through the Work Unit Information System (WUIS) database supported by the Defense Technical

---

[35] *Ibid.*, p. II-8.

[36] Philip K. Whalen, SRI International, *Test and Evaluation Technology Knowledge Base,* March 1990, vol. I, p. 1.

[37] *Ibid.*, vol. I, p. 6.

Information Center (DTIC). In surveying the DTIC WUIS database, SRI identified several thousand technology research candidates.

The analysis of the data from the WUIS search resulted in six projects considered applicable to the T&E Technology Exploratory Development Program. Within each project tasks and subtasks were outlined to address the issues involved. Analysis of the interviews provided a different perspective on future T&E needs. However, most requirements were at least partially covered by the six projects identified in the WUIS search.

The following projects were identified by the SRI report.

1. Test data collection, transmission, storage, processing and display technologies.
2. T&E design and methodology.
3. On-board instrumentation sensor technology.
4. Low observable testing technology.
5. Modeling, simulation and stimulation technology.
6. Instrumentation platforms, targets and test support technology.

Additional needs identified from the interview portion of the study that are not listed above include:

1. Need for testing in all-weather conditions.
2. Accuracy in signatures emitted from low-observable targets.

3. Testing of very high velocity and hypervelocity vehicles.

4. Testing of weapons based on directed energy technology.

Individual facilities of the MRTFB support their own mission and unique capabilities. However, a broader view of the resources needed to perform T&E is required. This view should reflect the needs of the entire T&E community. Such an approach, based on the functions of T&E, is presented as a foundation for the identification of T&E technology requirements.

3. Functional Analysis

A function constitutes a specific action required to achieve a given objective. For example, test ranges must perform certain operations to record airspeed data. Such actions may be accomplished through the use of equipment, personnel, facilities, software, data or a combination thereof. Within these functional areas there exist challenges to maintain and perform T&E. These challenges will be identified under each function.

Collecting and processing data are two primary functions that can be identified from the definitions of test and evaluation. Collection is all operations needed prior to recording the appropriate raw data. These operations include the examination of test items; instrumentation, targets, simulation/modeling, environmental tests and range safety.

Processing includes all functions necessary to record and transform the raw data into a useable form. Processing functions consist of recording, reduction and security of the data.

Some functions, such as modeling or telemetry, could be identified as either processing or collecting. In these situations a subjective decision is made to determine which category it falls under. T&E functions are listed in Table 5. The functional areas and challenges are defined in the next two sections.

a. Collection Functions

Instrumentation is hardware that enables data on test parameters to be collected. Instrumentation sub-functions include tracking, scoring, sensing, and communication. Tracking provides time, space and positioning information on platforms, targets and test objects in the range. Scoring provides data on the relative space interval between the target and test object. Sensing functions measure key environmental parameters with sufficient accuracy, coverage, sensitivity and timeliness. These environmental parameters include physical (meteorology) and electromagnetic data. Sensing operations can be performed internally within the test item, or externally based on the ground or on board a platform. Communications involves the transferring of data. Telemetry, which is the delivery of data from sensors to

recording equipment, is part of this transfer of data. Operator voice communication is another area of communication. Besides the transfer of data between sensors and recorders, communication is needed between ranges. Interoperability between ranges for long range testing is a required communication capability.

Challenges for instrumentation functions include the ability to track/score high-speed, hypervelocity, low-observable, and multiple test objects. Also, smart weapons and submunitions require high resolution in tracking/scoring capabilities. Future techniques in tracking/scoring encompass the use of lasers, photonics and high resolution video.

Better sensing is needed to provide measurements of the physical environment surrounding and internal to the weapon system. The electromagnetic environment is of particular interest. Technologies that will aid in achieving better sensors are infrared and electro-optical radar. Commonality among sensors will reduce the current practice of uniquely modifying test objects for each project.

Communications between ranges lacks common application software. Currently each MRTFB activity independently develops its own unique test and evaluation software, such as positioning information, command and control, and safety of flight.[38] Existing telemetry systems

[38] *op. cit.*, Test and Evaluation Committee, p. A1-4.

will not support known near term requirements. The need for high-capacity data rate systems has increased with significant increases in performance and complexity of weapon systems. The increased complexity can be seen in weapons using new smart, submunition tactics. Other challenges for telemetry include high quality error free transmissions while preserving security.

Targets should closely simulate the characteristics of threats so that realistic presentations can be made. The targets should stress the weapon systems being tested in ways that can be directly related to the stress that a real threat would present in actual combat.[39]

Challenges for future targets are the correct emission of low-observable, electronic countermeasures, visual, infrared and acoustic signatures. Target speeds, flight profiles and altitudes are also important details of the target presentation. High-speed, hypervelocity, low altitude and space systems can be seen as possible future problem areas for targets.

Simulation and modeling is non-live fire testing that is mainly done on computers. Modeling is the research and programming of test object parameters. For example, performance characteristics such as velocity are entered into

---

[39] *op. cit.*, Philip K. Whalen, SRI International, vol. I, p. 49.

the computer. Simulation takes these parameters, interfaces them and with given starting conditions, sets them "into motion."

Simulations can be purely analytical or hardware-integrated. For example, analytical simulation of a tactical missile can include trajectory, separation, emulation, and lethality simulations.[40] As systems become more complex and sophisticated, hardware-integrated simulations have evolved because of the difficulty in obtaining a valid analytical representation.[41] The hardware integration approach yields a more realistic test and avoids more complex modeling problems. As testing requirements become increasingly complex and demanding simulation takes on a more important role. Some test situations cannot be performed safely in the controlled test range and evaluations of highly complex and versatile systems would require so many live operations and participants that full testing is not economically feasible.[42] Future needs in modeling relate to increasing the signature database. This database includes friendly as well as threat signatures. This task also covers development of improved techniques for measuring target signature characteristics and implementation

---

[40] Emil J. Eichblatt Jr., ed. "Test and Evaluation of the Tactical Missile," vol. 119 of *Progress in Astronautics and Aeronautics*, p. 130.

[41] *Ibid.*, p. 163.

[42] *Ibid.*, vol. I, p. 41.

of these techniques to obtain needed measurements for the database.[43]

Environmental testing addresses ground test facilities used to subject models, components, sub-systems and systems to physical environments. This testing is required to provide development information and evaluate performance. Facilities include wind tunnels, space chambers, environmental chambers, acoustic chambers, structural test stands, and engine test cells. There is currently a lack of hypersonic ground test facilities with capabilities above mach five.[44] To meet the next generation of hypersonic vehicles the requirement for these test facilities has increased.

Another task is the development of technology for use in laboratory test chambers to simulate target and background radar and infrared signatures. Space systems require the capability to adequately test large structures. There is no such national capability in the existing or planned test facility base.[45] In addition, it is anticipated that a space chamber will be needed to test critical performance characteristics of space sensor concepts and designs under development.[46]

---

[43] *Ibid.*, vol. I, p. 42.

[44] *op. cit.*, Test and Evaluation Committee, p. A1-24.

[45] *Ibid.*, p. A1-26.

[46] *Ibid.*

Range safety refers to the ability to ensure protection against mishaps during testing. This ability pertains to both targets and test objects. The ability to command and destruct all vehicles on the range is important in maintaining safety. This ability can be internal to the vehicle or external, as part of the range. A challenge for the future ranges is to provide this command destruct capability without modifying the test object. This reduction in modifications enables the use of a more realistic production system. More importantly, it produces a test closer to actual combat.

b. Processing Functions

Processing functions deal mainly with the data that is collected during testing. These processing functions include data recording, reduction and security. Data recording is comprised of storage, retrieval and archiving operations. Data storage is the process whereby transmitted raw data is stored upon some medium. These mediums can be magnetic tape, disks, programmable chips, or paper. Retrieval of data can be described as recouping data once it has been stored. It can be seen as the "read" function, where storage is the "write" process. Archiving is the means of preserving and filing data for later retrieval.

The amount of data to be handled in future T&E operations not only taxes transmission systems, but also the

ability of systems used for data storage.[47] The challenge is to be able to store, recall and locate vast amounts of data. This can either be done by increasing the number of actual storage mediums, or by increasing the capacity of individual mediums. Another related challenge will be the time needed to write, read and locate data. For example, there exists a difference in time of reading a computer program using a floppy disk or hard drive. The hard drive is much faster and able to store more information.

Reduction of data is the operation of separating relevant and important sections of data for analysis. Once the data is reduced it has to be displayed. This presentation can take many forms and is important in providing a "quick look" capability. Pre-processing can aid in reducing the amount of raw data.

The challenge is to develop techniques to automate, accelerate and improve processing techniques. Techniques to be considered in this effort include development of improved analysis tools through better techniques. These techniques include faster and more mathematically-sophisticated software, artificial intelligence, expert systems, parallel processing, neural networks and modular design concepts.[48]

---

[47] *op. cit.*, Philip K. Whalen, SRI International, vol. I, p. 17.

[48] *Ibid.*, vol. I, p. 25.

Data security is signal conditioning, modulation and encoding of data. Its purpose is to maintain the integrity of the data while securing it from collection. Compromise of information during test and evaluation can permit adequate lead time for foreign governments to develop countermeasures. There are inadequate provisions in existing and planned test capabilities for ensuring against unauthorized (hostile) collection of data on the capabilities of weapons during test and evaluation.[49]

The challenge is to provide data security for new telemetry systems. These systems, as mentioned previously, will transfer much more data. In addition there is a need to update current encryption techniques. Artificial intelligence, mathematical structures, algorithms, parallel processing and sub-miniature telemetry technologies all have implications for telemetry signal conditioning problem.[50]

The TRMP, the SRI International reports, and the author's analysis describe the functions and future challenges in T&E. These plans, reports and analysis try to relate the operations performed by T&E to future required resources. It should be noted that the operations identified assume that the planned test will provide the necessary data for the decision making process. This is not always the case. However, for the

---

[49] *op. cit.*, Test and Evaluation Committee, p. A1-10.

[50] *Ibid.*, p. A-9.

purpose of this analysis the technical aspects of the T&E functions were emphasized. They will form the basis for assessing the impact of the Critical Technologies plan on T&E.

In the next chapter the author's list of T&E functions, shown in Table 5, will be the foundation for evaluating and analyzing the impact of the Critical Technologies Plan on T&E. A matrix will be developed to relate critical technologies to T&E functions.

IV. IMPACT OF THE CRITICAL TECHNOLOGIES ON THE TEST AND EVALUATION FUNCTIONS

The impact of the Critical Technologies Plan (CTP) on Test and Evaluation (T&E) is assessed in terms of the T&E functions introduced in Chapter III. First, a reactive or defensive impact is described. Ten of the twenty critical technologies that are assessed as having the greatest impact in a reactive way are analyzed. Second, a proactive or offensive impact is discussed. All twenty critical technologies are analyzed from this viewpoint.

A. REACTIVE IMPACT

An obvious impact the critical technologies will have on T&E is a reactive one. In many cases the CTP introduces and specifies new abilities in weapon systems. Reaction will be required from the Services, particularly the Major Range and Test Facility Base, on how to test these new technologies.

Most of these technologies are hardware or software related. For example, new hardware is projected in Air-Breathing Propulsion, Hypervelocity Projectiles, Composite Materials, Pulsed Power, and Signature Control.

In Air-Breathing Propulsion, the development of hypersonic technology, primarily scramjets, has the potential to extend

military missions to new flight regimes.[51] This would require a test and evaluation activity to expand its test range to cover these increased performance and mission capabilities.

Hypervelocity Projectiles will tax current T&E abilities in tracking and scoring of test objects. This is certainly a concern during weapon/target interception.

Advanced Composite Materials produce difficulties in structural testing. This is particularly true in determining strength characteristics and structural soundness after damage.

Signature Control technology will produce difficulties in tracking and sensing. Advancement of stealth technology through Composite Materials will present a major challenge to the tracking and sensing functions. In addition, targets will have to mimic the signature characteristics of the threat. This not only includes absolute levels but also fluctuation rates.[52]

Lastly, safety factors could present problems in High Energy Materials and testing Pulsed Powered Weapons. Used as propellants, High Energy Materials will increase the range and velocity of test objects. Used as explosives, velocities and pressures of detonation output will increase. Both of these

---

[51]Department of Defense, *Critical Technologies Plan,* March 15, 1990, p. A-154.

[52] *Ibid.*, p. A-113.

factors will have to be considered during range safety analysis. Also, the enormous voltages and currents of pulsed power weapons, coupled with their long range capabilities will require a unique solution to safety in testing.

New software related technologies include Parallel Computer Architectures, Software Producibility, Semiconductor Materials and Microelectronic Circuits, Signal Processing and Photonics.

Software for Parallel Computer Architectures will entail the development of new system software (operating systems, languages, compilers and debuggers).[53] The T&E community will be required to maintain competency and testing abilities with such new software. In addition, parallel processors are able to execute currently infeasible computations.[54] The increased computing speeds made possible by parallel processing, will result in more effective weapons at a lower cost. Other challenges presented by parallel processing include verification during testing of automatic target recognition, "smart skins," and atmospheric modeling.

Verifying and testing the increasing number of lines of code arising from the development of Software Producibility is proving to be difficult. Also real-time performance

---

[53] *Ibid.*, p. A-20.

[54] *Ibid.*, p. A-34.

evaluations and fault detection may require the development of automatic software testing.

Microelectronics technology, improvements in computing speed and complexity will challenge production and quality assurance testing. Also, microelectronics technology may affect self-test circuitry. Test and evaluation of system maintenance and reliability will require the consideration of such circuits.

Signal processing can automate wide area surveillance, target search, classification, identification, tracking, and aimpoint selection, as well as provide survivable communications.[55] Smart weapons and surveillance systems rely on advanced signal processing to recognize and classify targets. During T&E, the requirements for proper transmission of these signals are vital.

Photonics, like parallel architectures, offers improvements in computing speed. Photonic devices also offer superior electromagnetic pulse and radiation hardness.[56] It is up to the testing agency to provide a system to test the level of this radiation resistance. Photonics can also aid in developing faster, smaller and more reliable, communications and intelligence systems. The verification of signal rates and reliability will be challenges the T&E community must

---

[55] *Ibid.*, p. A-101.

[56] *Ibid.*, p. A-66.

meet. The above discussion has briefly outlined how ten of the twenty critical technologies can impact test and evaluation in a reactive manner. By precisely reading the CTP, all of the technologies could be similarly analyzed. However, the main focus of this chapter is to determine the impact of the CTP in a proactive or offensive fashion.

B. PROACTIVE IMPACT

A proactive impact means that the test and evaluation community would consider the CTP as a means of assistance. Rather than regarding the CTP as a forecast of new weapons that need to be tested, the perception would be that the critical technologies identified in the plan may facilitate the performance of test and evaluation activities. To expand on this idea, input from the T&E community could be provided to decision-makers involved in developing the CTP. Then the critical technologies could be planned to further the MRTFB capabilities. It is these two views which will be developed in assessing the proactive impact of the CTP on test and evaluation.

The framework used to analyze the proactive impact of the CTP on T&E starts with the functional areas of T&E introduced in Chapter III. A subjective assessment, with inputs from T&E experts, was made to determine if the 1990 list of critical technologies could affect each T&E functional area (see Table 6). The discussion that follows explains the logic behind each

assessment and describes the extent to which the critical technologies can assist and possibly advance T&E operations.

1. Semiconductor Materials and Microelectronic Circuits

Improvements in the performance of computer hardware coupled with decreasing costs have spread computing into many areas. Consequently, this technology is viewed as making some contribution in all areas of T&E. Processing functions will be particularly affected by this technology. Data storage, retrieval, archiving, reduction and display will benefit from lower power demands, higher reliability, lower cost and very high computing speeds. All collection functions utilize some form of microelectronics. For example, tracking and scoring functions may be enhanced by the ability to collect more positional data faster. Environmental testing could have more parameters, (humidity, acoustic noise, etc.) monitored and controlled by these more efficient circuits. In particular, communication systems will be able to expand with increased circuit complexity and functionality.[57] Also, target guidance and control will use the same integrated circuits. Important as microelectronics are today, future T&E systems will rely more on advances in semiconductor fabrication.

2. Software Producibility

Software, as with microelectronics, has become increasingly available and affordable. It has become the focus

---

[57] *Ibid.*, p. A-6.

TABLE 6. SUMMARY OF THE IMPACT OF DOD CRITICAL TECHNOLOGIES ON TEST & EVALUATION FUNCTIONS

Test and Evaluation Functions / Critical Technology	COLLECTION								PROCESSING				
	INSTRUMENTATION								DATA RECORDING				
	Tracking	Scoring	Sensing	Communications Telemetry	Targets	Simulation Modeling	Environmental Testing	Range Safety	Storage	Retrieval	Archiving	Data Reduction & Display	Data Security
1. Semiconductor Materials and Micro-electronic Circuits	S	S	S	S	S	S	S	S	S	S	S	S	S
2. Software Producibility	S	S	S	M		S			M	M	M	M	M
3. Parallel Computer Architectures	S	S		M	S	M			M	M	M	M	M
4. Machine Intelligence and Robotics	S				S		S	S					M
5. Simulation and Modeling			S		S	M	S	S	S	S	S	S	S
6. Photonics			S	M					S	S	S	S	
7. Sensitive Radars	M	S	M		S								
8. Passive Sensors	S	S	M		S								
9. Signal Processing	S	S	S	M									
10. Signature Control	S	S	S		S	S							
11. Weapon System Environment			S			S	M	S					
12. Data Fusion				S		S						M	S
13. Computational Fluid Dynamics	S				S	M		S					
14. Air-Breathing Propulsion					S			S					
15. Pulsed Power			S		S	S		S					
16. Hypervelocity Projectiles					S			S					
17. High Energy Density Materials					S			M					
18. Composite Materials	M				S		S	S					
19. Superconductivity				S					S	S	S	S	
20. Biotechnology Materials and Processes			S						S				

M = capable of making major contributions
S = capable of making some contributions

of functionality and flexibility in most large scale systems.[58] A major impact of the development of software will be to maximize the potential of parallel processors. Parallel processing will further enhance signal processing in communications. Similarly, all of the T&E processing functions will be impacted by Software Producibility. New algorithms and programming technologies will improve the specific function of data security. The promise of reusable software will increase availability for all data recording functions along with data reduction and display.

3. Parallel Computer Architectures

This critical technology has the potential to generate a large impact on T&E. The exploitation of complex parallel and distributed systems offers orders of magnitude improvements in availability and dependability in communication, data processing and engineering design.[59]

A major impact will affect data storage, retrieval, archiving, reduction and security. The current ability to access historical testing results and evaluation reports from large, multi-site databases is an effective use of parallel processing.

---

[58] *Ibid.*, p. A-19.

[59] *Ibid.*, p. A-21.

High performance parallel computing will also enhance simulation and modeling by increasing computing speed. For example, lengthy calculations in predicting atmospheric patterns and strategic defense system simulation are possible with parallel computing.

Contributions will also be made in the tracking and scoring function. Parallel systems will allow for faster transmission of more data. These capabilities will allow tracking of multiple objects and enhanced positional data.

4. Machine Intelligence and Robotics

Data security will experience a major impact from this critical technology. A security challenge results from the employment of artificial intelligence in tracking. Security, oversight and control will decrease as autonomous systems transmit sensitive data. Data security concerns will have to be built into these intelligent data collecting systems.

Targets and range safety will benefit from the development of machine intelligence and robotics. Command, control and intelligent actions of autonomous robotic ground and unmanned air vehicles will increase through expert systems. This increased command and control of targets will benefit range safety functions.

Robotics technology also involves creating and controlling complex motion to perform manufacturing

operations. These controlling abilities can be used in environmental testing, where repetitive motions or hazardous environments are required. Automatic tracking of test objects may also gain performance from complex motion control.

5. Simulation and Modeling

This critical technology has the potential to generate a large impact on T&E. It correlates directly to the simulation and modeling T&E function. As the costs of weapon systems increase and costs of simulation decrease, T&E will be accomplished with more simulations validated by live-fire tests.

The CTP describes two aspects of simulation and modeling. The first of these, which does not directly apply to T&E, is the cost effective training of personnel for operation and maintenance of equipment. The other, however, describes testing, system prototyping, computer based simulation and modeling, and physical simulation. These activities directly impact operations in T&E. This critical technology can also have application to predictions of the physical effects of environmental influences such as temperature or weather conditions.[60]

---

[60] *Ibid.*, p. A-56.

Data processing functions will likewise benefit from the development of Simulation and Modeling. Some contributions will be realized in these areas because Simulation and Modeling relies on computer hardware and software improvements.[61] Also, networking the accumulation of hundreds of simulations will enhance the size and technicalities of a common environmental database.

6. Photonics

The main area of utilization associated with photonics lies with communications. Fiber optics will provide higher bandwidth capabilities to ships, aircraft, and undersea communications at lower cost than current cables by factors of ten to 100.[62] Low loss fibers would permit longer distance communications and allow development of fiber guided missiles. Optical storage discs and display devices are currently being manufactured. These disks increase storage capacity and will benefit the data recording functions of T&E. Fiber optic sensors will also gain performance from development in this technology.

---

[61] *Ibid.*, p. A-59.

[62] *Ibid.*, p. A-65.

7. Sensitive Radars

Test and evaluation activities - tracking and sensing (detection, classification, and identification) - will be significantly enhanced by the development of this technology. Ultra-wideband radars (operating at lower frequencies) offer a potential to detect stealthy targets and will provide simpler, lower cost, more reliable, radars.[63] Integrated sensor approaches will allow for multiple functions and collection of multiple target signatures.[64] Scoring may be enhanced by being able to detect low-observable and multiple test objects. As mentioned previously, tracking and scoring of multiple objects will also rely on parallel processing. Also, navigation will improve for targets with the use of laser radar imagery.

8. Passive Sensors

Development of passive sensors will reinforce the larger sensing function of T&E. Multi-band passive infrared and electro-optical sensors can reduce the sensitivity of existing sensors to environmental and target signatures.[65] Integrated sensors will allow for collection of multiple

---

[63] *Ibid.*, p. A-78.

[64] *Ibid.*

[65] *Ibid.*, p. A-88.

target signatures. Target and scoring functions will realize important radar capabilities from passive sensors without the radiation emitted needed to find test objects. Superconductivity will allow the development of super directive compact antennas.[66] These compact antennas will have lower profiles and reduce the size and weight of guidance systems in targets.

9. Signal Processing

Signal processing can be most utilized by the communications/telemetry function. With the vast amounts of data transmitted through sensors, signal processing can extract relevant information. This process, which relies on parallel processing and artificial intelligence, would reduce the amount of data requiring reduction. Similarly, signal processing can also automate tracking, scoring and sensing functions. Although fully automatic target recognition is not expected in the near term, immediate opportunities exist for automatic target cuing.[67] Neural network technology, which is a critical aspect of signal processing, may increase the capabilities of target command and control.

---

[66] *Ibid.*

[67] *Ibid.*, p. A-101.

10. Signature Control

The research in reducing signatures of weapons systems will provide some contributions in simulation and modeling. Target signatures and models used in simulations will become more realistic as a result of this research. To a lesser extent research in weapon system signatures will provide some contributions to the collection functions of T&E. Testers will be able track and sense test objects easier if they understand the limits and characteristics of future signatures. The emphasis here is use of the technology developed for low-observable weapons systems to the T&E communities' advantage.

11. Weapons System Environment

This technology will have its greatest impact in environmental testing. An increased understanding of environmental factors associated with and affecting the use of weapons will lead to more realistic production and acceptance testing.

Improved data in atmospheric predictions, ocean circulation and electromagnetic fluctuations can estimate the potential leverage of environmental factors. These estimations will aid in assessing system reliability, failure rate, maintainability and operability. The development of predictive ionospheric models will permit the maximum effectiveness of

magnetic sensor systems.[68] Integration of environmental knowledge in the design of targets and test objects may lead to a better understanding of their range characteristics. This understanding could potentially improve range safety concerns.

12. Data Fusion

The synthesis of useful data from diverse sources will significantly impact the data reduction function of T&E. It is essential to the decision process that only relevant information be presented for consideration. Without some form of automated data fusion, decision makers may be overwhelmed by increasing amounts of data. In addition, "quick look" capabilities must be enhanced by integrating expert systems to identify critical events during testing.

Communications and simulations could also benefit from the filtering of data. Estimating sensor outputs and network capacity will maximize these systems' capabilities. The amount of transmitted data could actually be reduced before recording. Trends analysis within recorded data, will lead to the transmission of only critical data.

Data fusion requires the use of sensitive information. Multi-level security procedures would have to be introduced to

---

[68] *Ibid.*, p. A-120.

insure exclusion, proper access, reliability and protection of sources.

13. Computational Fluid Dynamics

This critical technology will improve simulation and modeling functions of T&E. Computation fluid dynamics, coupled with advances in computer hardware, will be able to simulate test object characteristics. It will be employed through computers to evaluate new shapes at multiple velocities and fluid densities.

The calculation of fluid flow around bodies is one consideration to improve performance characteristics of flight vehicles, ocean vehicles and air breathing engines. This technology can be applied to concepts such as target maneuvering aerodynamics, propulsion, and signature treatment. Comprehension of performance characteristics through simulation can provide information for range safety and tracking functions.

14. Air-Breathing Propulsion

Gas-turbine technology will make some contributions to targets and flight safety. Since it is a major element of targets, size, performance, mission capability, and life cycle costs are directly dependent on the propulsion system. Hypersonic targets will be possible with scramjet technology developed in this area. Knowledge of test object and target

performance characteristics will aid safety personnel in determining range requirements during testing.

15. Pulsed Power

The ability to provide high power in light weight, compact systems will impact targets, sensing and simulation. Hypervelocity targets, rapid fire rates, and advanced electromagnetic launchers are some applications that may be furthered by this technology. Ultra-Wideband and laser radars will benefit from the controlled solid-state switching needed in the development of pulsed power.[69]

In addition to powering targets and sensing devices, pulsed power technology is vital to assessing and simulating the vulnerability of present and future systems to nuclear, directed and kinetic energy weapon systems.[70] From these simulations, predictions can be made on required range safety precautions.

16. Hypervelocity Projectiles

As mentioned in Pulsed Power, the ability to propel projectiles at greater than conventional velocities will impact targets. Hypervelocity targets will result in more realistic testing. Other target characteristics that may

---

[69] *Ibid.*, p. A-166.

[70] *Ibid.*, p. A-163.

improve are effective range, high fire rate, lower weight and lower costs. Again, knowledge of these target and test object performance characteristics will aid in assessing range safety requirements.

17. High Energy Density Materials

This technology will produce major challenges for range safety and provide enhanced capabilities for targets. Advances in fuses, bombs, mines and weapon warheads will tax the requirement for safe testing. New approaches will be needed to consider the safety of increased detonation output.

Used as propellants, targets will be able to travel greater distances at higher speeds. Improved realistic target signatures may result from newly developed compositions.

18. Composite Materials

Composite Materials, which are key to low-observable, stealth capabilities, will have a major impact on tracking. Tracking low-observable targets and test objects will pose a major challenge for T&E. As tracking technology develops, the question then becomes how realistic the target signature is and to what level the test object signature has been reduced. The development of this technology will also affect range safety. The ability to insure the position of low-observable targets and test objects is crucial to the range safety mission.

Structural analysis, which is included in environmental testing, will also be affected by this technology. Research into composite materials will supplement the task of predicting fatigue, hardness, elasticity and other structural qualities of these composites. Of particular interest are the damaged strength and electromagnetic absorption characteristics of these composites.

Target design will be able to use composites in structural frames. Typical weight savings over metal designs are 20 to 30 percent.[71] This weight reduction can be used to increase range, payload, velocity, maneuverability or reduce fuel consumption.

19. Superconductivity

This technology will reduce performance limitations and power losses of electrical and electronic equipment.[72] Consequently, data recording and reduction, and communications will be affected. Computers are essential in data storage, retrieval, archiving, reduction and display. They will benefit from more efficient energy storage and distribution devices. Such future systems will offer greater immunity from brown out, easier repairs (due to small size), and local control of

---

[71] *Ibid.*, p. A-205.

[72] *Ibid.*, p. A-213.

available energy.[73] Energy devices for communication systems will likewise benefit in a similar manner.

20. Biotechnology Materials and Process

Sensing and data storage functions could be affected by the development of this technology. The biosensor program will develop automated sensors that will couple highly specific biomolecules for chemical recognition.[74] This capability could be used to test the lethality of new chemical weapons. Other testing could determine the level of protection provided from current chemical warfare safety gear.

Bioelectronics will focus on optical storage and switching devices using biomolecules.[75] This research will enable the production of semiconductor devices with substrate thicknesses less than 0.5 microns.[76] This thin film manufacturing process will aid in lowering costs, and increasing circuit density.

In sum, the CTP is considered to have a significant impact on T&E. It is important for the T&E community to consider the CTP as one avenue to procure and possibly advance required technologies for future T&E. Thirteen out of 20

---

[73] *Ibid.*, p. A-215.

[74] *Ibid.*, p. A-229.

[75] *Ibid.*, p. A-230.

[76] *Ibid.*

critical technologies are concluded to be capable of making major contributions in 11 of the 13 T&E functional areas. All other critical technologies could provide some contributions through related research.

The next chapter will summarize these relationships. In addition, conclusions and recommendations are cited on the impact on planning and budgeting for T&E.

V. CONCLUSIONS AND RECOMMENDATIONS

In this chapter the impact of the Critical Technologies Plan (CTP) on Test and Evaluation (T&E) is summarized. Recommendations are then provided, discussing the possible actions the T&E community can employ to influence the CTP and its processes.

A. CONCLUSIONS

The CTP is deemed to have a significant impact on T&E. Thirteen out of 20 critical technologies are concluded to be capable of making major contributions in 11 of the 13 functional areas of T&E. All of the critical technologies are concluded to be capable of making some contributions to all of the T&E functional activities.

Of the 20 critical technologies, Simulation and Modeling and Parallel Processing are determined to have the greatest impact on T&E.

Simulation and Modeling duplicates simulation and modeling identified in the T&E collection functions. Development of new computer languages and algorithms, particularly artificial intelligence, will make complex simulation more realistic, easier and more affordable. Future modeling efforts will be used to help develop optically based targets, provide analyses

in concealment and deception, and measure performance during wargaming exercises.[77]

In addition, the bulk of T&E data is derived from simulation.[78] Computational Fluid Dynamics is viewed as a subset of simulation and modeling. It will make major contributions in simulating dynamic fluid flow around rigid bodies.

Development of Parallel Computer Architectures affects the data processing, communications and simulation and modeling functions. Parallel Computer Architectures offers at least an order of magnitude improvement in computing speeds, availability and dependability. Availability and dependability capabilities permit access to large, multi-site databases. Increased computing speeds will allow tracking and scoring of multiple test objects from multiple sensors. Time consuming calculations in complex simulations that are not possible today will be feasible with parallel computing.

Semiconductor Materials and Microelectronic Circuits is the most pervasive technology for T&E, making some contributions in all functions. Along with this technology, Software Producibility has its greatest impact on communications and data processing functions.

---

[77] Department of Defense, *Critical Technologies Plan*, March 15, 1990, p. A-59.

[78] *op. cit.*, Emil Eichblatt Jr. ed., p. 182.

Progress in Weapon System Environment technology is viewed as making major contributions to production and acceptance testing. As a element of environmental testing, this technology will produce the data required to model more realistic tests.

Two technologies, Passive Sensors and Sensitive Radars, are determined to be subsets of sensing functions in T&E. Sensitive Radars is also perceived to make major contributions in tracking operations. Composite Materials introduces challenges in tracking low-observable, stealthy targets and test objects.

Machine Intelligence will present challenges in data security. Autonomous data collection and transmission of sensitive data will require unique solutions to maintain security.

Development of High Energy Density Material will produce challenges for range safety operations. Increased performance in both propellants and explosives will require unique solutions to limited range areas.

Lastly, Photonics and Data Fusion are capable of making major contributions in the areas of communications and data reduction and display, respectively.

The main objective of the CTP is to identify, prioritize, consolidate and focus critical technologies requirements and milestones within DoD and DoE. The function of T&E is to provide a technical management tool used to reduce risk

throughout the acquisition cycle. It is certainly possible for these two objectives to support each other, to their mutual benefit. T&E will gain required technologies for future tests through the CTP process. Also, testers could anticipate future weapon systems from the identified critical technologies. The CTP and its processes may become more attentive to the technology needs of the T&E community within DoD.

Because many T&E activities are performed by the Services through the Major Range and Test Facility Base (MRTFB), there exists a limited constituency to support a long term investment strategy. This limitation restricts the resources available to solicit funding or to broaden the CTP decision-making process to include T&E requirements.

Also, future budgetary constraints will reduce the amount of funding available. The Central Test and Evaluation Investment Program is one attempt to provide new test resources to improve the capabilities of the MRTFB. However, the Pentagon's request of $186 million was cut this year to $112 million, and the plan to spend $1.7 billion through 1997 was deemed unrealistic by lawmakers.[79] It is the responsibility of the T&E community to use every available means to maintain the technologies needed to adequately test future weapon systems.

---

[79]Jack Weible, "Congress Slashes $74 Million From New DoD Testing Program," *Defense News,* November 19, 1990, p. 20.

B. RECOMMENDATIONS

The CTP is one forum for the T&E communities' technology and funding concerns. It is this author's opinion that the Science and Technology Strategic and CTP planning processes should include T&E technology interests. It is recommended that personnel from the Deputy Director, Defense Research and Engineering (Test and Evaluation) be placed on the working group responsible for developing the CTP. This working group recommends possible technologies as critical. Specifically, the Directors of Test Facility Resources and Weapon System Assessment may be of greatest assistance.

Additionally, the T&E community should actively concentrate on using the CTP process not only as a method of anticipating future weapons, but as a process to acquire and advance T&E technologies. This is especially true for technologies already identified in past CTPs. Simulation and Modeling and Parallel Computer Architectures will have a major impact on T&E. Therefore it is in these areas that the T&E community should attempt to provide influence and guidance and obtain funding.

Finally, it is recommended that T&E technology requirements be incorporated into future CTPs. Test and Evaluation planning documents and studies should be used as a means of identifying possible critical technologies for future CTPs. Some examples included in the Test Resource Master Plan are:

1. Existing telemetry systems will not support the need for high-capacity data rates.

2. There exists no national capability to adequately perform structural testing of large space structures.

3. There exists no hypersonic wind tunnel capable of testing above Mach 5.

4. There are inadequate provisions for insuring against unauthorized (hostile) collection of data during T&E.

APPENDIX A.

PUBLIC LAW 100-456, SECTION 823

Arms and munitions

SEC. 822. CRITICAL TECHNOLOGIES PLAN

(a) IN GENERAL.—(1) Chapter 139 of title 10, United States Code, is amended by adding at the end the following new section:

"§ 2368. Critical technologies plan

"(a) ANNUAL PLAN.—(1) Not later than March 15 of each year, the Under Secretary of Defense for Acquisition, in consultation with the Assistant Secretary of Energy for Defense Programs, shall submit to the Committees on Armed Services of the Senate and the House of Representatives a plan for developing the 20 technologies considered by the Secretary of Defense and the Secretary of Energy to be the technologies most essential to develop in order to ensure the long-term qualitative superiority of United States weapon systems.

"(2) In selecting the technologies to be included in the plan, the Secretary of Defense and the Secretary of Energy shall consider both product technologies and process technologies.

"(3) Such plan shall be submitted in both classified and unclassified form.

"(b) CONTENT OF PLAN.—Each plan submitted under subsection (a) shall include, with respect to each technology included in the plan, the following matters:

"(1) The reasons for selecting such technology.

"(2) The milestone goals for the development of such technology.

"(3) The amounts contained in the budgets of the Department of Defense, the Department of Energy, and other departments and agencies for the support of the development of such technology for the fiscal year beginning in the year in which the plan is submitted.

"(4) A comparison of the positions of the United States and the Soviet Union in the development of such technology.

"(5) The potential contributions that the allies of the United States can make to meet the needs of the alliance for such technology.

"(6) With respect to the development of such technology, a comparison of the relative positions of the United States and other industrialized countries that are prominent in the development of such technology and the extent to which the United States should depend on other countries for the development of such technology.

"(7) The potential contributions that the private sector can be expected to make from its own resources in connection with development of civilian applications for such technology.".

(2) The table of sections at the beginning of such chapter is amended by adding at the end the following new item:

"2368. Critical technologies plan.".

(b) FIRST REPORT.—The first report under section 2368 of title 10, United States Code (as added by subsection (a)), shall be submitted in 1989. 10 USC 2368 note

APPENDIX B

PUBLIC LAW 101-189, SECTION 605

EXCERPTS FROM NATIONAL DEFENSE AUTHORIZATION ACT FOR FISCAL YEARS 1990 AND 1991: ANNUAL DEFENSE CRITICAL TECHNOLOGIES PLAN (PL 101-189)

(b) ANNUAL DEFENSE CRITICAL TECHNOLOGIES PLAN.—(1) Chapter 148 of title 10, United States Code, is amended by adding at the end the following new section:

"§ 2508. Annual defense critical technologies plan

"(a) ANNUAL PLAN.—(1) The Secretary of Defense shall submit to the Committees on Armed Services of the Senate and House of Representatives an annual plan for developing the technologies considered by the Secretary of Defense and the Secretary of Energy to be the technologies most critical to ensuring the long-term qualitative superiority of United States weapon systems. The number of such technologies identified in any plan may not exceed 20. Each such plan shall be developed in consultation with the Secretary of Energy.

"(2) In selecting the technologies to be included in the plan for any year, the Secretary of Defense and the Secretary of Energy shall consider both product technologies and process technologies, including the technologies identified in the most recent biennial report submitted to the President by the National Critical Technologies Panel under title VI of the National Science and Technology Policy, Organization, and Priorities Act of 1976.

"(3) Each such plan shall cover the 15 fiscal years following the year in which the plan is submitted.

"(4) Such plan shall be submitted not later than March 15 of each year and shall be submitted in both classified and unclassified form.

"(b) PRIORITIES AND FUNDING.—Each plan submitted under subsection (a) shall—

"(1) designate priorities for development of the technologies identified in the plan; and

"(2) specify the funding requirements of the Department of Defense, the Department of Energy, and other appropriate departments and agencies of the Federal Government for the development of the technologies identified in the plan for the five fiscal years following the year in which the plan is submitted.

"(c) CONTENT OF PLAN.—Each plan submitted under subsection (a) shall include, with respect to each technology identified in the plan, the following:

"(1) The reasons for the selection of that technology, including—

"(A) a discussion of the consideration given to the most recent biennial report submitted to the President under title VI of the National Science and Technology Policy, Organization, and Priorities Act of 1976; and

"(B) the relationship of the technology to the overall science and technology program of the Department of Defense and the long-term funding strategy associated with that program.

"(2) A designation of the lead organization within the Department of Defense or the Department of Energy responsible for the development of the technology.

"(3) A summary description of the lead organization's plan for the development of the technology, including the milestone goals.

"(4) The amounts contained in the budgets of the Department of Defense, the Department of Energy, and other departments and agencies for the support of the development of such technology for—

"(A) the five preceding fiscal years; and

"(B) the fiscal year beginning in the year in which the plan is submitted; and

"(C) each fiscal year thereafter for which the Secretary of Defense, with respect to the Department of Defense, and the Secretary of Energy, with respect to the Department of Energy, has prepared a budget.

"(5) A comparison of the positions of the United States and the Soviet Union in the development of that technology.

"(6) The potential contributions that the allies of the United States and other industrialized nations can make to meet the needs of the United States and its allies for that technology.

"(7) A comparison of the extent to which the United States has access to research conducted on such technology in allied nations and other industrialized nations with the extent to which such nations have access to research conducted in the United States on such technology and a discussion of the effects of any imbalance in such access on development of that technology.

"(8) With respect to the development of such technology—

"(A) a comparison of the relative positions of the United States and other industrialized countries that are prominent in the development of such technology;

"(B) the trends in the relevant industrial bases of such countries;

"(C) the competitiveness of the United States industrial base supporting research in, and the development and use of, such technology;

"(D) the extent to which the United States should depend on other countries for the development of such technology; and

"(E) the extent to which action should be taken by the Federal Government to maintain and improve—

"(i) research efforts in the United States; and

"(ii) the industrial base supporting such efforts.

"(9) The potential contributions that the private sector can be expected to make from its own resources in connection with the development of civilian applications for such technology.".

(2) The table of sections at the beginning of such chapter is amended by adding at the end the following new item:

"2506. Annual defense critical technologies plan.".

APPENDIX C

BILL S.2884, SECTION 801

Calendar No. 707

101ST CONGRESS
2D SESSION

S. 2884

[Report No. 101-384]

To authorize appropriations for fiscal year 1991 for military activities of the Department of Defense, for military construction, and for defense activities of the Department of Energy, to prescribe personnel strengths for such fiscal years for the Armed Forces, and for other purposes.

IN THE SENATE OF THE UNITED STATES

JULY 20 (legislative day, JULY 10), 1990

Mr. NUNN, from the Committee on Armed Services, reported the following original bill; which was read twice and placed on the calendar

---

A BILL

To authorize appropriations for fiscal year 1991 for military activities of the Department of Defense, for military construction, and for defense activities of the Department of Energy, to prescribe personnel strengths for such fiscal years for the Armed Forces, and for other purposes.

TITLE VIII—ACQUISITION POLICY AND MANAGEMENT

PART A—DEFENSE INDUSTRIAL AND TECHNOLOGY BASE

SEC. 801. ANNUAL DEFENSE CRITICAL TECHNOLOGIES PLAN

(a) INCREASED INFORMATION RELATING TO FUNDING.—Section 2508(b) of title 10, United States Code, is amended—

(1) by striking out "and" at the end of paragraph (1);

(2) by striking out the period at the end of paragraph (2) and inserting in lieu thereof a semicolon; and

(3) by inserting at the end the following new paragraphs:

"(3) identify each program element (contained in the budget information submitted to Congress by the Department of Defense in support of the budget submitted by the President pursuant to section 1105(a) of title 31 for the first fiscal year covered by the plan) for which funds are budgeted for the support of the development of any critical technology identified in the plan; and

●S 2884 PCS

"(4) for each such program element—

"(A) specify the amount included for each critical technology covered by the program element; and

"(B) include a comparison of that amount with the amount, if any, available to the Department of Defense for development of such critical technology for the fiscal year preceding the first fiscal year covered by the plan.".

(b) APPLICABILITY.—The amendments made by subsection (a) shall apply to annual defense critical technologies plans submitted after March 1, 1991.

APPENDIX D

SUMMARY OF CRITICAL TECHNOLOGIES

This appendix is provided to describe, in more detail, the critical technologies identified in the 1989 and 1990 CTPs. A more in-depth explanation of each technology can be found in the original CTPs which are identified in the bibliography.

A. 1989 CRITICAL TECHNOLOGIES

The twenty-two technologies identified in the 1989 CTP are summarized below. This summary includes an overview description, total S&T funding (best available estimate), impact on weapons systems and comparisons with other countries. The funding figures are taken directly from the CTPs and as mentioned in those plans, are generally not precise budgetary quantities.

The first seven or eight of these technologies are very closely related to one another and, in fact, are part of what could be considered the revolution in our capability of information processing and handling.[80]

---

[80]Senator Jeff Bingaman, *Hearings Before the Committee on Armed Services, United States Senate, Part 7,* Defense Industry and Technology, March 17, 1989, p. 15.

1. Microelectronic Circuits and Their Fabrication

Microelectronic circuits is a process technology that will lead to better production of ultra-small integrated electronic devices for high speed computers, sensitive receivers and automatic controllers. The emphasis is on developing more reliable methods to produce silicon for microelectronic circuits. Total S&T funding for this critical technology in FY 1990 is on the order of $200 million.

This technology will provide integrated circuits that will be less susceptible to interference in weapons systems and more resistant to damage from either natural or man-made radiation. Miniaturization techniques allow for major modifications on current weapons platforms, new weapons concepts and ability to build in self-test circuitry.

Japan is considered the leader in most aspects of microelectronics manufacturing with the exception of microprocessors and application specific integrated circuits.[81] The NATO allies, individually, do not presently rival either the US or Japan. However this could change, because the European countries have extensive capabilities in a number of important supporting technologies. The US microelectronics industry leads all communist countries. The

---

[81] Department of Defense, *Critical Technologies Plan, Revised,* May 5, 1989, p. A-9.

Warsaw Pact nations are severely limited in their ability to close the microelectronic technology gap.

2. Preparation of Gallium Arsenide (GaAs) and Other Compound Semi-Conductors

This technology is concerned with the manufacture and preparation of high purity gallium arsenide (GaAs) and other semiconductors. These new semiconductors will be used in integrated circuits. The major advantage of GaAs is the increased electron drift velocity. Total S&T funding for this critical technology in FY 1990 is on the order of $100 million.

Using GaAs will result in signal and data processing which is about seven times faster than that which is achievable with silicon.[82] In addition to increased speed, the integrated electronic circuits will be more resistant to radiation. This radiation hardening enables them to survive better in the battlefield and space environments. Use of GaAs will affect circuits in electronic warfare, radar, smart weapons and communication systems.

Japan is the leader in GaAs materials technology and could clearly make contributions to US capabilities.[83] European research and design is significant and growing but is

---

[82] *Ibid.*, p. A-11.

[83] *Ibid.*, p. A-13.

not as extensive as either the US or Japan.[84] Soviet work is believed to remain behind advances in the US by approximately eight years.[85]

3. Software Producibility

Software producibility refers to the objective of producing reliable, affordable, and secure software in a timely fashion. This includes the goal of producing software that is reusable. Total S&T funding for this critical technology in FY 1990 is on the order of $70 million.

Software is a key element in virtually all major weapon systems. Costs of development and maintenance of software are a large portion of the overall costs. Advances in software technology will yield important capability improvements such as high reliability for secure and life-critical systems, rapid adaptability for systems in a changing environment, reliable and secure large-scale distributed computation for command, control, and communications (C^3) applications, and access to the performance potential available in low-cost highly parallel hardware.[86]

A perceived Japanese lead in supercomputing is somewhat offset by a US lead in serial production and applications of lower-cost machines with parallel processing

---

[84] *Ibid.*

[85] *Ibid.*, p. A-14.

[86] *Ibid.*, p. A-15.

architectures.[87] The NATO countries have strong capabilities in selected areas of computer technologies. However no single country has proficiency in as many areas as the US. The Soviet Union has shown some good theoretical work in computer science, but software is an area of deficiency because of the shortage of computers.

4. Parallel Computer Architectures

Parallel computer architectures greatly increase the speed at which computers currently operate. Generally it is believed that parallel architectures will increase computing speed by 1000 times while reducing costs by ten times.[88] Total S&T funding for this critical technology in FY 1990 is on the order of $80 million.

This technology supports the computational capability needed for computational fluid dynamics done for hypersonic flight, anti-submarine warfare and automatic target recognition. Computer systems are expected to continue to provide a critical edge coming from superior performance of weapons and command/control systems which serve as a force multiplier.

The US has a significant worldwide lead in serial production and practical application of parallel processing

---

[87] *Ibid.*, p. A-17.

[88] *Ibid.*, p. A-21.

hardware.[89] Japan, the UK, the Netherlands and Germany all have credible efforts in advanced computing. The Japanese are a few years behind the US in highly parallel systems, particularly in systems software, but can be expected to close that gap.[90] The UK was a primary contributor in the development of a programing language for parallel computers and the Netherlands has become more active in the area of algorithms.[91] There is no evidence that the Eastern Bloc has any success in high-performance computing. The Soviets are, and will continue to be, severely hampered by the lack of micro-circuits; therefore their capabilities will be limited to theory, research and small prototyping.

5. Machine Intelligence/Robotics

Machine intelligence and robotics is an attempt to apply artificial intelligence and expert systems to defense applications. This is primarily a integration process to build robotics and machines that can help with battlefield management. Total S&T funding for this critical technology in FY 1990 is on the order of $70 million.

The faced paced battlefield of the future will include many sensors and weapons identifying targets. Intelligent systems will be used to integrate, process and analyze this

---

[89] *Ibid.*, p. A-23.

[90] *Ibid.*

[91] *Ibid.*, p. A-23.

data. These systems will enhance military intelligence, timely decision making, replanning and survivability. The use of unmanned air vehicles and robotic vehicles will reduce the number of operators on the battlefield. Additionally, application of robotics and intelligent machines to the manufacturing process will lead to flexible manufacturing and reduce set-up and lead times.

The US has had a commanding lead in the computing capabilities needed for this technology, but that lead is being diminished. Japan and, to a lesser extent some of the European allies have made significant advances in the industrial application of such technology. The Soviet Bloc significantly lacks in machine intelligence and robotics, although they have a good theoretical understanding and creativeness in applying the technology.[92]

6. Simulation and Modeling

Simulation and modeling involves testing concepts and designs without building physical replicas. This technology will encompass both hardware and analytical simulations. Hardware simulations have been produced in the past for aircraft development. Realistic simulations are now very close to the hardware and missions pilots have to perform. The analytical simulations are models that would greatly influence

---

[92] *Ibid.*, p. A-29.

training. Total S&T funding for this critical technology in FY 1990 is on the order of $115 million.

Simulation and modeling can be applied to every major weapon system development program. Design and production costs will decrease while improving performance and maintenance. Training costs will decrease by providing operators with realistic simulations. Also there will be enhanced capabilities in war gaming and teaching commanders how to use the information provided to them.

Generally, Japan lags the US in its development of databases that are required to do effective military modeling.[93] NATO allies are advancing computer modeling and simulation technology, but most lack the high-speed scientific computers needed. The Soviet Union lags the US in large-scale computers and graphic workstations. However they extensively use simulation and modeling for war-gaming and weapons development.[94] Their knowledge base may equal or lead the US in these specific areas.

7. Integrated Optics

Integrated optics, also known as optronics or photonics is the marriage of optical and electronic processes and capabilities. Increased capabilities will be realized in both storage memories and in data processing. If this

---

[93] *Ibid.*, p. A-34.

[94] *Ibid.*, p. A-35.

technology is successful, processing speeds will be approximately one hundred times faster than today.[95] Storage discs will also increase their capacity for information. Total S&T funding for this critical technology in FY 1990 is on the order of $25 million.

Enhanced processing is important on the battlefield for real-time display of information and to update this rapidly changing information. Expanded memories will give individual commanders more information than in the past. For example, the commander would be able to retrieve detailed maps either instantaneously or within seconds.

The US and Japan share a worldwide lead in this technology. The NATO allies have significant efforts that, if combined together, have the potential to compete with the US or Japan. The Warsaw Pact is lacking key aspects of the technology, particularly in materials and manufacturing techniques and optical interconnection techniques.[96]

8. Fiber Optics

Fiber optics' primary purpose is to transfer information, rather than its production or storage. Information will be able to be transmitted at ten times the capacity of present channels at one-tenth the error rate.[97]

---

[95] *Ibid.*, p. A-37.

[96] *Ibid.*, p. A-40.

[97] *op. cit.*, Senator Jeff Bingaman, p. 19.

This will raise the quality and quantity of information available to the battlefield. Total S&T funding for this critical technology in FY 1990 is on the order of $20 million.

This technology will be useful in submarine detection and will have its primary impact in the surveillance and communications fields. Fiber optic communication links will add a whole new range of capabilities for weapon guidance since they provide for wideband, non-line-of-sight, two way communication.[98] Another application integrates fiber optics with gyros. Fiber gyros are more accurate, smaller, all solid state, more rugged and more reliable.

The US and Japan share a worldwide lead in this technology. Japan clearly leads the world in converting research and design in fiber optic technologies into various commercial applications and has manufactured low-loss optical fibers.[99] NATO countries have shown some production of low-loss optical fibers but may have difficulty in producing such fibers in large quantities.[100] The Warsaw Pact is seen as lagging in all important aspects of this technology including; production, components and interconnections.

---

[98] *op. cit.*, Department of Defense, p. A-44.

[99] *Ibid.*, p. A-46.

[100] *Ibid.*, p. A-47.

9. Sensitive Radars

Sensitive radars are a mature but very important technology. The objective is to produce radar sensors capable of detecting low-observable targets and/or capable of classification, recognition and identification of uncooperative targets. This could be laser technology as well as microwave technology. Total S&T funding for this critical technology in FY 1990 is on the order of $130 million.

Non-cooperative targets challenge radar technology not only in low observable detection. Classification, (aircraft, missile, tanker, etc.) recognition, (friend, foe, armed, unarmed) and identification (time and placement) information are needed to select an appropriate action. This technology will counter the emerging stealth threat while improving electronic counter-counter measure capabilities and operation in high-clutter environments.[101] In addition, it will aid in long-range detection of mobile military targets under all weather conditions and reliable detection of concealed or camouflaged military targets.

Both Japan and NATO countries are believed to be able to make some contributions to this technology. France and Germany are actively pursuing joint investigation in the use of laser radar technology for helicopter detection and

[101] *Ibid.*, p. A-50.

recognition.[102] Both France and Norway are studying the use of imaging techniques against surface targets. Outside of NATO, Sweden seems to have a significant effort covering topics relating to non-cooperative target recognition.[103]

10. Passive Sensors

Development of weapons against radars is fairly sophisticated. Therefore, the advancement of passive sensors has been identified as critical. Passive sensors would supply information that is usually supplied by radars. These sensors do not emit signals to detect targets, monitor the environment, or determine the status or condition of equipment. Sensor methods include infrared, visible, ultraviolet, X-rays and microwave radiation. Total S&T funding for this critical technology in FY 1990 is on the order of $90 million.

Passive sensing will be used to complement the effort to counter stealth threats. Sensors will improve battlefield capabilities, improve target acquisition performance and improve sensitivity in adverse weather. Other uses included long-range search, target acquisition, tracking for fleet air defense, high altitude unmanned air vehicles, ship defense and aircraft target detection.

---

[102] *Ibid.*, p. A-53.

[103] *Ibid.*

In general, the US is ahead of our allies in all respects of passive sensing technology.[104] Principal cooperative opportunities will exist with NATO countries. This includes Germany, which is already producing a US modular infrared detector under US license, and with the UK.[105] Japan's solid-state technology, in the area of dissimilar compound semiconductor materials, could clearly make contributions. Eastern Bloc countries are believed to have developed a infrared detector. However, there is little evidence of mass production and deployment.[106]

11. Automatic Target Recognition

Automatic target recognition is an application based technology. It is a combination of computer architecture, algorithms, and signal processing for near real-time detection, identification and tracking of targets. Total S&T funding for this critical technology in FY 1990 is on the order of $75 million.

This application is essential in very smart weapons which can be self-guided to the target. It will assist operators of tanks and aircraft to identify targets and to aim the weapons at the target. Opportunities also exist in undersea targeting, over-the-horizon targeting, airborne

---

[104] *Ibid.*, p. A-59.

[105] *Ibid.*, p. A-59.

[106] *Ibid.*, p. A-61.

multiple target fire control, anti-ship and other air-to-surface missiles.[107]

The US enjoys a significant lead over other countries in the area of automatic target recognition, and the development and use of the large databases needed to support this effort.[108] Work going on in NATO could contribute to the advancement of smart sensors and algorithms applicable to automatic target recognition.

12. Phased Arrays

There are three types of phased arrays - radars, acoustic and optical. Phased arrays form spatial beams by controlling the phase or amplitude of signals of many small individual radiating elements. By correctly shifting the inputs of the individual radiators, the radar beam can be steered through a very large angle without mechanical motion. This is essentially a signal processing technology which includes system architecture, processing algorithms, and hardware components. Total S&T funding for this critical technology in FY 1990 is on the order of $80 million.

This technology could be used to eliminate antennas on aircraft or other platforms by enabling the skin itself to become the antenna. This greatly reduces drag and identification possibilities. Also, the requirement for

---

[107] *Ibid.*, p. A-64.

[108] *Ibid.*, p. A-67.

cooling decreases because the energy output is distributed over a larger area. This improvement in cooling efficiency increases reliability.

The US has established a significant lead over other nations, specifically in the development of air and ship based phased-array radar. Related work is being performed by many NATO countries and Japan. Significant contributions may be made in the application of GaAs to active arrays.

13. Data Fusion

Data fusion is taking information from many sensors in many different forms, integrating it and making it presentable to a human operator. For example, the commander or pilot has to have information presented so that they can interpret it quickly and use it essentially in real-time. Total S&T funding for this critical technology in FY 1990 is on the order of $90 million.

This battlefield management technology will have an application to smart weapons, self-guided cluster weapons and to large area surveillance systems. It will assist commanders by providing wide area surveillance from space and sea, predicting environmental conditions and managing assets. It will also assist platform operators such as pilots in future cockpits and navigation.

Principal cooperative opportunities lie with NATO countries in the areas of modeling, algorithms, and data

links. Access to Japan's technology in electronics and faster data links would make significant contributions. The Warsaw Pact is seen as lagging in faster data links and, in general, lagging in all but some aspects of data fusion.[109]

14. Signature Control

Signature control is the ability to control target signatures. These signatures include radar, optical, acoustic, or other detectable characteristics. The reduction of vehicle signatures increases survivability. This technology includes stealth capabilities. This effort is a way of not only increasing the camouflage, concealment and deception of platforms and weapon systems, but also to counter them. Funding for this critical technology comes mostly from outside the S&T program.

The use of signature reduction technology for strategic systems can render the Soviet Union's early warning system ineffective, allowing penetration without losses.[110] In tactical systems such as fighter and attack aircraft, increases in effectiveness based on the use of stealth technology are possible.

Discussion of a comparison with other countries for this technology is not possible due to its sensitivity.

---

[109] *Ibid.*, p. A-78.

[110] *Ibid.*, p. A-81.

15. Computational Fluid Dynamics

Computational fluid dynamics is the modeling and simulation of complex fluid flow. This technology will have the capability of solving fluid flow equations in three dimensions. Wind tunnel facilities and other hardware experiments will be replaced by computer models and simulations. This technology is primarily under development by a joint DoD and NASA effort for the national aerospace plane. Total S&T funding for this critical technology in FY 1990 is on the order of $30 million.

Computational fluid dynamics will lower design risks and lower costs of future flight vehicles, while enabling testing of hypersonic vehicles. The technology can be applied to aircraft, missiles, projectiles, re-entry vehicles, and ocean vehicles. The first application will be trying to model the hypersonic flow above Mach eight, the current limit of wind tunnel testing.[111] If the decision is made to build the national aerospace plane (X-30), simulation will be needed at orbital speed - Mach twenty. This technology can reduce drag in both air and sea vessels resulting in higher speeds, increased ranges with smaller engines, and use of less fuel.

The US possesses the key elements at a high level of sophistication to maintain a lead in the area of computational fluid dynamics. Japan's supercomputing software expertise

---

[111] *Ibid.*, p. A-83.

could help the effort in this technology. NATO countries could provide assistance in the are of algorithm developments. The Soviet Bloc and other adversaries are believed to be behind the US in this technology and are unlikely to close the gap because of US superiority in computers, software, and materials.[112]

16. Air Breathing Propulsion

Air breathing propulsion is a mature technology that has experienced steady, slow improvements. The objective is to produce dramatic improvements in light-weight, fuel efficient engines using oxygen to support combustion. Total S&T and NASA funding for this critical technology in FY 1990 is on the order of $116 million and $35 million respectively.

The obvious application is in maintaining air superiority of our current aircraft. This superiority will be seen in increased range, time aloft, and payload. These increases can and will also be perceived in rotorcraft and commercial and transport aircraft. Additionally, cruise missile will realize payoffs of lower costs, high Mach capability and increased range.

The two key aspects of this technology that indicate significant capabilities are development, and application of light-weight/high-temperature/high-strength materials and modeling and simulation of aerodynamic flow. Both NATO

---

[112] *Ibid.*, p. A-88.

countries and Japan are believed to be capable of making major contributions in the area of material development, with only some contributions in modeling and simulation.[113] The Warsaw Pact is generally lagging in modeling and simulation and materials developments.

17. High Powered Microwaves

High powered microwaves are being developed jointly by the DoE and DoD. High powered microwaves produce radiation similar to those produced by nuclear weapons. Since some of our systems are susceptible to such damage, the interest is to determine the survivability of our weapon systems. The other interest is to see if this technology can be applied to systems the enemy may field. Total S&T funding for this critical technology in FY 1990 is on the order of $50 million.

High power microwaves offer a means of defeating the enemy systems in mass by disrupting the ever increasing use of microelectronics and electrical subsystems. It may also play a role in interrupting communications without resorting to nuclear weapons. Also, there is a complementary need to

---

[113] *Ibid.*, p. A-93.

protect sensitive friendly electronic circuits in dense electromagnetic environments, such as on board ships.

The Warsaw Pact is seen to have significant leads in the development of components needed for this technology, but is lacking in power handling and control of microwave beams.[114] NATO countries and Japan are considered capable of making some contributions in both development of components and power handling and control.

18. Pulsed Power

Pulsed power is a technology which addresses the problem of generating power in the field with relatively low-weight and low-volume devices. It is specifically aimed at directed energy weapons, anti-armor, high powered microwave weapons and electromatic guns. The main thrust is to improve energy storage capability by an order of magnitude or more. Total S&T funding for this critical technology in FY 1990 is on the order of $65 million.

The use of electromagnetic guns will permit an extended range of anti-armor weapons, close air support (such as the A-10), and surface ship missile systems. Ground-based directed energy weapons can also be used in many different warfighting scenarios. High powered microwaves can upset smart electronic systems rendering missiles and smart mines ineffective.

---

[114] *Ibid.*, p. A-97.

The US is the world leader in the development of compact, lightweight power systems. Recent breakthroughs in US capacitor fabrication which increase energy storage densities, have established a significant US lead in this area.[115] However, the Soviet Union has an extensive program in pulse power and may lead in a number of other areas. NATO and Japan have demonstrated competence in specific areas of switching and Japan has developed primary power sources that may prove adaptable to pulse power.[116]

19. Hypervelocity Projectiles

Hypervelocity projectiles is more of a application technology. The purpose is to provide the capability to shoot projectiles at greater than conventional velocities (over 1.6 km/sec).[117] This technology also investigates the unique behavior of projectiles and targets at such velocities. Total S&T funding for this critical technology in FY 1990 is on the order of $100 million.

This technology is important for electromatic guns and the ability to defeat advanced armors on the battlefield. Hypervelocity projectiles generate more destructive capability against simple, composite, and active armors. This increase in destructive capability per projectile also offers a potential

---

[115] *Ibid.*, p. A-101.

[116] *Ibid.*

[117] *Ibid.*, p. A-103.

reduction in system weight. Increasing the effective range is another advantage of hypervelocity projectiles.

The US is the leader in this technology in all critical aspects. Soviet technology differs in that their projectiles are employed at much greater velocities. The Soviets may have a technological lead over the US in developing very high power sources for electromagnetic guns.[118]

20. High-Temperature/High-Strength/Light-Weight Composite Materials

This technology is a process technology involving materials possessing high-strength and low-weight with the ability to withstand high temperatures. The essential problem is to manufacture advanced materials in a reliable, reproducible, low cost process. This includes the development and production of polymeric composites, metal-matrix and ceramic-matrix composites, and carbon-carbon based materials or coatings.[119] Total S&T funding for this critical technology in FY 1990 is on the order of $110 million.

This technology is required for many vehicle structures, such as high-temperature propulsion systems, hypervelocity vehicles, vertical take-off and landing vehicles, as well as for spacecraft, advanced hull designs and

---

[118] *Ibid.*, p. A-106.

[119] *Ibid.*, p. A-107.

submarine structures. Advanced materials offer substantial improvements in performance and reductions in cost. Weight savings of approximately 25 to 50 percent can be achieved in ground and air vehicles.[120] The use of adhesives can effect a 10 percent weight reduction in helicopters.[121] High-temperature composite materials can increase engine thrust by more than 50 percent and reduce fuel consumption by as much as 40 percent.[122] New processing techniques can also bring the cost of armor ceramics down to usable levels.

Both NATO and Japan have active materials development programs and may lead in selected aspects of material research. The US has an overall lead in the design and effective use of advanced materials in military applications. The Soviet Union is second only to the US and Japan in materials and structures research and design. Therefore, the US no longer has the strong lead it previously enjoyed. The Soviet Union's large scale research and design effort, abundant natural resources, extensive capital investment, and support from the Warsaw Pact Allies all contribute to the decline of the leads the US had possessed.[123]

---

[120] *Ibid.*, p. A-108.

[121] *Ibid.*

[122] *Ibid.*

[123] *Ibid.*, p. A-111.

21. Superconductivity

Superconductivity has been termed an enabling technology, one that is emerging from science but has not yet been applied. This technology is concerned with the fabrication and exploitation of superconducting materials. It is focused on understanding the physics of high and low temperature superconductivity and developing materials which will increase its applications. Total S&T funding for this critical technology in FY 1990 is on the order of $100 million.

Future applications include electric drive systems for ships (and possibly land vehicles and aircraft), generators, energy storage for directed energy weapons, electromagnetic shields, supermagnets, communications and surveillance systems and very high speed computers.[124] Many of these systems cannot be achieved with conventional electronics technology, while others will offer new capabilities to platforms that are currently incapable of supporting semiconductor counterparts.

The US and Japan share a worldwide lead in this technology. Japanese technology enjoys a significant lead in digital superconducting devices and electronics.[125] NATO research generally lags the US and Japan has traditionally

---

[124] *Ibid.*, p. A-113.

[125] *Ibid.*, p. A-115.

been strong in basic research, but has trailed in applications except in narrow areas such as magnets and cables.

22. Biotechnology Materials and Processing

Lastly, biotechnology is, again, an enabling technology. It is the systematic application of biology for an end use in military engineering or medicine. It is now possible to genetically engineer plant and animal cells for high yield rates and efficiencies. This technology has the potential for resolution of operational and logistical problems in both medical and non-medical arenas. Total S&T funding for this critical technology in FY 1990 is on the order of $100 million.

Medical applications include developing vaccines to protect troops, sensors to warn of chemical or biological attack, response to those attacks, artificial blood, and rapid wound healing promoters. In the non-medical arena this technology will lead to the development of bacteria to reduce environmental hazards from toxic wastes, specialty lubricants, high-strength polymers and composites, protective gear, biosensors, and bioprocessing memories.

Because of the importance of biotechnology in health and agriculture sectors, there is a universal interest and activity in the field. Many European countries are active in the area and they are likely to continue developing this field rapidly. The Soviet Union has an extensive program in

biotechnology research which is concentrated in a relatively small number of research and design centers.[126] Since much of the research in this field is published in open literature, the USSR has not faced restrictions in accessing scientific knowledge. Moreover, the Warsaw Pact countries have been able to readily acquire western biotechnology organisms and products.

B. 1990 CRITICAL TECHNOLOGIES

The two new technologies identified in the 1990 CTP are summarized below. This summary includes an overview description, impact on weapons systems and comparisons with other countries. In addition, updated funding profiles are given for the remaining technologies.

1. *Weapon System Environment*

Weapon system environment technology differs from other critical technologies because it does not develop specific hardware. Weapon systems are increasingly influenced by environmental effects (weather, seasons, terrain) due to their increasing sensitivity. To increase system capabilities these environmental factors must be clearly understood.

Application of environmental conditions through logic modules, design and testing will reduce the false alarms on current smart weapons. Knowledge of electromagnetic

---

[126] *Ibid.*, p. A-123.

fluctuations in the ionosphere will enhance over-the-horizon radar capable of detecting low-observable targets.[127] Minehunting, magnetic submarine sensors, and communications performance are also affected by ionospheric disturbances. Enhanced weather predictions will aid in choosing tactical weapons. Knowledge of environmental effects will enable designers to optimize imaging and detection systems.

Because of international cooperation in weather prediction and oceanography, there is a high level of activity and capability in this technology. The Soviet Union is most capable in the weapon-target environment and the theoretical aspects of underwater acoustics.[128] The US and its NATO partners lead in the employment of environmental products because of a lead in computers and related software and hardware.

2. High Energy Density Materials

High energy density materials are composites of ingredients used as explosives, propellants or pyrotechnics. They either propel the ordnance to the target and/or kill the target by fragments or blast. All three Services use these materials in both strategic and tactical weapon systems.

---

[127] Department of Defense, *Critical Technologies Plan,* March 15, 1990, p. A-120.

[128] *Ibid.*, p. A-127.

High energy density material can increase performance of weapon systems by increasing range and penetration. Other areas of improvements will be seen in a reduction of potential hazards, signature reduction, availability, dependability and reliability.

The US has the lead in the development of certain explosives. However, countries such as France can match US capabilities while incorporating these materials into weapons quickly.[129] Besides France and the UK, most other countries are not believed to be pursuing the development of higher energy density material beyond current production. The Soviet Union has an extremely large R&D program for the development of this technology. Because the Soviets have made investments in areas that do not compare with the West, they are more advanced in these areas.[130]

3. Funding Profiles

Funding is derived from programs in the DoD budget. Because most programs involve several technologies, it becomes a matter of judgement how many dollars to count toward which technology. All figures reported are in millions of dollars.

	Fiscal Year						
GROUP A	86-90	91	92	93	94	95	96
1. Composite Materials	670	170	180	180	180	180	170

[129] *Ibid.*, p. A-198.

[130] *Ibid.*, p. A-200.

2.	Computational Fluid Dynamics	420	80	80	90	90	90	90
3.	Data Fusion	210	50	50	50	50	50	50
4.	Passive Sensors	1,900	460	420	420	430	440	440
5.	Photonics	560	100	110	110	15	120	120
6.	Semiconductor Materials and Microelectronics	2,100	450	460	480	480	480	480
27.	Signal Processing	580	130	130	140	140	140	140
8.	Software Producibility	420	130	140	150	150	150	150
GROUP B								
9.	Air-Breathing Propulsion	720	180	210	210	210	210	210
10.	Machine Intelligence and Robotics	540	120	100	100	100	100	100
11.	Parallel Computer Architectures	250	120	140	150	150	150	150
12.	Sensitive Radars	880	110	130	140	150	150	150
13.	Signature Control	No Data Available						
14.	Simulation and Modeling	810	210	250	230	230	230	230
15.	Weapon System Environment	620	180	210	220	210	200	200

GROUP C

16. Biotechnology Materials and Processes	451	100	100	100	105	110	115
17. High-Energy Density Materials	370	90	100	100	100	100	100
18. Hypervelocity Projectiles	460	120	130	130	130	130	130
19. Pulsed Power	640	160	150	160	160	170	170
20. Superconductivity	300	95	110	140	145	150	160

BIBLIOGRAPHY

Baker, Caleb, "Armed with Technology, Soldier Still the Ultimate Weapon in 2015," *Defense News,* September 3, 1990.

Bingaman, Jeff, "Congressional Perspective, Key to Defense Efforts," *Signal,* February 1990.

Bond, David F., "Pentagon Seeks to Protect Funding for Critical Technology Development," *Aviation Week and Space Technology,* April 16 1990.

101st Congress, Second Session, *Senate Bill S.2884: National Defense Authorization Act for Fiscal Year 1990: Acquisition Policy and Management, Part A, Section 801,* July 20 (legislative day, July 10), 1990.

Committee on Armed Services, United States Senate, 101st Congress, First Session., *Hearings: Department of Defense Authorization for Appropriations for Fiscal Years 1990 and 1991, Defense Industry and Technology, Part 7, March 17; May 11, 16, 17, 31; June 2, 1989,* Washington, D. C.: Government Printing Office, 1989.

Defense Systems Management College, *Test and Evaluation Management Guide,* March 1988.

Dereska, Stanley P., "DARPA's Advances Provide Basis for Rapid Progression," *Signal,* February, 1990.

Department of Defense, *Critical Technologies Plan, for the Committees on Armed Services, United States Congress,* March 15, 1990.

Department of Defense, *Critical Technologies Plan, for the Committees on Armed Services, United States Congress,* March 15, 1989.

Department of Defense, *Department of Defense Directive, Number 5000.1, Major and Non-Major Defense Acquisition Programs,* Under Secretary of Defense, Acquisition, September 1, 1987.

Department of Defense, *Department of Defense Directive, Number 5000.3, Test and Evaluation,* Under Secretary of Defense, Research and Engineering, March 12, 1986.

Department of Defense, *Department of Defense Directive, Number 3200.11, Major Range and Test Facility Base,* Under Secretary of Defense, Research and Engineering, September 29, 1980.

Department of Defense, *Department of Defense Instruction, Number 5000.2, Defense Acquisition Program Procedures,* Under Secretary of Defense, Acquisition, September 1, 1987.

Department of the Navy, *RDT&E/Acquisition Management Guide,* 11th Edition, January 1989.

Eichblatt, Emil J., Jr., ed., *Test and Evaluation of the Tactical Missile, Vol. 119, Progress in Astronautics and Aeronautics,* by Martin Summerfield. Washington DC: American Institute of Aeronautics and Astronautics, Inc., 1989.

Major Ghortlety USAF, Robert, C., *Instrumentation Fundamentals for the Novice Test Director,* Air University, Maxwell Air Force Base, Alabama, April 1979.

Hinely E. P. and others, *Naval Aircraft and Air Weapons Test and Evaluation Technology Exploratory Development Program,* SRI International, Menlo Park, CA, November 1987.

Herzfeld, Charles, M., *Statement on the DoD Critical Technologies Plan to the Subcommittee on Defense Industry and Technology of the Committee on Armed Services U.S. Senate,* Director Defense Research and Engineering, March 28, 1990.

Hoeschen, Harold, A., "Defense Technologies in the Coming Decade," *Signal,* August, 1989.

Holzer, Robert, "Surface Warfare Faces Dramatic Changes in '90s," *Defense News,* August 13, 1990.

Holzer, Robert, "Future Naval Weapons will be Smarter, Adaptable," *Defense News,* August 13, 1990.

Kimmel, Dr. Steven, H., "Quality Weapons: A Test and Evaluation Challenge," *Program Manager,* March-April 1989.

Kuttner, Robert, "Industry Needs a Better Incubator than the Pentagon," *Business Week,* April 30, 1990.

Leopold, George, "Sensor Will play Active, Passive Roles in Future Fleets," *Defense News,* August 13, 1990.

Millburn, George, P., *Statement on the DOD Critical Technologies Plan to the Subcommittee on Defense Industry and Technology of the Committee on Armed Services U.S. Senate,* Deputy Director Defense Research and Engineering (Research and Engineering), March 28, 1990.

*National Authorizatic*n *Act For Fiscal Years 1989 and 1990: Annual Defense Critical Technologies Plan, Public Law 100-456,* September 29, 1988.

National Authorization Act For Fiscal Years 1990 and 1991: Annual Defense Critical Technologies Plan, Public Law 101-189, November 29, 1989.

Norman, Colin, "DoD Lists Critical Technologies," *Science Magazine,* March 24, 1990.

Nordwall, Bruce, D., "Electronic Technology to Dominate Next Generation of Weapons Systems," *Aviation Week & Space Technology,* June 6, 1988.

Norman, Colin, "Defense Research After the Cold War," *Science Magazine,* January 1990.

O'Bryon, James, "Realistic Weapon Testing Vital," *Defense News,* September 3, 1990.

Office of Technology Assessment, Congress of the United States, *The Defense Technology Base, Introduction and Overview,* U.S. Government Printing Office, March 1988.

Pastine, John, D. Dr., "A Crisis Looms in Research and Development," *Signal,* February, 1990.

Randolph Bernard, P. General, USAF, "The Importance of Technology Development," *Signal,* August 1989.

Ruckert, William, C., *Navy Program Manager's Guide: Draft Copy,* 1987 Edition.

Stevens, Roger, T., *Operational Test and Evaluation: A Systems Engineering Approach,* Robert E. Krieger Publishing Company, Malabar, Florida, 1986.

Stoddard, Rob, "Senator Bingaman on 'Critical Technologies'," *Defense Electronics,* January 1990.

Senate Armed Services Committee, *Acquisition Policy and Management Report,* 1990

Test and Evaluation Committee, *Draft Test Resource Master Plan,* April 24, 1989.

United States Army, Headquarters Materiel Command, *Materiel Acquisition Handbook,* Army Materiel Command and Army Training Doctrine Command, 1987.

United States Army, White Sands Missile Range, *Instrumentation Development and Acquisition Plan for FY91 - FY98,* White Sands Missile Range, NM, January 1990.

Weible, Jack, "Congress Slashes $74 Million From New DoD Testing Program," *Defense News,* November 19, 1990.

Whalen, Philip, K., *Test and Evaluation (T&E) Technology Knowledge Base, Volumes I and II,* SRI International, Menlo Park, CA, March 1990.

White Sands Missile Range, *Range Users Handbook,* White Sands Missile Range, NM, 1990.

Wickham, John A., Jr., General, USA (Ret.), "Military Requirements and the Defense Industry," *Signal,* February, 1990.

INITIAL DISTRIBUTION LIST

1.	Defense Technical Information Center Cameron Station Alexandria, Virginia 22304-6145	2
2.	Library, Code 52 Naval Postgraduate School Monterey, California 93943-5002	2
3.	Commander, Pacific Missile Test Center Assistant to Executive Director, Code 02A Point Mugu, California, 93042-5000 Attn: Mr. William Luttrell	1
4.	White Sands Missile Range, Code PL-A New Mexico, 88002 Attn: Mr. James Kilcrease	1
5.	Office, Deputy Director of Defense Research and Advanced Technology The Pentagon, Room 3D1089 Washington, D.C., 20301-3080 Attn: Dr. Leo Young	1
6.	Defense Systems Management College DSMC-SE-S Fort Belvoir, Virginia, 22060-5426 Attn: Mr. Daniel Costello	1
7.	U.S. Army TRADOC Analysis Command P.O. Box 8692 Naval Postgraduate School Monterey, California, 93943-0692 Attn: Major James Hoffman	1
8.	Commander, Pacific Missile Test Center Weapons Evaluation Directorate, Code 2000 Point Mugu, California, 93042-5000 Attn: Lyle K. Hochberger	1

9. Commander, Pacific Missile Test Center 1
Armament Systems Division, Code 2040
Point Mugu, California, 93042-5000
Attn: Edward Romero

10. Naval Postgraduate School 2
Department of Administrative Sciences, Code AS/DY
Monterey, California, 93943-5002
Attn: Professor Dick Doyle