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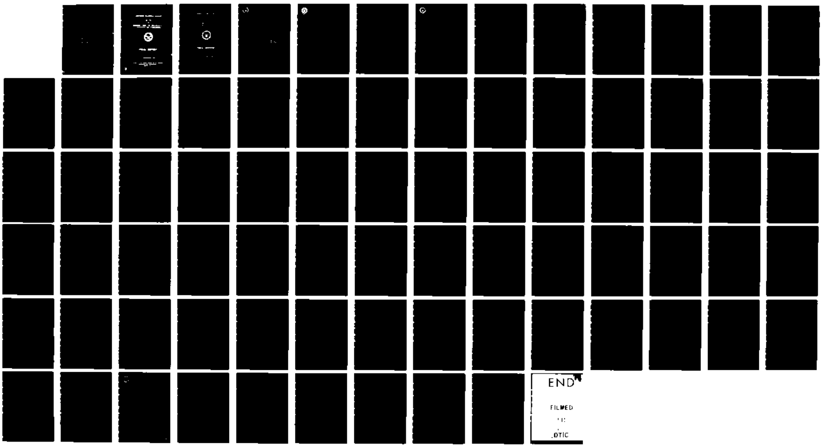

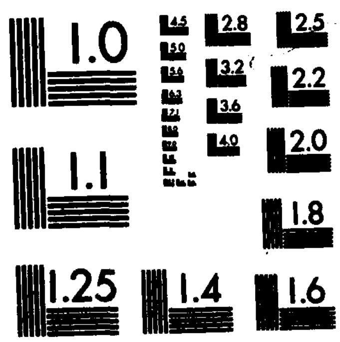

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DEFENSE SCIENCE BOARD

TASK FORCE ON EMBEDDED COMPUTER RESOURCES (ECR) ACQUISITION AND MANAGEMENT

FINAL REPORT

NOVEMBER 1982

OFFICE OF THE UNDER SECRETARY OF DEFENSE
RESEARCH AND ENGINEERING
WASHINGTON, D. C.

DEFENSE SCIENCE BOARD

TASK FORCE

ON

EMBEDDED COMPUTER RESOURCES (ECR) ACQUISITION AND MANAGEMENT

FINAL REPORT

NOVEMBER 1982

OFFICE OF THE UNDER SECRETARY OF DEFENSE
RESEARCH AND ENGINEERING
WASHINGTON, D. C.

THE SECRETARY OF DEFENSE

WASHINGTON, THE DISTRICT OF COLUMBIA

4 DEC 1982

MEMORANDUM FOR UNDER SECRETARY OF DEFENSE FOR RESEARCH AND ENGINEERING

SUBJECT: Embedded Computer Instruction Set Architectures

I have reviewed the Defense Science Board Task Force Report on Embedded Computer Resources and have approved the recommendations contained in the letter of the Defense Science Board Chairman that transmitted the report to me.

Accordingly, please ensure that the Department's implementing instructions for standardizing embedded computer instruction set architectures (ISA) contain provisions for adding suitable commercial ISAs to the Department's approved list--while maintaining an open and equitable competitive environment.

23866

OFFICE OF THE SECRETARY OF DEFENSE
WASHINGTON, D.C. 20301

DEFENSE SCIENCE BOARD

8 November 1982

MEMORANDUM FOR SECRETARY OF DEFENSE

THROUGH: UNDER SECRETARY OF DEFENSE FOR RESEARCH & ENGINEERING

SUBJECT: Report of Defense Science Board Task Force on Embedded Computer Resources (ECR)

The enclosed final report of the Defense Science Board Task Force on Embedded Computer Resources Acquisition and Management was prepared under the Chairmanship of Dr. Thomas H. Crowley. The Task Force was chartered to:

> "...review, evaluate and make recommendations concerning the acquisition, management and utilization of digital computers and associated technology to support the military mission of the Department of Defense."

The scope of this study does not apply to all computers to be purchased by the Department; it applies only to MIL-SPEC Computers which must have a specially-designed character to meet military needs.

The principal findings of the Task Force are that:

1. Embedded Computer Instruction Set Architectures should be standardized on a few select architectures.

2. The Government should have unlimited rights to the Instruction Set Architectures used so as to guarantee that a basis exists for competitive procurements with fair and equitable competition.

3. There is no consistent management approach across the OSD Staff and the Military Departments relating to computer technology.

4. The Ada[R] Computer language program is sound, is clearly a step in the right direction, and should continue to be implemented.

Specific recommendations are made by the Task Force to address these and other critical areas. Action has already been taken to centralize computer acquisition management within the Office of the Under Secretary of Defense for Research and Engineering. I understand that plans are also being made to strengthen the Technology Base activities in this important area and that these two activities will be very closely coordinated. This will be a major step toward implementing the recommendations of this study and of the DSB 1981 Summer Studies on the Technology Base and on Operational Readiness.

I recommend that you:

1. Review the Executive Summary.

2. Approve distribution of the report.

3. Ask the Under Secretary of Defense for Research and Engineering to add suitable commercial Instruction Set Architectures to the Department's approval list--while maintaining an open and equitable competitive environment. (Memo attached for your signature.)

In my view, this report provides insight into issues which are critical to the combat and cost effectiveness of many of our most complex weapon systems. As you know, the efforts of this Task Force have received considerable scrutiny in recent months. The subject matter at hand is inherently subject to some degree of disagreement among competent and honest investigators. The interests of the Department will be best served, in my judgment, by making this report available to the public so that it might be scrutinized openly and its findings weighed in an appropriate manner.

Norman R. Augustine
Chairman

Attachment:
ECR Report

Copy to:
DepSecDef
Chairman, JCS

OFFICE OF THE UNDER SECRETARY OF DEFENSE

WASHINGTON, D C 20301

1 November 1982

RESEARCH AND
ENGINEERING

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Final Report of the Task Force on Embedded Computer Resources (ECR) Acquisition and Management

Enclosed is the final report of the Defense Science Board Task Force on Embedded Computer Resources (ECR) Acquisition and Management. It treats all of the questions asked by Dr. DeLauer in his request of August 20, 1981. As you are aware, the full Defense Science Board was briefed on the study and was presented the Findings and Recommendations on February 10, 1982.

Most of our attention was absorbed by the question of whether the Department should adopt a policy of standardizing the so-called Instruction Set Architectures (ISAs) of militarized computers. This issue has been hotly debated in many forums and was a principal motivation for the establishment of the Task Force. Much of the controversy here is because of the natural differences between producers and consumers. We looked very carefully at the needs and points of view of both sides of this question. Our conclusion is that the needs of the Department for battlefield survivability and sustainability are paramount. We found that limiting ISA choices to a few is a big help in meeting those needs. Individual companies do precisely this for economic reasons; DoD must adopt this approach if there is to be any possibility of capping the exploding logistics and software costs. Language standardization is not sufficient by itself, as many claim. We recommend that proposed DoD Instruction 5000.5x be issued immediately. There are programs under way in each of the Military Departments which implement 5000.5x. We recommend that those programs proceed with some relatively minor changes.

We firmly support the Ada® program. There is almost universal agreement that this program is sound in objective and action. Specific recommendations are offered to strengthen some areas and to assure its continued support, but, by and large, it is proceeding in the right direction.

We make both specific and general recommendations on OSD's management of the acquisition and management of computers and related digital technology. More centralization of policy and oversight is needed and we note that action is already under way to improve this situation.

Our detailed Findings and Recommendations are summarized in the Executive Summary (Chapter 1) of the attached Report.

Finally, I wish to express my appreciation for the fine work and dedication of the Task Force and to those in the Department, the Services and in Industry who supported us.

Thomas H. Crowley
Chairman
DSB Task Force on ECR

Enclosure.

FOREWORD

The significance of the use of computers in defense systems has grown explosively over the past decade. Costs associated with this phenomenon have also increased exponentially. The Electronic Industries Association in their "DoD Digital Data Processing Study, a Ten-Year Forecast," completed late in 1980 predicted that DoD's investment in embedded computer hardware and software would increase from approximately $4.1 Billion in 1980 to almost $38 Billion in 1990.

Various measures have been taken to control this rapid increase in investment while increasing the effectiveness of defense systems through better and more extensive automation. Still other measures, such as standardizing the Instruction Set Architectures for militarized computers, have been proposed. These policy initiatives have met with varying degrees of acceptance in the Department of Defense and in Industry. In August, 1981, the Under Secretary of Defense, Research and Engineering asked the Defense Science Board to:

> "...review, evaluate and make recommendations concerning the acquisition, management and utilization of digital computers and associated technology to support the military mission of the Department of Defense."

This is the Final Report of the Task Force on Embedded Computer Resources (ECR) Acquisition and Management which was formed in response to that request.

Chapter 1 is the Executive Summary which describes the Scope and Objectives of the study and the approach which was taken. The major findings and recommendations are then given with the recommendations listed in "priority" order.

The Background which led up to the formation of the Task Force is discussed in Chapter 2. Chapter 3 provides a description of key programs within the Components of DoD which attack the problems of costs and other critical problems associated with increased reliance on computers in mission systems. Chapter 4 gives a general perspective on standardization — an important mechanism for management of computers and software — and discusses the possibilities of a High level Language (HLL) machine for future applications. A thorough treatment of the issues surrounding proprietary data rights is presented in Section 4.3 beginning on page 32. This area was found by the Task Force to be one of the most difficult to handle in the decision of whether to base standardization only on Government-owned intellectual property or whether there is an equitable way in which proprietary designs may be included.

In Chapter 5 we discuss the major issues posed in the Charter for the Task Force with concentration on whether the proposed DoD Instruction 5000.5x concerning Instruction Set Architecture (ISA) standardization should be issued. We also include, in Section 5.2, recommendations relative to the existing Service programs which implement the intent of 5000.5x. Section 5.3 discusses DoD's High Order Language (HOL) standardization program; Section 5.4 contains recommendations on the near-term use of Ada® and hardware from the Military Computer Family project in the upgrade of the World-Wide Military Command and Control System (WWMCCS). Sections 5.5 and 5.6 contain recommendations on overall DoD policy and on the management and oversight process. Section 5.7 discusses the implementation of recent legislative changes (10. U.S.C. 2315).

Appendix C contains a set of recommended definitions for the specialized terms used in the embedded or mission-critical computer arena. The Task Force recommends that these definitions be adopted for DoD-wide use.

We wish to thank Mr. Norman V. Brown, a patent attorney assigned to the Naval Sea Systems Command, for his valuable contributions to the discussion of rights in data (Section 4.3). Special commendation is due Mrs. Jo Ingram, OUSD(R&E)ECR, for her outstanding administrative support of the Task Force and to Messrs. Miguel Hornedo, OUSD(R&E) and Burt Newlin of the Defense Materiel Specifications and Standards Office for their excellent staff support and preparation of the meeting minutes.

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1. EXECUTIVE SUMMARY

1.1 Scope and Objectives

The basic direction and guidance to the Task Force was contained in a memorandum dated August 20, 1981, from Dr. Richard D. DeLauer, Under Secretary of Defense for Research and Engineering. This Memorandum is included as Appendix A. The Task Force was asked to:

> "...review, evaluate and make recommendations concerning the acquisition, management and utilization of digital computers and associated technology to support the military mission of the Department of Defense."

More specifically, Dr. DeLauer posed the following key questions:

- Are current and proposed management policies appropriate?
- Are key embedded computer resource programs properly constituted and supported?
- Are Management and Oversight adequate?
- What is the effect of the Legislative and Regulatory Environment?

1.2 Approach

Task Force members were selected to provide a wide variety of views on the topic of computer-related research and development, acquisition and utilization. A balance of producers, system integrators, academicians and Military representatives was sought. Several of the members had previous experience in senior level government positions. Mr. William A. Long, Deputy Under Secretary of Defense, Acquisition Management, was the Task Force Sponsor. Dr. Thomas H. Crowley, Bell Laboratories, served as Chairman. Appendix B lists the members and staff of the Task Force.

Briefings were received from both Government and Industry. In addition, a request for information was published in the Commerce Business Daily which elicited 20 detailed responses.

The Task Force met four times in the Washington, DC area. In addition, a subgroup met on the West Coast and a team visited the Army Communication and Electronics Command (CECOM) at Ft. Monmouth, NJ to gather more detail on the Army's Military Computer Family Project which was of major interest.

1.3 Major Issues

The Task Force identified the following seven major issues:

1. Should DoD's proposed policy to standardize on a small set of Instruction Set Architectures (ISAs) be issued?

2. Are the Service programs which implement this proposed policy reasonable?

3. Should the DoD's program to provide a common language for broad use across the Department -- the Ada®,[1] Program -- be modified?

4. Should Ada® and the Military Computer Family (MCF) be used for the World Wide Military Command and Control System (WWMCCS) Information System (WIS) upgrade?

5. Are changes needed in DoD Directive 5000.29, "Management of Computer Resources in Major Systems?"

6. Are changes desirable to management of DoD's computer acquisition and management policies?

7. Should the acquisition process itself be modified?

1.4 Major Findings

Major findings are:

1. The controversy over proposed DoD Instruction 5000.5x is largely between interests which have as primary concerns the marketing and procurement of military embedded computers and interests which have as primary concerns the operation, maintenance, deployment and post-acquisition support of these same computers. Both sides often neglect complex issues inherent in these concerns. The situation is further complicated by the fact that procurement issues are immediate and precisely measurable in dollars soon, while providing a cost-effective deployment and support environment for the rest of the century is longer range and harder to quantify. In other words, the time-frame foci of the two sides in this controversy are quite different. Arguments are further confused over the questions:

   a. "Should there be a standard set of ISAs at all?"

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[1]Ada is a registered Trademark of the U.S. Department of Defense (Ada Joint Program Office)

b. "If there are to be standards, should they be Government-owned or Commercial ones?"

2. Embedded Computer Instruction Set Architectures (ISAs) should be standardized. This action is necessary if the Department of Defense is to improve its position with respect to software development costs and, further, it is a mandatory step toward improvement of the logistic support and, above all, the battlefield sustainability of automated systems.

3. Given our finding of support for ISA standardization, Government control over the ISAs is required. It is unwise to commit for an extended period to an ISA which can be changed or differently supported in the interests of a commercial entity. Too many considerations of competitive follow-on procurement, overseas manufacture and ongoing support are at stake. There may yet be an acceptable approach for including "commercial ISAs" on the DoD-approved list while maintaining an open and equitable competitive environment. Past failures should not dissuade OSD from continued efforts toward this objective.[2] ISA Standardization will affect competition for hardware procurements and the effect may be either positive or negative in specific cases. With standardization on a "good" set of government-owned ISAs, Industry has the opportunity to enter competition on an equal basis.

4. It is important that implementation of the standardization policy for ISAs be actively managed from the OSD level -- particularly the waiver process -- to assure that Service conformance is neither cavalier nor slavish. Carefully done, the policy could facilitate the introduction of technology; carelessly done it could significantly impede progress.

5. Current Service programs based on ISA standardization are in accord with general policy intent; there are, however, areas wherein they could be strengthened. The issue of multiple producers for logistically-identical hardware is still an open question and one which deserves more study.

6. No formal program exists to bring the long-term ISAs of the Services together. This convergence could be a great step towards promoting Joint Task Force (JTF) interoperability as well as other capabilities for combined interservice operations. An important chance to nudge the Services together now exists. The Air Force is monitoring and participating in the Army's NEBULA program. Air Force adoption of NEBULA represents a one-time opportunity to accomplish convergence between the two Services who operationally need it most.

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[2] Cf., Section 4.3.2.3, page 35.

7. High Order Language (HOL) standardization has had a positive effect on software development and support costs. Implementation of the policy to use HOLs has, however, been spotty.

8. DoD's Ada® Program is well based and, in general, is proceeding satisfactorily. It could, however, be improved through better DoD-wide coordination. The Ada Language System (ALS) does not appear to be receiving adequate attention in view of its criticality to the MCF Program and to efforts of the other Services. Both the Navy and the Air Force could accelerate the availability of Ada for their specific use with modest additional investments.

9. A large quantity of existing software -- some 10 to 15 million lines of code -- must be preserved in the WWMCCS Information System (WIS). There will be some two to three million lines of code added, as currently estimated. The schedules for the upgrade generally precede the availability of either Ada or MCF. However, it appears to us that use of Ada as a Program Design Language (PDL) is desirable and that its structure and discipline have much to offer in such a major undertaking as the WIS upgrade.

10. DoD Directive 5000.29 is the basic policy document for automated defense systems and its revision and update are urgent matters for action. Problems still exist with regard to computers and software and it is too early to force this area into the routine oversight pattern afforded to more mature technologies. Work is needed to rationalize DoD's inconsistent set of specifications and standards for computer resources. Further, recent legislative changes must be promulgated and 5000.29 is a proper vehicle for this.

11. There is no consistent management process across the OSD Staff and the Military Departments relating to computer (automation) technology. OSD has been relying on a committee management approach which was born of necessity in 1976. The scope of automation in systems and in their support has far outstripped this approach.

12. Although the legislative initiative of the Senate Armed Services Committee to separate DoD's acquisition of computers from the Brooks Act process is an important step forward, we found that there is yet confusion as to how this change should be implemented. Logistics systems are particularly a source of concern as they still fall in the gray area between two acquisition approaches.

1.5 Recommendations

We recommend that:

1. The proposed DoD Instruction 5000.5x be issued. It should be reviewed for consistency with acquisition regulations and the scope should be clarified, e.g., where does it apply and where does it not. OSD should actively manage implementation of the policy and control both the waiver process and changes to the approved ISA list.

2. The Military Departments proceed with current programs -- the Army Military Computer Family (MCF), the Navy Tactical Embedded Computer Resources (TECR) Program and the Air Force MIL-STD-1750 Program -- but with some modifications:

   a. The Army increase the quantity of Advanced Development Models (ADMs) and/or Full Scale Development Models (FSDMs) of the MCF hardware to provide and support early software development experience.

   b. Both the Army and Navy revise their acquisition strategies to make use of multiple producers of logistically-identical computer hardware, if economically feasible.

   c. The Air Force bound the number of unique implementations of MIL-STD-1750 with an eye toward achieving logistic cost avoidance.

   d. The Air Force consider adding Input/Output specifications and other hardware-independent details to MIL-STD-1750.

   e. Army and Air Force develop an implementation plan for their Memorandum of Agreement covering joint adoption and use of MIL-STD-1862. This plan should be subject to OSD review and approval.

   f. The three Military Departments, in conjunction with OSD, develop an approach and plan for joint action toward a truly common architecture much as was done for the common language, Ada. The activities of the preceding paragraph should form a basis for this recommended action.

3. Designate a Senior Policy Official (USDRE) for 10 U.S.C. 2315 matters and establish a consistent management approach across the OSD staff and within the Military Departments. The first action has been taken concurrently with our deliberations and preparation of this report. The Under Secretary should now:

   a. Determine the level and mode of operation and provide revised guidance to the Components regarding implementation of P.L. 97-86 (codified as 10 U.S.C 2315).

b. Establish a uniform set of R&D objectives and acquisition policies which are mutually supportive.

c. Provide OSD management of selected generic automation programs, such as has been done for Ada and the Very High Speed Integrated Circuits (VHSIC) Program.

d. Task the official to whom this new policy designation is delegated to be a principal advisor to the Defense Systems Acquisition Review Council (DSARC) on computer and software (automation) matters.

e. Improve OSD's oversight of Components' computer and software R&D and acquisition activities.

4. DoD Directive 5000.29 be revised expeditiously. Incorporate changes in acquisition approach enabled by 10 United States Code 2315. Emphasize the "software-first" approach to system design and development and encourage use of rapid software prototyping and competitive concept definition. Source selection procedures should specifically include software considerations (this may require DAR revisions).

5. DoD Instruction 5000.31 be updated quickly to remove outdated languages and to add Ada.

6. The Under Secretary assure adequate and continuing support for the Ada Joint Program Office. (We note that his statement to the Congress[3] contains specific mention of the Ada Program.)

7. The Service Ada Programs be strongly supported and that they continue to receive adequate staff and funds. Components of this Program should be better coordinated.

8. DoD develop and apply a consistent set of computer hardware and software specifications and standards across the Department. Current work by the Joint Logistics Commanders Joint Policy Coordination Group for Computer Resource Management (JPCG-CRM) may be an adequate basis but DoD should assure uniform implementation of the resulting product, whatever its genesis[4].

9. Intersystem and local network protocols be developed from existing DoD standards and emerging international standards. Standards for data elements should also be developed.

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[3]The FY 1983 Department of Defense Program for Research, Development, and Acquisition.

[4]The Embedded Computer Resources Area Standardization Plan describes the scope of this needed activity.

10. OSD review the opportunities for cost savings within the Air Force JOVIAL language program and that the Air Force be encouraged to strengthen this interim standardization program to achieve increased return on investment.

11. OSD conduct a careful review of the Defense Acquisition Regulations (DARs) to assure that they are in step with computer acquisition policy. In particular, care should be taken that time limitations in the DARs do not drive technology insertion schedules through misinterpretation. The DARs must not attenuate sharing of government-developed applications or support software.

12. The WIS Joint Program manager adopt Ada into the WIS language family as soon as its stability is assured and support software of adequate performance and maturity is available. It is estimated that this will occur in the 1984-1985 time period. We also recommend that WIS use Ada now as a Program Design Language when acquiring parts of the system which involve major software development.

13. The confusing technical and management terminology which abounds should be clarified immediately. A glossary of key terms should be published and widely distributed and the usage should be stabilized for a rational period, say five years. Appendix C contains a recommended set of terms and definitions.

2. BACKGROUND

2.1 Policy Evolution

Computer technology and its application are critical to the Department of Defense. Almost without exception, important systems used in the conduct of the mission of the Department depend on computation and information processing, communications, display and other computer based processes. In fact, the integration of defense systems processes and actions is actually carried out more in the information domain than it is in the physical realm.

In the mid-1970s, the Department came to the stark realization that the costs associated with computer applications to weapons and other defense systems were growing at a startling rate. A study conducted in 1974[5] concluded that the costs of software to the Department of Defense for Fiscal Year 1973 were in the range of $2.9 to 3.6 Billion.

With the growing dependence on computers and software in both major and non-major systems, it was decided that special management attention was necessary at all levels of the Department and its Components (Office of the Secretary of Defense (OSD), the Military Departments, the Organization of the Joint Chiefs of Staff (OJCS) and the Defense Agencies). A series of policy initiatives were undertaken:

- A DoD Defense System Software Management Plan was generated in August, 1975.
- A Statement of Policy[6] was drafted in October, 1975 and subsequently signed by the Secretary of Defense in November, 1976.
- An interim list of approved High-Order Languages was established[7].
- A policy[8]. of standardizing on a few Instruction Set Architectures was proposed.

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[5]Fisher, David A., "Automatic Data Processing Costs in the Defense Department" Institute for Defense Analyses Paper P-1046, October, 1974

[6]DoD Directive 5000.29, Management of Computer Resources in Major Defense Systems, November 1976.

[7]DoD Instruction 5000.31, interim List of DoD-Approved High Order Programming Languages (HOL), November 24, 1976

[8]Draft DoD Instruction 5000.xx, interim List of DoD Approved Computer Architectures, March 10, 1978

The objective of DoDD 5000.29 is to assure that computer resources are treated as important subsystems throughout the development, acquisition and support phases of the life cycle of defense systems. Since the nature of this application of computer technology goes beyond the functioning of the computer as a stand-alone item, the term "embedded" was coined to differentiate from the term "ADPE" generally used to apply to common, commercial, off-the-shelf products. ADPE was growing to be thought of, principally, for business and financial management applications and, under the provisions of the Brooks Act, P.L. 89-306, it was a commodity subject to a special acquisition and management process outside the major system acquisition process.

DoD Directive 5000.29 provided policy guidance in seven main areas:

1. Software Requirements and Risk Analysis

2. Software Configuration Management

3. Computer Resource Acquisition Planning

4. Support Software Deliverables

5. Milestone Definition and Demonstration Criteria

6. Software Language Standardization and Control

7. Coordinated Research and Development

A major mandate of the Directive was that defense systems software be developed in a High Order Language (HOL) and, further, that the choice of language was to be from a DoD-approved list. The rationale for this degree of detail was that the costs associated with software were growing rapidly and the application of modern software development techniques was seen as potentially effective to stem this growth. It was well recognized that the efficiency of the software development process could be improved through the use of HOLs and that the possibilities for reuse and the ease of post deployment supportability would be improved[9,10].

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[9] DoD Weapons Systems Software Acquisition and Management Study, MITRE Technical Report 6908, May 1975.

[10] DoD Weapon Systems Software Management Study, Applied Physics Laboratory, The Johns Hopkins University, Special Report 75-3E, June 1975

The interim list contained seven languages which were in common use within the Department and hence languages for which a support commitment had been made or was planned. Those languages were:

- CMS-2
- SPL-1
- TACPOL[11]
- JOVIAL J-3B
- JOVIAL J-73/I[12]
- COBOL
- FORTRAN

The more general policy of moving to the minimum essential number of such approved languages was established and the search for a single language which would serve the broadest spectrum of DoD applications was undertaken. This activity has become the Ada® Program managed by the Ada Joint Program Office (AJPO) within the Office of the Deputy Under Secretary of Defense (Acquisition Management). The objective of the Ada Program is:

> "To develop a single high order language for writing software for DoD embedded computer (real time) applications."

Quoting from the Charter for the AJPO:

> "[Its] objective is to provide for management of the total Department of Defense effort to implement, introduce and provide life cycle support for Ada, the DoD common, High Order Programming Language for embedded computers. Ada is to be a DoD-wide standard which will enhance software portability and afford the maximum commonality of tools (environment) needed to develop and support defense systems software. The Ada Joint Program Office shall assure that validated Ada compilers and the associated software development and support environments are available to support a policy of using only accredited support software on DOD programs."

The Ada Program is described more fully in Section 3.1.

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[11]The Army has subsequently asked that TACPOL be dropped from DoDI 5000.31.

[12]The Air Force has replaced J3-B and J73/I with JOVIAL-J73 as described in MIL-STD-1589B.

Although use of an HOL in the development of software and standardizing on a minimum number of HOLs are a considerable help in reducing cost and improving the overall process, there is still required a considerable specialization of the development environment. It must be tailored to the specific host/target combinations of interest. Thus, reusability and portability of both support tools and applications programs are attenuated.

For these and other reasons, consideration has been given to reducing the number of unique environments within which HOL-based applications programs must run. This can be done by controlling the interface between software and the target environment, i.e. the Instruction Set Architecture (ISA) of the target machines. The definition of this interface was taken to be:

> "INSTRUCTION SET ARCHITECTURE (ISA). The attributes of a digital computer or processor as might be seen by a machine (assembly) language programmer, i.e., the conceptual structure and functional behavior as distinct from the organization of the data flow and controls, logic design, and physical implementation.
>
> "This definition includes the processor and input/output instruction sets, their formats, operation codes, and addressing modes; the memory management and partitioning if accessible to the machine language programmer; the speed of accessible clocks; the interrupt structure; and the manner of use and format of all registers and memory locations that may be directly manipulated or tested my a machine language program.
>
> "This definition excludes the time or speed of any operation, the internal computer partitioning, the electrical and physical organization, the circuits and components, the manufacturing technology, the memory organization, the memory cycle time, and the memory bus widths[13]."

Standardization at the ISA level is the basis of a Proposed DoD Instruction[14]. The present version of the proposed policy evolved after some two years of study and review. In March, 1978 an earlier version of the policy was circulated within the OSD Staff Elements, the Components and to the major affected industry associations. Consensus was not achieved and the

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[13] Computer Resources and the DSARC Process--A Guidebook, U.S. Department of Defense, April 31, 1981. The definition was generated by the Instruction Set Architecture Panel and included in their report of March 26, 1980.

[14] DoD Instruction 5000.5x, Instruction Set Architecture (ISA) Standardization Policy for Embedded Computers, Draft December 24, 1980.

instruction was not issued. An interim policy[15] was, however, developed. That memo recognized that the unbounded proliferation of ISAs was causing problems with respect to continued growth of software costs associated with defense systems. It directed that a working group be formed to study this issue and to recommend a course of action. Further policy guidance was provided in a subsequent memorandum[16]:

> "It is the intent of DoD Instruction 5000.5x, in addition to preventing unwarranted hardware proliferation and facilitating software development and support, to assure that all embedded computer acquisitions can and are accomplished in a meaningfully competitive manner. DoD Instruction 5000.5x has always been predicated upon government ownership, or appropriate license for government use, of architectures on the list. No architecture claimed to be proprietary shall be included on the list unless a valid license agreement is in force and effect at the time the architecture is included. [Emphasis added.]
>
> "The Army Military Computer Family (MCF) Program is an important developmental approach toward achieving vendor independence with respect to embedded computer architectures and, as such, is fully supported by OSD. We support the Army's position that standardization is an essential element in their efforts to automate the battlefield in the '80s and beyond and to achieve the meaningful competition mandated by the Congress."

The recommendations of the Instruction Set Architecture Panel (ISAP) formed in response to the November 21, 1978 memo were:

- That a DoD Instruction be issued directing the DoD Components to limit the number of ISAs implemented is systems controlled by DoD Directive 5000.29 and providing guidance in the acquisition of defense systems that do not fall in the major systems category.

- Each Component identify a life-cycle-cost model which it will employ in the application of the Instruction.

- A joint program office be established to competitively develop or acquire the rights to a large-word-size, large-virtual-address-space ISA.

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[15]USDRE Memorandum, Defense System Embedded Computer Architectures, November 21, 1978.

[16]DUSDRE(AP) Memorandum, Defense System Embedded Computer Architectures, April 12, 1979.

The Panel provided a draft Instruction for consideration. This early draft was discussed widely and a "for comment" version was completed on October 5, 1979. It was reviewed on October 26, 1979 by the Management Steering Committee for Embedded Computer Resources (MSC-ECR). The Committee, by and large, agreed with the need for the policy and with the content of the draft Instruction.

To assure that industry had ample opportunity to review the proposed policy, an "Open Forum" was held at the Andrews Air Force Base theater on November 2, 1979. This forum was announced well in advance in the Commerce Business Daily (CBD)[17] As a result of these and other comments, a revised draft was circulated for official coordination (SD Form 106) on December 24, 1980. This version of the policy was also provided to the major industry associations for comment.

Agreement was not reached and the Under Secretary of Defense (Research and Engineering) decided that a review by the Defense Sc)ence Board would be appropriate prior to any further processing of the Instruction.

2.2 Defense Science Board ECR Task Force

Several related issues cropped up which were felt to deserve the attention of such a review as well. Accordingly, the Under Secretary of Defense (Research and Engineering) chartered[18] a Task Force to review DoD's approach to acquisition and management of embedded computer resources.

The Task Force was asked to:

> "...review, evaluate and make recommendations concerning the acquisition, management and utilization of digital computers and associated technology to support the military mission of the Department of Defense."

Although the instant and precipitating issue which spawned the Task Force was DoD's concern over the need for DoDI 5000.5x and Industry's resistance to it, there were related questions which the Task Force was specifically asked to address, i.e.:

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[17] Commerce Business Daily, U.S. Department of Commerce, PSA-7433, page 18, October 12, 1979.

[18] USDRE Memorandum for the Chairman, Defense Science Board, Defense Science Board Task Force on Embedded Computer Resources (ECR) Acquisition and Management, August 20, 1981. (cf. Appendix I.1)

1. Are the management policies enunciated in DoD Directive 5000.29, DoD Instruction 5000.31 and the proposed DoD Instruction 5000.5x appropriate to the present? If not, how should they be modified for the upcoming generation of technology? What are the costs and benefits of these policies and to what extent can they be quantified? Is the implementation of these policies within the DoD Components adequate?

2. Are the key embedded computer programs of the Department -- Ada, NEBULA[19], NECS[20], and MIL-STD-1750[21] -- properly constituted and supported? What changes can and should be made to afford maximum benefits to the Department as a whole? To what extent should these programs and the policies of 1., above, be considered for near-term programs such as the WWMCCS upgrade [WIS]?

3. Does the Management Steering Committee for Embedded Computer Resources (MSC-ECR) serve a useful role? How could it be improved or is there a better mechanism to provide oversight and policy guidance? Are there other organizational issues of consequence and, if so, what recommendations can be advanced for improvement?

4. What is the effect of the Legislative and Regulatory Environment upon the ability of the Department of Defense to make adequate use of Digital Technology? Consideration should be given to Public Law, Defense Acquisition Regulations, Component Regulations, business practices and appropriate policies, both central and local.

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[19] NEBULA is a nick-name for the Instruction Set Architecture described by MIL-STD-1862. It is the basis for the Army's Military Computer Family Program

[20] Now better described as TECR, the Navy Tactical Embedded Computer Resource Program

[21] This Military Standard is the Air Force standard 16-bit Instruction Set Architecture.

3. KEY PROGRAMS

3.1 Ada®, The DoD Common Language

3.1.1 Introduction

Ada is a modern high order computer programming language which will become the standard language for writing software for DoD embedded computer applications. The Ada Program extends well beyond simple language standardization and will help control the cost and improve the quality of software by facilitating the application of modern software development practices. The Ada Joint Program Office (AJPO), attached to the DUSD(R&AT), is managing the DoD effort to implement, introduce, and provide life-cycle support for Ada.

3.1.2 Background

In 1975, the High Order Language Working Group (HOLWG) was established -- with representation from Army, Navy, Air Force, DCA, NSA and DARPA -- to investigate the feasibility of adopting a common high order computer programming language for use on embedded computer systems.

A comprehensive set of requirements was developed through extensive coordination in DoD, allied countries, industry and academe. Existing computer languages were formally evaluated against these requirements. No existing language was sufficiently powerful to serve as the common language. The HOLWG undertook a competitive international procurement for the design of a language to meet those requirements. Funds for this activity were provided by by the Services and technical management was provided by DARPA.

The language design was completed in May 1979. Extensive public exposure and language testing followed, leading to some refinements and a final definition in July 1980. The Ada programming language was officially issued as MIL-STD-1815, dated December 10, 1980. Notice 1 to MIL-STD-1815 was issued on June 10, 1981 to indicate that Ada® is a trademark of the U.S. Department of Defense. The language is named Ada, after Augusta Ada Byron, ostensibly the first computer programmer (who worked with Charles Babbage in the 1800's) and daughter of the poet Lord Byron[22]

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[22]For detailed historical development and rationale, see "Introducing Ada," W.E. Carlson, et al, Proceedings of the 1980 ACM Annual Conference, San Diego, CA, October 27-29, 1980, pp 263-271.

3.1.3 The Ada Program

The AJPO was established to implement, introduce and provide life-cycle support for Ada. It will manage the maturation and evolution of the Ada language and support systems. The AJPO will coordinate the development of an Ada Programming Support Environment (APSE) and encourage development of the supporting culture, including management and technical discipline, to assure the DoD a consistent, integrated, programming system which will enhance software portability and afford maximum availability of common tools needed to develop and support defense systems software.

There are three major Ada Program Objectives in support of this purpose.

3.1.3.1 Language Standardization

First, the AJPO must ensure the implementation and maintenance of Ada as a consistent, unambiguous standard recognized by the DoD and also by the widest possible community. Recognition of Ada as a standard is a necessary step in the realization of software and people portability. A difficulty experienced by most other computer languages is the failure to control adherence to the formal definition by implementers and the resulting proliferation of dialects through subseting, superseting and inconsistencies.

In pursuing the acceptance of Ada as a standard outside of the DoD, a certain amount of control must be shared with to the standards bodies. This is an advantage in that it will provide a baseline for Ada and protect the language from future whimsical or capricious changes by the DoD or any other body. The AJPO is in the late stages of the American National Standards Institute (ANSI) canvass process to gain acceptance of Ada as an ANSI Standard. Through ANSI X-3, the AJPO is pursuing standardization with the International Standards Organization (ISO) Technical Committee 97, Subcommittee 5.

3.1.3.2 Introduction and Acceptance

Second, the AJPO must ensure the smooth introduction and acceptance of Ada in the DoD as early as possible consistent with the needs of individual Components.

There are a number of projects which could benefit from an early introduction of the language. The momentum of the Ada program has produced a climate ripe for early acceptance. However, the advantages offered by the use of Ada will not be realized unless the programming support environment is also available. Therefore, this objective must balance the need for an early introduction of the language against the risk of a premature introduction. Ada should not be employed on a major DoD program until the Ada Programming Support Environment is available to support the needs of that project. The AJPO is responsible for providing current information to DoD program managers who must choose a language for their programs. The AJPO will consult with those program managers to ensure that the appropriate support systems are developed. Use of Ada as a Program Design language (PDL) is being promoted and this strategy has been adopted by some DoD programs.

3.1.3.3 Support Systems

Finally, the AJPO must ensure the provision of life-cycle support for Ada through the development of a robust Ada Programming Support Environment (APSE) to improve productivity both in development and in continued evolution.

Ada is not simply a new language. By design, it incorporates many of the features needed to support modern programming practices. As such, Ada introduces a new culture which will be fully realized when a sophisticated Ada Programming Support Environment is made available and is widely accepted and used. A robust APSE, complete with advanced development and management tools, will provide the opportunities for substantial improvement in life-cycle software management. Although each Service employs a different strategy in the acquisition and management of software, there will be a set of tools which can be shared.

The Navy has been tasked to lead a joint service review team to identify and recommend conventions for DoD supported APSEs in support of a Memorandum of Agreement between OUSDRE(AM) and the Service Assistant Secretaries to work toward a consistent set of APSE interfaces. Contracts will be initiated to develop tools targeted to reside on the Army and Air Force funded developments.

Additional Ada Programming Support Environments are expected to be developed independently by academe and industry. These APSEs will not all be compatible with the chosen conventions. However, tools which are sufficiently powerful may be modified to interface with the APSE. The AJPO will foster development of a highly complete and powerful APSE so that it becomes the leading candidate to evolve as the predominant support system. This should encourage designers of independently developed tools to conform to the chosen conventions.

The AJPO is initiating preliminary investigations which will lead to tailoring of modern programming disciplines, supported by automated tools, to the use of Ada. This activity is expected to increase productivity and improve the quality of software.

A consequence of this objective is a requirement for close cooperation with the industrial sector to encourage acceptance of the language and development of Ada products in the marketplace. Cooperation outside the U.S. has also brought much vital technical input. It has made possible an exchange with our allies and a more viable relationship with the multinational computer and defense industry.

3.1.4 Status

Several contracts for Ada developments are either under way or planned. The AJPO is managing a few contracts such as those with Honeywell, SofTech, and Intermetrics. Honeywell is revising the language reference manual (LRM), which is the principal document defining the language, in conjunction with the

ANSI standardization process. The new LRM should be ready early in 1982. SofTech is adding tests to the Ada Compiler Validation Capability (ACVC) to ensure compliance with the revised LRM to correspond to the expected ANSI standard.

Most Ada Program contracts are managed by the Military Departments using their own funds as well as those provided by the AJPO. The Army's contract with New York University has produced an interpreter which runs on the VAX-11/780 and which is available through NTIS. The interpreter is being modified to conform to the revised LRM and will be validated by the ACVC this spring.

SofTech, also under contract to the Army, is scheduled to deliver the Ada Language System (ALS), a Minimal Ada Programming Support Environment (MAPSE) hosted on the VAX, in late 1982. The Air Force expects to let a contract in March for the Ada Integrated Environment (AIE), a MAPSE hosted on IBM and Interdata machines for delivery in 1984. The Navy is leading a joint service KAPSE Interface Team (KIT) to identify and recommend conventions for DoD-supported APSEs. The Navy will initiate contracts to develop tools, targeted to reside on the ALS and the AIE, which will serve to reveal issues relevant to tool transportability and will provide tools useful in both the ALS and the AIE.

Several commercial efforts have been announced, including compilers by Western Digital, TeleSoft, and Intel which are currently incomplete, when measured against the complete Ada language specification. All three companies have announced plans to market complete, validated compilers.

3.2 Military Computer Family (MCF)

The Army's Military Computer Family Program stems from a vital need for system survivability on the battlefield. Computers have become an essential part of Army battlefield systems which perform the functions of communications, command and control, intelligence analysis, surveillance, target acquisition, air defense, weapons control, fire support, electronic warfare, navigation, equipment control, and combat support services. These computers operate in jeeps, armored vehicles, aircraft, vans, etc. and must survive on the nuclear battlefield. These computers should not be confused with those used in normal business and office automation functions in DoD and the Services.

The Army conducted a Post Deployment Software Support (PDSS) study and developed a plan to support its systems on the battlefield. It identified extensive proliferation in software support systems; over 44 assembly languages and dialects of higher order languages were being used. Current estimates show over 50 different computer types to be supported logistically. Proliferation significantly increases the cost and complexity of software development and support as well as hardware logistics, maintenance, training, and acquisition. The goals of the Army's Ada and MCF Programs are to make the Army's battlefield automated systems survivable, supportable and affordable. Following review by a Task Force from the Army Science Board in early 1980, the Army established policy[23] and has implemented programs in three areas -- software support, ISA, and standard hardware.

One of the major benefits to be derived from this standardization program will be the reduction of the system development cycle time. By providing adequate software development facilities and logistically supported computers to new systems, adequate early prototyping of software can be accomplished.

Software development, maintenance, and configuration management for systems deployed to tactical units on the battlefield is done centrally. These systems are too complex to be programmed in the field. Acknowledging Ada as the eventual DoD standard, the Army dropped TACPOL as its standard language and, in a coordinated program with the Ada Joint Program Office and the other Services, is developing the Ada Language System (ALS). The ALS is hosted on a commercial computer -- the DEC VAX-11/780 -- and is required to be transportable to others to assure future competition. It makes use of commercially-developed hardware and operating systems in the software development and maintenance environment and will provide operational software to be fielded and run on computers in the field. The ALS will be available initially in early 1983. The Army's preference for Ada does not prevent use of other languages in DoDI 5000.31.

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[23] AR 1000-1, Basic Policies for Systems Acquisition, May 1, 1981.

The Instruction Set Architecture (ISA) to be used in MCF is MIL-STD-1862 (NEBULA), which has had extensive review by the government and industry[24]. NEBULA is a modern, efficient, 32-bit ISA which is vendor independent (see Section 4.3.2.3) and has allowed wide, open competition for implementations. There were 12 bidders for the MCF advanced development phase. NEBULA is stipulated to be "in the public domain" and available for use by industry in general. Wide use of NEBULA would create a strong knowledge base for the DoD and competition base for future production. Nonmilitarized or "commercial" MCF versions, if cost effective, could be used in many DoD applications, particularly in Command and Control.

At the hardware level, standard products would provide maximum interchangeability of hardware for survivability and maximum savings in logistics, maintenance, and training costs. Standard hardware allows savings in all areas from the production line to diagnostics and sparing. But, since technology is moving rapidly, positive plans must be made for the introduction of new technology to avoid technological obsolescence. The ISA and other interfaces, which will be maintained as upward-compatible standards, will provide maximum commonality for software savings while new technology is introduced into subsequent implementations. A study[25] and Army inquiries show that benefits from new hardware technology make it advisable to have subsequent implementations in 4 to 7 years for new weapon systems. Since the ISA is vendor independent and subsequent implementations could be produced by anyone, maximum access to competition is afforded. This is a form of Pre-Planned Product Improvement, P^3I.

Currently, three contractors -- GE/TRW, RCA, and Raytheon -- are competing for two full scale development (FSD) contracts. Each contractor is free to select a technology and internal design approach. Areas of competition are:

1. Reliability and maintainability,

2. Life-cycle costs,

3. Power dissipation,

4. Technology and hardware architecture,

5. Producibility,

6. Size and weight,

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[24]The Army's MIL-STD-1862 and the Military Computer Family, Technical Directions, vol.7, no. 2, Summer 1981, page 29-40, IBM Federal Systems Division

[25]Navy Computer Accreditation Study, IBM, Contract N00014-79-C-0986

7. Speed and memory capacity,

Performance measured in these parameters will be evaluated against the requirements of the battlefield. Each contractor will deliver a prototype of the super minicomputer (AN/UYK-41) and the microcomputer (AN/UYK-49) in early 1983. Maximum competition is being maintained. Chip-sets and a single board computer for smaller applications (components of the AN/UYK-49) will be available to embed in other equipment.

During FSD, the best two designs, using 1984 technology, will compete for one production contract scheduled for 1986. Pre-production models with ILS packages will be available for testing and early use. A fixed-price, requirements-type contract (unit prices established during competition) is currently planned for award to the winner of the competitive fly-off. The ordering period will be five years. The primary production period is expected to be 7 years with follow-on for repair parts. Standard MCF computers will become available from the production line in 1987 for use in systems. Other form factors, as needed can be standardized as the logistics situation dictates.

During the production phase, currently planned for 1986 to 1993, resolicitation, open to all manufacturers, will start the next iteration of MCF. Naturally, if technology advances more slowly, the Army has the option to "product improve" the current versions or establish multiple producers as the situation dictates.

For the interim period, the Army plans to limit unnecessary proliferation of new ISAs and software support systems. Choices for new systems can be made from those which are currently planned to be supported on the battlefield. Back up to MCF hardware is planned from the Ada Language System with additional code generators to other ISAs. A standard product line will be evolved from current equipment for which full support is planned. Additional "soft" or "AD" MCF models will be used by programs just getting started and for support software development.

3.3 TECR, The Navy Tactical Embedded Computer Resource Program

Because of the particularly severe problems surrounding the support of computers at sea, the Navy decided to limit the number of computer types and the variety of languages some 15 years ago. As a result, most Navy systems are designed around two principal machines, the AN/UYK-7 and the AN/UYK-20. The Navy standard airborne computer, the AN/AYK-14, is based on an ISA which is upward compatible from the AN/UYK-20.

The Navy has 5000 standard militarized, tactical "embedded" computers in 450 types of tactical system using over 50 million lines of computer program code. Even though most of these computers will remain on active service for another 10 to 20 years, the current computers are approaching obsolescence and are experiencing speed and memory saturation in many applications. In mapping out a program for successors to these computers, the Navy has considered constraints of physical interchangeability to maximize readiness of systems at sea and to minimize support costs, as well as the constraints of a large investment in software, with which the new computer must be compatible or which must be recoded -- with at least the original development cost.

These new standard militarized computers -- the AN/UYK-43 and the AN/UYK-44 -- are under competitive full scale engineering development to assure both high technology implementation and lowest production price. It is expected that the AN/UYK-43 production contractor will be competitively selected in September, 1983 and the AN/UYK-44 production contractor selected in January, 1983. Production contracts in both cases will be five-year, fixed-price "requirements" contracts. Options beyond the first five years are open and are being evaluated.

These computers will fulfill the needs of the Navy for standardization and software investment capture by upward compatibility with the existing "mainframe" AN/UYK-7 and the AN/UYK-20 "minicomputer", respectively. The AN/UYK-44 micro/mini series is also software compatible with the new AN/AYK-14 standard Navy airborne computer. Software upward compatibility is achieved in each machine by "emulating" the ISAs of predecessor machines while also extending the instruction sets with additional more powerful instructions which may be used with new software.

The AN/UYK-43 will be delivered to the Navy for testing in March 1983. It will run up to nine times as fast as the AN/UYK-7 and will initially contain up to 1.25 million words of memory in a single enclosure. AN/UYK-44 embeddable card sets were delivered by both contractors to the Navy for testing in December 1981; complete AN/UYK-44 computers will be delivered for testing in September 1982. The AN/UYK-44 will run up to twice the speed of the AN/UYK-20 and will contain up to 0.5 million words in a single enclosure. In both cases, the computers have a modular, "building block" construction using standard components to minimize at-sea logistics costs and to allow easy configurability to different performance requirements.

Navy units afloat must carry sufficient spare parts on board to ensure self sufficiency during a 90-day mission. It is estimated that the minimum cost of a fleet wide inventory of spares per type of computer used throughout the fleet is $30,000,000. This is so because the low parts consumption demand by modern high-reliability computers allows up to 50 same-type computers on a single ship to be supported by one basic "kit" of spares. However, if only one of a type of computer is carried on board it must be supported by a kit of "insurance-item" spares costing at least a quarter of the cost of the basic full kit. With this absolute minimum sparing, the computer will suffer a reduced operational availability due to the need to occasionally wait for off-board repair parts not in the minimum insurance-item kit. The key to obtaining highest computer operational availability while at the same time minimizing logistics costs is clearly through using the same computer types repeatedly throughout the many systems on a ship.

A key requirement in the development of these computers is achievement of unprecedented improvements in reliability, maintainability and availability through use of high reliability technology, fault tolerant design, redundant critical circuits, self testing, and fault diagnosing capabilities. As an example of internal diagnostic capabilities for the AN/UYK-43 "mainframe" computer, the length of the maintenance training school for enlisted maintainers has been cut from the 15 weeks required for the AN/UYK-7 to one week for the AN/UYK-43. Also, the machines will be capable of maintenance and repair by user system technicians (e.g., fire control technicians, missile technicians, sonar technicians) rather than specifically trained computer technicians. Initial program direction required that these reliability, maintainability, and availability improvements would take precedence over performance improvements in the new computers if necessary. However, to date, no compromises have been necessary and specifications of both types are being met or exceeded. All developments are on schedule.

Even with the improved performance capabilities, unit costs of the new standard computers are targeted to be no more than the current standard computers. It is is forecast that the various using Navy projects will buy approximately 1,500 of the "mainframe" AN/UYK-43s and 20,000 of the smaller AN/UYK-44 in its embeddable and complete computer versions.

Despite the preservation of existing support and applications software which these computers will allow, while transitioning projects and systems to the new DoD high order programming language, Ada, it is still forecast that there will be a quantum leap in the amount of new computer software required for Navy tactical systems because of new operational requirements. In the face of a forecast nationwide short fall of thirty percent in qualified computer programmers within ten years, the Navy must also intensify efforts to attract, train, and retain qualified programmers, to modernize and automate software engineering practices, and to invest in computer software support centers to fully capitalize on the forthcoming hardware performance and price "bonanza".

3.4 MIL-STD-1750, The Air Force Approach

3.4.1 Overview

The Air Force will implement DoDI 5000.5x as a logical extension of current Air Force policy, standardizing on two of the listed types:

- MIL-STD-1750A, "16-Bit Computer Instruction Set Architecture," and
- MIL-STD-1862A, "Instruction Set Architecture for the Military Computer Family (NEBULA)."

The Air Force approach fosters competition and encourages technology insertion by treating the ISA as an interface between programmer and machine, or between compiler and machine. By standardizing on the ISA, the Air Force can exploit a common base of software support resources; people, facilities and tools. The Air Force will not "lock in" on a single hardware standard; by avoiding a Service-wide hardware standard, competition among vendors will exist in development, in production and during system modifications. This approach has already yielded improved designs and more competitive pricing in several systems acquisitions including the F-111 Digital Upgrade Program and the F-5G II fighter aircraft.

Although the Air Force logistics environment differs markedly from that of other Services, additional levels of standardization beyond the ISA will prove valuable. Particular emphasis will be placed on standard interfaces, such as MIL-STD-1553[26] and MIL-STD-1760[27].

3.4.2 MIL-STD-1750A

MIL-STD-1750A is the Air Force developed and owned ISA. Developed through work at the Air Force Avionics Laboratory, the ISA was originally intended for use as the central computer in an avionics suite. Refinements resulting from open forum discussions between industry and Government expanded the ISA's memory addressability and improved its ability to effectively execute programs written in modern high order languages.

The MIL-STD-1750A Users Group -- a broad base of government and contractor developers and users -- has been instrumental in the acceptance and improvement of the standard. It is now concentrating on the support resources needed to exploit fully the benefits of the standard. At a recent meeting of

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[26]MIL-STD-1553, Aircraft Internal Time Division Command/Response Multiplex Data Bus.

[27]MIL-STD-1760, Aircraft/Store Electrical Interconnection System.

the Users Group, there were over 120 participants representing some 40 corporations.

The Mil-STD-1750 Control Board, an Air Force body, evaluates all recommendations of the Users Group and is responsible for the control of the standard. At this time, there is a minimum three-year freeze of the ISA to allow economical implementation and use over several applications. Of course, if critical problems are uncovered during the implementations, appropriate fixes must be authorized.

The Embedded Computer Standardization Program Office (ECSPO) is a joint AFSC/AFLC unit which manages Air Force work to support standard systems with standard tools. The ECSPO is working to certify and maintain a core set of compilers, code generators and other software development and maintenance tools.

Certification of computers to MIL-STD-1750 is underway at the Aeronautical Systems Division (ASD) Systems Engineering Avionics Facility (SEAFAC); Three firms' computers have passed the certification procedure and others await their turn.

At least 18 contractors and foreign agencies are implementing MIL-STD-1750A for a variety of applications ranging from the Army Division Air Defense System to the F-16 Multinational Staged Improvement Program (MSIP). The technologies employed range from bi-polar integrated circuitry to VHSIC chips to radiation-hardened CMOS/SOS.

3.4.3 MIL-STD-1862A, NEBULA

Because no one ISA can cost-effectively cover the entire spectrum of computer requirements for modern systems, the Air Force plans to require either the MIL-STD-1750A or MIL-STD-1862A instruction set architecture for embedded computers. The Air Force has joined the Army as an equal member of the MIL-STD-1862A Control Board. As with MIL-STD-1750A, the Air Force does not plan to adopt a Service-wide standard "black box"; open competition and technology insertion will be encouraged. For applications where the timing of the MCF hardware program matches, it is likely that the Air Force will be able to benefit from the Army's quantity buys.

4. GENERAL DISCUSSION

4.1 Standardization Perspective

The DoD Embedded Computer Resources (ECR) environment today reflects the history of problems which of the Military Departments have encountered in their attempts to use computers in systems which must survive and interoperate in the wartime environment to accomplish mission objectives. The effects of hardware and software proliferation, low interoperability and interchangeability, and maintenance and logistics difficulty have resulted in high life- ycle costs and mission degradation. The effects on each Service differ only in degree. In recognition of this situation, OSD instituted the policies discussed in Section 2.1. These policies are intended to control embedded computer resources and related activities. The objectives of this control are to reduce time to deployment, life-cycle cost, training, equipment proliferation, unnecessary replication, complexity of system change, and to enhance maintainability, interoperability, survivability and hardware interchangeability.

To achieve these objectives, many levels of standardization and/or coordination must be considered. Figure 4-1 lists possible levels or areas of control. As indicated, several of these levels are actively being considered for standards or have existing standards. The Task Force concentrated its attention on these areas and our findings and recommendations with respect to them are contained in Chapter 5.

STANDARDIZATION OBJECTIVES

LEVEL OF STANDARDIZATION	Time to Deployment	Life Cycle cost	Training	HW Proliferation	SW Proliferation	Maintainability	Extensibility	Interoperability	Survivability	Interchangeability
High Order Language	X	X	X	–	X	X	X	–	–	–
Instruction Set Architecture	X	X	X	X	X	X	–	X	X	X
Hardware-Box	X	X	X	X	–	X	–	–	X	X
Communications Interface	X	–	–	X	–	–	–	X	X	X
Software Environment	X	X	X	–	X	X	X	–	–	–
Runtime Operating System	X	X	X	–	X	X	X	–	–	–
Protocols	X	–	X	–	–	–	–	X	X	X
Data Dictionaries/ Descriptions	–	X	X	–	–	X	X	X	X	X
Hardware Module	X	X	X	X	–	X	–	–	X	X
Components	X	X	X	X	–	X	–	–	X	X

Figure 4-1: Standardization Options

Standardization at some of these levels is currently under way, standardization at additional levels should be initiated and the remaining levels should remain relatively unconstrained. Among the Instructions which already exist is DoDI 5000.31 which standardizes on a set of HOLs and proposes convergence to a single HOL, Ada. The Ada Joint Program Office (AJPO), which is conducting this effort, is also moving in the direction of standardizing a software support environment and support software interfaces. The Task Force believes the Ada software standardization program as presently constituted is sound and should be supported. Draft DoDI 5000.5x proposes standardization on a small set of ISAs and expresses a desire to converge this set to some "minimum" number.

Task Force views on DoDI 5000.5x are discussed is Section 5.1. The standardization concept is supported. Standardization at the hardware box level is in effect in both the Army and Navy. Owing to the logistic support problems of these two Services, standardization on ISA implementation appears both prudent and cost-effective. All Military Departments have adopted a set of standard electrical communications interfaces. The Task Force believes these are essential to a comprehensive ECR management endeavor. While the Task Force endorses these standardization initiatives, it recognizes a need to take a broader approach to standardization. This can be accomplished by coupling the current initiatives with additional attention to other control levels designated in Figure 4-1. We strongly believe that standardization at only the HOL and/or ISA level will not be sufficient to accomplish the desired control objectives. Among the standards which must be added are:

1. Standard software support support environment such as as that proposed by the AJPO, standard runtime operating system(s).

2. Protocols.

3. Data dictionaries and descriptors and, eventually,

4. A user interface.

At present, it does not appear that benefit would be gained from additional control of hardware modules or components.

4.2 High Level Language (HLL) Machines.

The bulk of today's installed computers reflect the classical von Neumann architecture in the sense that the instructions which the computer hardware can understand and execute are so-called low level. Such instructions typically deal with fundamental machine operations such as add, subtract, store memory, read memory. Computer programs written directly in the language of the machine are referred to as machine language programs or, sometimes loosely, assembly language programs. However, there are a large number of so-called higher order languages used by programmers which have the characteristic that statements made in such languages are more involved, closer to a natural language of English, mathematics, or a specialized field of application, but not directly comprehensible to a machine. Hence, in present art there exists a special software package called a compiler which accepts a computer program written in an HOL (usually called the source language) and produces an output in the language of the machine on which the program is to execute (the target or object language).

There is growing research interest in a category of machines commonly called a High Level Language (HLL) machine or said to have a high level architecture[28]. Another term for such a machine is an HOL machine, and conversely another term for a high order programming language is a high level language. If an HLL machine -- and this seems to be the preferred term -- directly accepts a high level language for execution, then it is said to be a direct execution HLL machine. Conversely, if the computer program in an HLL is first run through a translator -- which is typically the front end portion of a compiler -- to convert problem statements in an HLL to corresponding ones in some intermediate language which then becomes the input, such an HLL machine is said to be an indirect execution machine. Thus, the thrust of contemporary research on HLL machines can be encapsulated in the question:

> "How much of the compiler software can be absorbed directly into the hardware and architecture of the computer per se?"

To say it differently:

> "How close can the interface between the programmer plus the language which he uses be moved toward the computer hardware?"

Obviously, there are a whole series of corollary questions. Among them are:

- What are the payoffs of such a new architecture?
- What are the costs of such a new architecture?
- Is it technically feasible?
- Should such new architectures be considered for all computer applications or are there ones in which more conventional structures still remain appropriate or preferred?

After a computer program is written and tested, there is a phase known as validation and verification (V&V) which is, in effect, an extremely detailed step-by-step examination to assure that it also executes as intended without anomalies of behavior. The intent is to demonstrate that the program does what it is supposed to do and properly so. However, in today's V&V state of

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[28] Computer, vol.14, no.7, (July, 1981). An entire issue devoted to HLL architectures. IEEE, New York.

the art, it is impossible to demonstrate that a computer program does not do what it is not supposed to do; and therefore in an absolute sense, the V&V process cannot be carried to its theoretical completion. As a program written in an HLL is passed through the compiler to produce an executable machine-level program, a large amount of intricate manipulation occurs. Thus, it is possible for behavior intended by the programmer at the HLL level to be subverted or changed in subtle ways by the process of compilation. Hence, to assure the maximum certainty that the program is as intended, V&V efforts are typically carried out at the machine language level which implies that such tasks are tedious, enormously detailed, time consuming and, therefore, expensive.

Limited experience in doing V&V at the HLL level suggests that it is feasible for a large fraction of the operational programs for a weapon system (for example, the algorithms contained in such programs) to satisfactorily be done in this way[29]. However, a large part of such operational programs for so-called real-time code, probably still must be accomplished at the machine language level unless extremely strict discipline and standardization of both programming and compiler details are enforced. Furthermore, V&V at the HLL level (but then compiled) may need substantial special hardware adjuncts, for example, to make the program stop at a particular memory or symbol location -- details commonly obscured by the compiler. There may also be needed special software aids embedded in the compiler to extract from it details which are not commonly available. Alternatively, special computer architectures can be imagined which provide extra space in the computer word for details associated with subsequent V&V.

Since the process of compilation is a complex manipulation, an HLL machine should permit more ready discovery of errors made during the original programming process. In this regard such machines exhibit the same characteristics as those which operate in the so-called interpretation mode and directly accept statements in an appropriate HLL. Typically, the widely available so-called home or hobby level computers (e.g., Apple, TRS-80, Atari, Sinclair) operate interpretively in a language called BASIC. Since interpretative languages and machines facilitate not only programming per se but also testing and debugging, an HLL machine should have the same characteristic . There would then be less opportunity for the program to do something unforeseen by its creator.

On the other hand, an HLL machine obviously implies more hardware although it is not clear that such an issue is significant in the forthcoming VHSIC era. Clearly, however, a direct execution machine must be modified anytime changes are made to the language which it accepts, or alternatively some special features must be incorporated into it to permit changes or additions as the language which it tracks evolves. An indirect execution machine is more flexible in this sense because changes in the language would

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[29]Two bodies of experience are the DAIS Program conducted by the Air Force Avionics Laboratory and the Bell Laboratories work with programs for the new digital ESS switching center machines

imply only changes in the translator or preprocessor which is a software package hosted on a machine of choice.

There are a number of significant research issues. Among them are:

- The NEBULA (MIL-STD-1862A) Instruction Set Architecture (ISA) of the Army's MCF program approximates an HLL machine in that many of its instructions are identical to one in some HLL. Especially, the NEBULA ISA is said to be "Ada-oriented" because many Ada instructions map directly onto a corresponding NEBULA one. But how far should one go in matching the instruction set architecture of a machine to one particular HLL? Clearly, the Department of Defense will continue to support several high-level programming languages, and hence a standard for an instruction set architecture should presumably accommodate more than one of them. Does the NEBULA language go as far as reasonably appropriate? The answers to such questions obviously are a function of hardware technology; they are obviously related to the rigidity and completeness of standardization that the Department of Defense wishes to impose; and they obviously influence the complexity of hardware designs.

- What about the V&V process with an HLL machine? How significant are the advantages? How significant are the savings measured either in dollars or elapsed time? Are there any special features needed in the machine to facilitate the V&V process?

- What about real-time applications which characterize the bulk of the Department of Defense operational software? Are they readily handled in an HLL machine? Are there special programming conventions which must be imposed rigidly?

- For the indirect execution machine, what about the intermediate language that separates the original programmer-created program from the machine? What are its details? What flexibility is needed in it? Can one be designed that will accommodate a broad variety of HLL languages?

- How does the support software for an HLL differ from the customary utility packages now expected by the development programmer?

- What does an HLL machine do for computer security? Especially what are the implications for the operating system and the security safeguards which it must contain?

There is a small amount of research presently underway:

- The Air Force Avionics Laboratory has a contract with Sanders Associates.

- Professor Flynn at Stanford University and Professor Chu at the University of Maryland are both involved in research.

- The Federal Systems Division of IBM has examined HLL machines with IR&D funds.

- Sperry Univac is working on a GENEX architecture.

- The Aerospace Corporation with corporate funds is constructing an experimental ARC machine with an HLL architecture.

Interestingly, one commercial machine is considered a high-level machine or at least to have high-level features[30]. In addition, the Western Digital Corporation is designing an HLL machine for the language PASCAL and Intel Corporation is designing its iAPx432 chip set that will accommodate a subset of the language Ada. The Space Division of the Air Force Systems Command, jointly with the Aerospace Corporation, hosted a workshop on high-level-language computer architectures in Los Angeles, October 7-9, 1981. During the meeting, IBM's Yorktown Research Laboratory and the Fairchild Semiconductor Corporation both expressed interest in such novel architectures.

Clearly, HLL machines and their special architectures must be an item of interest for the Department of Defense. However, there are technical uncertainties which must be overcome before such machines will become a practical reality. Until research presently underway resolves these uncertainties, it would be unwise to delay acquisition programs with the expectation that an HLL machine could be part of the development process. Furthermore the appropriateness and payoff from such machines is not yet solidly established; thus is is inappropriate for the DoD to panic for a huge research activity. However, it is quite appropriate for all of the Services to be actively involved in the HLL research area as one aspect of general exploration of new architectures for future machines.

Some of the present industrial activity has been stimulated by the DoD adoption of Ada, and some work is directly or indirectly supported by military funding. However, the community of research is not large and continuing support and growth is obviously desirable. HLL machines will undoubtedly be a significant step in new computer architectures. The DoD must be properly informed about them so that appropriate choices and decisions can be made in acquisition of new weapon systems, or in retrofits of computer-based capabilities to older ones.

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[30] F.G. Soltis, "Design of a Small Business Data Processing System," Computer, vol. 14, no. 9, p.77ff, IEEE, New York.

4.3 Proprietary Data Rights as Affecting ISA and Hardware Selection

4.3.1 General

In considering the major issues discussed in Chapter 5, it became clear that an important factor was the feasibility of the Government's obtaining legal rights to use an ISA not in the public domain. A definitive resolution of this concern was not possible. However, the underlying and controlling issues will be discussed in this Section, including the effect of proprietary data as it impacts upon management of embedded computer resources.

4.3.2 Legal Techniques For Protecting ISA's

This section will discuss legal protection techniques applicable to ISA's, aspects of DoD use of a commercial ISA, and considerations of data rights in hardware acquisition strategies.

There are three legal techniques which are generally used to protect a company's proprietary ISA from its competitors and others:

1. Patents,
2. Copyrights and
3. Trade secrets.

4.3.2.1 Patents

Patents protect a patented item against any unauthorized manufacture, use, or sale of the patented item. This protection is broader than that of a copyright since it generally protects the item even if others have independently developed the same item. The Government (including contractors producing items for it) cannot be prevented from manufacturing or using a patented item; however the Government may have to pay a reasonable price for using such a patented item.

4.3.2.2 Copyrights

Copyrights protect an item only against direct copying of the item. They do not protect against an independent development or creation of the same item. Copyrights do not protect ideas -- they merely protect a. 'tem from direct (or substantial) copying. Just as in patents, Government contractors cannot be prevented from copying, however the Government may have to pay a reasonable price for copying of copyrighted items. It should be noted that the degree of protection afforded to ISA's through the mechanism of copyrights has not been tested in the courts. However, the courts have established that when a particular ISA (or a portion of it) is implemented in the form of a semiconductor chip, and the pattern for that chip is copyrighted, then that chip may not be copied.

4.3.2.3 Trade Secrets

"Trade secrets" are a legal form of protection which prevent unauthorized use of proprietary information which has been kept secret. Trade secret law does not prevent "reverse engineering" or independent development of the "proprietary" information. Unlike patents and copyrights, trade secrets must not be freely disclosed, and such trade secrets are generally not available to the public or Government except under conditions limiting disclosure by the recipient. Acquisition and protection of trade secrets is extremely complicated, is dependent upon state law, and is generally handled on a case by case basis.

The effectiveness and extent of protection of the above techniques depends upon many complex legal and technical factors. These considerations are important to ECR acquisition and management because they further complicate an already complex area of rapidly evolving technology.

DoD Utilization Of A Commercial ISA

An ISA forms the key link between the support software and the target computer. Computer programs written and compiled for one target computer cannot be used on another computer with a different ISA, unless the ISA of the second computer is related to that of the first in a special way, or unless the second computer is arranged specifically to emulate the first.

For a commercial ISA to be desirable for the DoD to utilize, it should be in wide use and have a rich support software base. The owners of any such commercially successful ISA protect both the ISA and software from competitors by one or more of the legal protection techniques discussed above. However, the legal protection available to owners is not iron-clad, and unlicensed second-sources are not an unknown phenomenon in the commercial computer software and hardware fields.

The Government must then license an ISA or develop its own if it is to reap advantages of commonality among computers utilized on the battlefield or at sea, and to achieve maximum operational redundancy by having the capability to run programs on any available computer.

At present, it appears that the commercial market share and demand for computers vastly exceed the perceived needs of the DoD. Therefore computer manufacturers generally find it economically unattractive to cater to the DoD's needs. Companies which have useful and valuable ISA's simply choose to pursue the profitable commercial market and are reluctant to enter into arrangements with the DoD which could result in disclosure of trade secrets or in ultimate market share competition with their own commercial line.

Given this perspective, it is not surprising that the Army found it virtually impossible to license a commercial ISA. Even agreement upon the most basic and fundamental definitions are extremely difficult. The first difficult definition is the ISA itself. Other examples of definitions which proved difficult in specific negotiations are:

1. Software identical,

2. Software compatible,

3. Battlefield environment,

4. Royalty-bearing equipment,

5. Militarized (vis a vis ruggedized commercial) equipment,

6. Computer software,

7. Utility software,

8. Proprietary data.

The bounds of the government's use of the ISA must be precisely defined Any company whose ISA is chosen will also want to sell the government its commercial equipment and not see that market negatively impacted by military equipment using that ISA. To protect its patents and trade secrets, the licensor may need to inspect other companies' manufacturing facilities and hence those companies' trade secrets would be in jeopardy. The licensor may negotiate to approve which companies receive RFP's or approve the contractors selected by the government to manufacture hardware. It may also make the license contingent upon approval of its other licensees, etc. There are countless other factors such as agreements to standardize in NATO for interchangeability and survivability which the government would have to negotiate with the licensor. The Task Force reviewed one check list for patent negotiations which was 12 pages long.

The NEBULA ISA was developed under Army contract (DAAK80-79-C-0767) by Carnegie-Mellon University and unlimited rights in data were acquired by the Army. While no mechanism exists to preclude any patent holder from bringing suit related to the NEBULA ISA, we know of no patents infringed by the NEBULA ISA. Even if valid patents are infringed, Government contractors could not be prevented from selling to the Government, but the Government would be liable for a reasonable royalty. Commercial sale, however, could be prevented unless necessary royalties were negotiated.

It is noteworthy that the Army has no objection to its MCF contractors marketing commercial implementations of the NEBULA ISA. Such action by MCF contractors would broaden the base of NEBULA; it would create knowledgeable talent for the government to draw upon, would promote the generation of a large base of NEBULA compatible Ada programs and would create incentive for those contractors to continue development of the ISA to increase its value and provide a broad base of knowledgeable contractors for future competition.

Because of its perception of the desirability of commercial implementation of the NEBULA architecture, the government made its best efforts to obtain a design which would not infringe known patents[31].

4.3.2.4 Nota Bene

One of the Task Force Members [GHH] offered the following additional observation and recommendation:

> "The commercial availability of 32-bit architectures in single chip form from several semiconductor companies represents a discontinuity that should be strongly considered by the DoD. In contrast to computer companies that have a vested interest in maintaining proprietary architectures, semiconductor companies benefit from offering their architectures, already in single-chip form, to everyone. Furthermore, each semiconductor company has multiple sources for their chip, thus ensuring the competition will result in lower costs to the DoD. It is recommended that the DoD explore the adoption of one of the existing large address space architectures already available in single chip form from several semiconductor companies, each with multiple sources of supply."

The Task Force did not discuss this specific issue in detail; it is included here for sake of completeness and for the appropriate further consideration of the DoD.

Data Rights In ECR Hardware Acquisitions

Data rights come into play not only with regard to development and use of an ISA, but in the acquisition of hardware as well. For instance, in the MCF program, even though the Government-owned NEBULA ISA has been specified, the four Advanced Development contractors are completely free to design and utilize hardware implementations which reflect and incorporate the best technology that the contractor considers appropriate for the given application--to design for cost, reliability, survivability and other design considerations.

There is no problem in incorporating the latest in technology into ECR systems, but in so doing the contractor is likely to utilize company developed

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[31] During the presentation of the findings and recommendations of the Task Force to the full Defense Science Board, the DSB indicated their strong feeling that there may yet be an acceptable approach for including "commercial ISAs" on the DoD-approved list while maintaining an open and equitable competitive environment. Past failures in this endeavor were not considered by the Board to be sufficient reason to discontinue efforts toward this objective. DoD promised to take the lead in initiating further discussion with industry, likely via one of the Associations.

trade-secret or patented technology. This presents obvious difficulty in then attempting to establish a second source for reprocurement or because the original source has either gone out of business or has simply decided not to continue to manufacturer or support the item. However, these problems and obstacles to second sourcing can be minimized if careful attention is paid to the acquisition strategy and contracting methodology at least before the advanced development phase begins.

5. MAJOR ISSUES, DISCUSSION AND RECOMMENDATIONS

5.1 On Proceeding with DoD Instruction 5000.5x

5.1.1 Discussion

DoD Instruction 5000.5x is the proposed Department of Defense Instruction which, upon issuance, would establish the DoD policy for embedded computer Instruction Set Architecture selection.

The principal elements of the policy defined by the proposed Instruction are:

- Only DoD-approved ISAs may be used in defense systems unless it is demonstrated that none of the approved ISAs are practical or cost-effective.

- Each DoD-approved ISA is to be assigned to a Service to ensure its stability of specification and configuration management.

- Approved ISAs shall be reviewed at least every two years.

- Each DoD Component shall initiate procedures to grant or reject waivers to this policy.

This Instruction covers all embedded digital computers and processors, regardless of implementation, technology or size, unless they are specifically excluded by the paragraphs below:

- Nonmilitarized, general-purpose, commercially-available stand-alone computers.

- Digital computers and processors used in hardware intensive[32] applications.

- Digital computers and processors utilized as part of Automatic Test Equipment (ATE) and Crew Training Devices (CTD).

- Certain commercial products which contain non-militarized computers such as instruments, materials handling systems, etc.

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[32] By hardware intensive we mean those computer applications in which the function to be performed is fixed, hence the computer program (software) is not expected to be changed for the lifetime of the physical component in which it is embedded.

The status of this proposed policy is that it has received formal review from each of the Military Departments, the cognizant OSD staff offices and industry but it has not yet been issued by the Under Secretary of of Defense (Research and Engineering). A principal motivation for establishment of the Task Force was lack of consensus on DoDI 5000.5x both within the Department and the affected industrial community. Future embedded computer acquisition programs of each of the Military Departments are heavily influenced by this Instruction. Hence, there is properly a wide interest in the appropriateness of this Instruction. The other conclusions and recommendations of the Task Force pivot strongly on the resolution of this issue so a major portion of the Task Force's time was spent in reaching our position on 5000.5x.

The Military Departments favor issuance of the Instruction because it eases the management problems associated with system development and, more importantly, limiting the number of ISAs is seen as ameliorating the growing Post Deployment Software Support (PDSS) problems of cost and manpower through the rest of this century. The Army views 5000.5x as a necessary fundamental step in its efforts to achieve battlefield survivability.

Each of the Military Departments, on its own, has issued policy which closely follows the guidance of 5000.5x. Failure to issue the Instruction will be taken as a repudiation of both the Instruction and the supporting Service policies.

DoDI 5000.5x is only a portion of the defining regulatory instructions for DoD computer acquisition. DoDI 5000.5x responds to the unique requirements of the Military Departments to support and maintain forces and equipment in the field under battlefield conditions. This requirement applies to equipment over a lifetime of several decades. It is a portion of the broad view taken of the computer resource acquisition process under the Warner language of Section 908 of the FY1982 Defense Authorization Act. This recent legislative language provides the new criterion of Mission Functionality as a determinant of computer resource acquisition methods. DoDI 5000.5x clearly does not apply to those data processing systems acquired under traditional Brooks Act procedures. The detailed language of 5000.5x needs to be reviewed for consistency with current acquisition policy before it is officially issued.

DoDI 5000.5x policies will, through time after issuance, change the development and acquisition practices of the Department. In the transition period, the waiver process will serve as a buffer mechanism to smooth over difficulties. Sensitive handling of waivers, in close coordination with the acquisition process, is required to balance competing forces of genuine and sometimes painful progress toward standardization and avoidance of paralysis induced by emerging, yet incomplete, standard achievements.

The arguments in favor of DoDI 5000.5x are based on the following important considerations:

- Battlefield Survivability achieved by computer-based systems which can substitute for each other at a direct ISA level to maintain capability despite battle damage.

- Logistic Supportability in the dynamic environment of battle, achieved by cannibalization or adequate logistic sparing permitted by the reduced number of types of equipments.

- Economic Feasibility to Logistically Spare due to the reduced number of types of deployed embedded computers.

- Substantial Cost Avoidance over a time frame of several decades due to the availability to use in common applications and utility support software developed for a limited number of permitted ISAs.

- Greatly Reduced Software and Hardware Personnel Needs due to the economy of scale and not having to provide for several decades the very many specially trained people required for the present proliferation of embedded computer equipment.

The arguments of those who oppose this proposed policy center on the idea that:

> "Standardization will stultify the introduction of new technology and that it will negatively affect competition and hence gradually increase DoD costs."

There is also wide-spread belief that commercial computer technology is changing so fast that restriction to a limited number of ISAs will preclude DoD's use of the best U.S computer technology. There is also a belief that it is not possible to fix a list of ISAs now for application a long time into the future since new developments may well obsolete them.

The crux of the resistance seems to be that the specific effect of this new policy on traditional market share and business practice is not easily forecast. That is to say, the policy injects a new risk parameter into business and marketing strategy. For most militarized computer acquisitions in the past, once a design (hence supplier) was chosen for a major system, it was nearly impossible to find alternate sources for follow-on production. Nearly every militarized computer included proprietary design features so that, when actually possible to establish second sources for mobilization and economic considerations, it is only with the sufferance of the principal supplier. Furthermore, the support equipment often had to be maintained long after the commercial world had moved on to other systems.

5.1.2 Findings

On balance, the DSB Task Force finds the arguments in favor of restricting the number of ISAs to be compelling. Insertion of new technology into Military Department implementations is believed by the Task Force to be quite possible under DoDI 5000.5x and a proper implementation of the policy can be monitored to ensure technology insertion.

The Task Force recognizes the importance of competition in procurement which, it appears, can be suitably achieved under DoDI 5000.5x. In general, direct application of commercial equipments as embedded computers will be difficult due to the need for these equipments to meet environmental requirements of the military application. However, the adoption of emerging commercial techniques into equipment designed to 5000.5x ISAs should not present any unusual problems. The Task Force believes that emerging development in components (e.g., VHSIC) or computer organization (e.g., array processors) can be advantageously included in equipments based on the ISA policy of 5000.5x.

The policy, as written, offers adequate opportunity for waiver when conformance to the policy is not warranted. The policy also offers adequate opportunity for expansion of the approved list of authorized ISAs, if and when necessary, to respond to emerging technology. It also offers the opportunity for reduction in numbers of ISAs as the Military Departments converge their approaches to next-generation ISAs.

5.1.3 Recommendations

Our recommendation is to issue the Instruction and, through other actions as noted, to produce a context in which the potential benefits of ISA standardization will be realized by the DoD. Any new standard provides opportunities for misuse. This Instruction, if properly implemented, has adequate provisions to avoid misuse and is a necessary, but not sufficient, part of the total standardization and coordination efforts required in OSD.

Before issue, the language of DoDI 5000.5x should be reviewed for consistency and clarity in the context of the recent Warner language of Section 908 of Public Law 97-86. In particular, the delineation of which defense systems will fall under the provisions of DoDI 5000.5x policy needs clarification as does the matter of which system are exempt. A system might use a non-5000.5x ISA either because 5000.5x does not apply to its mission or, if 5000.5x does apply, because the system falls into one of the specific exemption categories listed in 5000.5x. The version of 5000.5x issued must be clear on the issues of applicability, exemption and authority in the current acquisition environment.

Exemptions from DoDI 5000.5x under the hardware-intensive category deserve very careful consideration. The ubiquity of microprocessors in large quantity in DoD applications is inevitable. While the software content in each hardware-intensive application may be small, the multiplier over all DoD on this software can produce a large expenditure. We recommend that the Military Departments, with OSD review, define criteria appropriate to their needs for the hardware-intensive exemption category with emphasis on software lifetime support as opposed to any hardware characteristics. A decade of reprogramming after acquisition is expensive whether for a mainframe or any kind of microprocessor-based system component, no matter how small. Since 5000.5x is intended to help contain life-cycle software support costs, hardware-intensive exemptions should be limited to applications with small expected continuing software support requirements.

Once a list of standard ISAs is official through issuance of DoDI 5000.5x, its current appropriateness must be closely monitored. OSD should develop criteria for adding and especially for deleting entries on the list and should monitor waiver actions for early notice of technical trends which indicate needed changes. OSD should annually review the Departmental actions implementing 5000.5x. DoD-sponsored work leading to new ISAs should be planned coherently and coordinated in execution.

We recommend appropriate attention to follow-on steps which will be possible because of 5000.5x. For example, one reason for issuing DoDI 5000.5x is to facilitate battlefield survivability. This Instruction provides the authority for a common ISA in battlefield situations which, in turn, could permit exchange of tactical [object code] software from damaged into working equipment. However, many further actions are required to achieve this capability in fact. The need for software exchange must be formally included in requirements, designed into the field systems, and then validated in the T&E phase of development. If appropriate follow-up actions are not taken and adequate resources not provided, issuing DoDI 5000.5x will be an exercise in bureaucratic futility with respect to life-cycle cost containment.

5.2 On Implementation of Proposed DoDI 5000.5x

5.2.1 Discussion

As noted in Subsection 5.1.1, each of the Services has already found it desirable to initiate programs to restrict the number of ISAs used in their embedded computer systems. The Army's Military Computer Family (MCF) based on the NEBULA ISA is described in Section 3.2. The Navy's Embedded Computer System (NECS) is described in Section 3.3. The Air Force approach based on MIL-STD-1750 is described in Section 3.4. Each of the Services plans to base its implementation of DoDI 5000.5X on its current program. Therefore, the Task Force reviewed these programs in some detail to judge the reasonableness of the approaches and to consider possible changes to them.

Each of the programs was reviewed with respect to the factors discussed in Section 5.1.1 which were found to affect the desirability of limiting the number of ISA's. For all Services, the dominant concern in implementing 5000.5x is to maximize their probability of meeting mission requirements and, thus, maximize their war-fighting capability. In general, each of the Services has found that the advantages summarized in Section 5.1.1 do apply, e.g., substantial reductions in support software costs have resulted or are fully expected to result. However, the relative importance of these factors varies substantially across the Services. By standardizing on an ISA, each Service has the capability to reduce its continuing software support cost. This is possible by reducing the number of software support systems and the amount of support software which must be created for each ISA. This is not unlike the approach industry has followed. Further, the resulting savings from reducing unnecessary software proliferation can be applied to the necessary software development and support systems, increasing productivity and transportability. This is viewed as a major step toward the long-range goal of reducing future costs of software development and support. The expected cost avoidance cannot be easily quantified, but is thought to be sizeable. Some statements to the Task Force would estimate these costs in hundreds of millions of dollars.

Survivability on the battlefield, at sea, and in the air is greatly enhanced with interchangeability of computers for automated systems. Each Service has a variety of applications for embedded computers. Although acquisition strategies for implementations (hardware) vary depending on the application, standardizing on an ISA will facilitate interchange equipment in critical situations.

The Air Force acquisition strategy for implementation of MIL-STD-1750A takes advantage of the most important factors for the Air Force. With each new aircraft, the most important factor is reduced cost and time required for system development due to the complete software support environment which is available to the program manager for MIL-STD-1750A.

The Navy acquisition strategy for the AN/UYK-43 and -44 is almost identical to the Army's for the Military Computer Family, yet it is tailored for the specific needs of the Service and its environment. The Navy has a sizeable investment in software and is acquiring the 43 and 44 with extensions to the AN/UYK-7 and -20 ISA's to capture its software investment. Early success in this program proves that ISA's can maintain upward compatibility and new technology can be inserted. For the Navy program, the most important consideration is the substantial savings which result from reduced sparing required to achieve the required operational availability. A simple model estimated $30,000,000 cost avoided per computer type by not placing different hardware implementations of the same or different ISAs aboard ship. Increased operational availability is achieved due to sparing as the number of identical copies of hardware is increased.

The Army currently has a large number of computer types either fielded, in production, or in development -- some 55 distinct types in 62 specific systems. This proliferation of computers increases development, production, maintenance, and training costs while reducing survivability. The major advantage of standardization for the Army is increased survivability on the battlefield through interchangeability and cannibalization of computers, while benefiting from increased operational availability, as in the Navy's case. The Army will also benefit from reducing the number of computer types in logistics channels. Not including benefits from maintenance training, reliability, system software development, or post deployment software support, an unvalidated, but conservative, cost-avoidance estimate is $500,000,000 by 1992 with the Military Computer Family Program as compared to continued proliferation of computer types.

Quantitative data available to the Task Force was weak. Economic studies are inherently suspect because they must use assumptions about projected requirements, projected costs, and "straw-man" alternative programs. However, the Navy and Air Force experience that common support programs are really being used across many systems and the Navy experience that a restricted number of ISA's really are advantageous on shipboard serve to reinforce the economic studies and qualitative arguments.

The Task Force reviewed the approach being used on the Army's Military Computer Family (MCF) program which uses an ISA (NEBULA) designed within the program rather than a commercial ISA for which rights would need to be purchased. In theory, the use of a commercial ISA might provide two main advantages:

1. The ISA would have been implemented commercially and tested in many installations so that a minimum shake-out period would be required.

2. A large body of software would exist and, thus, development cost and time could be avoided.

Major disadvantages of standardizing a commercial ISA include:

1. All valuable commercial ISA's and support software for them are protected by patents, copyrights, or as trade-secrets (or a combination of protections). Negotiations for any particular ISA must include definitions of terms which are extremely difficult and time consuming to resolve such as: software identical, software compatible, royalty bearing equipment, utility bearing equipment, etc. Other items such as rights of other contractors, where the equipment will be used, governing law, disposition of equipment, positions of other existing licensees, must be negotiated. Army's experience indicates that it is very difficult if not impossible, to acquire the rights without many restrictions even if there is no royalty involved.

2. Changes to the ISA and/or the support software over a period of time are not under control of the government. This leaves continued support of the ISA dependent on commercial success.

3. Efforts to evaluate one ISA over another are extremely time consuming, imprecise and somewhat subject to its implementation in hardware rather than on the merit of the ISA alone.

4. Since ISA's are valuable to the owner and therefore protected, choice of a commercial ISA for DOD or a service will be an economic bonanza for the company whose ISA is chosen. Competition is seen being limited in the long term, due to the sole-source nature of the licensing process.

After lengthy discussion, the Task Force concluded that neither the economics nor the availability of software necessarily favored use of a commercial ISA and that the technical risk associated with a new ISA was not great although it could result in some increase in currently-planned schedules. The value of the support software issue is ameliorated by DoD's work with Ada and the fact that the Army's Ada Language System (ALS) is hosted on a commercial machine which takes advantage commercially-available software. The ALS is required to be re-hostable to other commercial machines for transportability.

The Army contingency plan to counter a significant schedule slip, should such a slip occur, is to continue their transition program making use of a subset of the ISA's and software support systems currently planned to be supported. New systems would be started on these until the ALS and MCF are available. The current policy and waiver process would improve up-front planning and allow for exceptions. Delays to the ALS and MCF will delay the availability of survivability, economic, and other benefits of MCF, but will not significantly reduce them.

After reviewing the Air Force, Navy and Army programs, the Task Force discussed the variations among them. There are clearly differences in their present status which lead to variations. For example: The Air Force has a very different maintenance and logistic situation than do the Army and Navy, and the Navy has a large existing software base on just two types of computers while the Army is faced with over 50 different types of computers in the inventory. After discussion as to whether strong measures should be taken immediately to adopt a single ISA for all Services, we decided that was not practical at this time. It may never be practical to go to a single ISA for all three Services. However, we believe that steps should be taken to make the next generation as close to "all Service" ISAs as possible. A recommended approach to achieving this is indicated in Section 5.1.3.

5.2.2 Recommendations

The Task Force recommends that each of the Services proceed with its current program. However, we also recommend that each of the Services consider the following changes in detail to their plans and report the conclusions of their considerations for review by OSD.

5.2.2.1 Army and Navy

1. It is possible that lower production costs can be obtained over the full production cycle if more than one contractor can produce produce logistically-identical machines, either right from the start or after an initial production period. Both the Army and the Navy should determine the front-end costs of possible arrangements for doing this and estimate the overall costs or savings.

2. We have concern that time limits in procurement regulations may lead to a development cycle that is shorter than is desirable from technological considerations. OSD should determine whether changes in the Defense Acquisition Regulations (DAR) must be requested to provide the necessary flexibility in timing of new development cycle.

5.2.2.2 Army

Increase the number of prototype NEBULA machines to be available at an early date for advanced development by projects planning the use of MCF soon after its availability.

5.2.2.3 Air Force

It is clear that the trade-offs for different implementations of MIL-STD-1750A are likely to make it desirable to have more than one implementation. However, Army and Navy studies indicate that the logistic savings may be substantial for each different implementation that is eliminated.

1. The Air Force should consider bounding the number of unique implementations of MIL-STD-1750 with an eye toward achieving logistic cost avoidance.

2. The Air Force should consider the possible advantages of adding I/O specifications to MIL-STD-1750A.

5.3 On Implementation of DoDI 5000.31

5.3.1 Discussion

The intent of DoD Instruction 5000.31 is to encourage the use of High Order Languages (HOLs) in defense applications and to limit the number of HOLs used to a small set with eventual convergence to a minimum (one). There is very little controversy over this policy. It has been in effect since November, 1976, and few, if any, negative effects have been noticed.

The proposed revision to this Instruction has been prepared which reaffirms DoD's commitment:

1. To reducing the number of programming languages used in military systems,

2. To minimizing use of machine-oriented (assembly) languages, and

3. To transition to modern, machine-independent languages.

The revision also discusses Ada, to wit:

> "Ada is intended to be the common, machine-independent, embedded computer system programming language for DoD-wide use. Individual DoD Components shall not implement a more restrictive policy which would require a waiver to use Ada within their Component."

While the original issue of 5000.31 required an exception for use of any language not on the approved list, the revision is more specific. It states:

> "A waiver must be obtained for each Defense System:
>
> 1. For the use of any High Order Language (HOL) or special purpose language not listed ...
>
> 2. For use of any Machine Oriented Language (MOL) as the principal programming language of the system, or
>
> 3. For the use of any extensions to or enhancements of an approved language."

Waivers are to be issued <u>only</u> when it is demonstrated that none of the approved HOLs are technically practical or cost effective over the system life cycle.

5.3.1.1 Approved High Order languages

The HOLs proposed for the revision of DoDI 5000.31 are as follows:

1. CMS-2M; "CMS-2M Computer Performance Specifications," NAVSEA 0967LP-598-2210, October 1978.

2. JOVIAL-J73; Military Standard MIL-STD-1589B (USAF), March 15, 1979.

3. ANS FORTRAN-1978; ANSI X3-1978; FIPS 69.

4. Ada; Military Standard MIL-STD-1815, December 1980[33].

The Instruction also proposes to approve three "special purpose" languages which may be used in their respective application:

1. Automatic Test Equipment (ATE) Applications

   - ANS ATLAS; "IEEE Standard ATLAS Test Language (Full ATLAS)," ANSI/IEEE Standard 416-1980.

   - "Common ATLAS"; IEEE Standard 716-1981.

2. Signal Processing Applications

   - SPL/1; "SPL/1 Language Reference Manual, 5490-163; NRL, Washington, DC.

3. Business and Management Information Systems (MIS) Applications

   - ANS COBOL; ANSI X3.23, 1974.

Implementation of DoDI 5000.31 has been spotty and, at present, there is little motivation for any of the Components to adopt existing languages developed for use by others. The Army found reliance on TACPOL to be inappropriate and has requested that it be dropped form the list of approved HOLs. The Army may, therefore, use FORTRAN, ask for an HOL waiver or use one of the other 5000.31 languages. The Navy course continues to be set on the use of CMS-2 for the current generation because of the huge investment they have in applications code. In the case of the Air Force, the interim standard language is JOVIAL-J73.

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[33] MIL-STD-1815 is being coordinated as an ANSI Standard Document via the canvass method

It appears that each of the Military Departments is proceeding with DoDI 5000.31 in spirit; however, for the time being they are on parallel rather than converging paths. The first real opportunity for the Services to move form their past course in the direction of convergence is expected to accompany the introduction of Ada. Each of the Services anticipates this and appears to be aggressively planning accordingly.

In the instance of the Army, the MCF program incorporates Ada standardization. In fact, the Army Ada Language System (ALS) is important to DoD's actual implementation of Ada. Our major concern here is that the Army Ada effort may be too lightly funded. In addition, strict adherence to rigid time requirements on this schedule-driven program may preclude some opportunities to improve the eventual implementation of Ada. Further, we have concern over the completeness of the support software suite. The Air Force Ada program appears well conceived and should complement the Army effort.

5.3.2 Recommendations

The Task Force recommends that revised DoD Instruction 5000.31 be issued, basically as drafted. In that time has passed since formal coordination of the draft, it should be reviewed to assure adequate encouragement of the introduction of Ada. The policy in the Instruction should be correlated with the current status of the Ada Program. The latest versions of the defining documents should be cited.

Since the success of Ada is very important and since that success is not yet assured, continued management attention should be given to single-service and multi-service Ada development and promotion efforts. Funding support for the introduction and development of Ada and Ada-related tools will be of critical importance throughout the Program.

We recommend that encouragement and funding be provided to the Navy to facilitate and expedite transition to Ada. This may include development of code conversion aids and multi-language support tools for interim use.

We recommend that the Army Ada Program be reviewed to assure:

1. **That funding is adequate,**

2. **That schedule requirements are not overly ambitious,**

3. That schedule requirements do not prematurely preclude benefits derived from slightly greater language/environment maturity and

4. **That the support software suite is comprehensive.**

We recommend that OSD, together with the Air Force, review the opportunities for cost savings within the JOVIAL Program. We recommend that the Service Ada language programs be strongly endorsed, and that they continue to be receive adequate staff and funds. The various components of this Program should be better coordinated.

5.4 Application of Ada® and MCF to the WIS Upgrade

The Task Force considered the potential for use of current and proposed standards for such significant programs as the WWMCCS Information System (WIS) upgrade. Our assessment of the situation and resulting recommendations follow.

5.4.1 Discussion

There is a considerable amount of software running today which supports WIS site operation (some 10 to 15 million lines of code) and which will remain in COBOL or FORTRAN as the WIS is upgraded to new hardware and architecture. The amount of new code which will be generated is estimated to be on the order of two to three million lines over the upgrade period from 1983 to 1989. It is expected that commercial support will be available in higher order languages (COBOL, FORTRAN and Ada) to meet most WIS support needs. The schedules for development of Phases I and II of the present upgrade plan precede the availability of Ada and its support environment. The schedules for Phases III and IV are more compatible with Ada availability except for the potential lack of maturity of the language and the completeness of the support environment early in these Phases.

Each command or agency may choose a different set of hardware to meet its command-unique requirements and its logistic support concerns as influenced by the totality of ADP hardware and its support needs (WWMCCS and non-WWMCCS) at the command. To support the use of different hardware and to aid future transition, support software specifications should be at the level of general capabilities and standard user interfaces.

Inter system and local network protocols should be developed from the existing DoD standards and emerging international standards. Standards for data elements as well as protocols are required.

5.4.2 Findings

For reasons of economic necessity and technical practicality. a very large base of existing software must be preserved during the upgrade of the WIS. An estimated two to three million lines of new code must be added to the system.

Although the schedules for the earlier phases of the WIS upgrade precede the availability of Ada for operational or applications code, it is not at all too early to use Ada as a Program Design Language.

5.4.3 Recommendations

We recommend that the Joint Program Manager for WIS adopt Ada into the WIS language family as soon as reasonable language stability and support environment maturity are assured. Our current estimate is that this will occur in the 1984 to 1985 time period.

We strongly recommend that the JPM use Ada as a Program Design Language now. The structure and discipline could be quite important to a program as large and complex as WIS. Further, it could facilitate the use of Ada as a programming language at the earliest opportunity.

5.4.4 Additional Observations

During our brief review of the planned WIS upgrade we made some additional observations which may be of both specific and general value:

1. The limited amount of skilled resources which may be available to carry off the upgrade may dictate a more conservative approach to changeover which relies more heavily on emulation or plug compatibility.

2. The amount of readily available support software may not cover as many WIS needs as expected. Some greater investment in support software may be required to provide necessary capabilities.

3. A greater investment to speed Ada maturity and applicability for WIS may be desirable.

4. The level of standardization throughout WIS should be at the level of user-visible functions rather than at the machine or language level to aid transition, reduce development costs and reduce personnel needs.

5. Approaches to multilevel security should be conservative and rely on equipment separation, contingencies to back up new development short falls, and manual and physical controls as necessary to handle critical multilevel security. NSA developments may provide some new approaches in the next few years.

6. Instruction Set Architecture (ISA) standardization, as support environments mature, may become attractive as a mechanism to ease future transitions. This likelihood would be enhanced for WIS by emphasis on;

   - Development of the upper end of the MCF product line;

   - Development of large-scale peripheral devices;

   - Development of a full repertoire of system support software, including protocols, storage management and support for user interfaces.

5.5 On the Implementation of DoD Directive 5000.29

5.5.1 Discussion

DoD Directive 5000.29, Management of Computer Resources in Major Systems," covers two primary topics:

1. The nature and organizational structure of DoD's Embedded Computer System (ECS) oversight process. This topic is covered in Section 5.6 of this report.

2. Guidelines for the ECS acquisition and life-cycle management process within DoD. This topic is covered in this Section.

Overall, the Task Force found that the ECS acquisition and life-cycle management guidelines are well-formulated and realistic. They have done a great deal to ameliorate DoD problems in the ECS area. However, a good many DOD programs still encounter significant ECS problems. The task Force's assessment is that these problems have the following primary causes:

1. Lack of application of the existing guidelines within DoD Directive 5000.29. The Task Force's recommendations to cover this problem are contained in Section 5.6 on the DoD Oversight process.

2. Insufficient ECS concept validation and commitment to fixed ECS solutions and budgets before the system's ECS requirements are well understood.

3. Conflicting, confusing and over constraining ECS acquisition standards.

4. Software program details, costs and schedules frequently are not obliged in enough detail to be a basis for contractor selection. Rather, these software plans are often formulated only several months after contract award. This practice results in a deemphasis on software adequacy in contractor selection. Also, since funds are by then fixed, adequate software plans are frequently scaled back to meet funds available.

In the area of ECS concept validation, the Task Force found that a number of recent DoD programs had been able to clarify ECS requirements and reduce program risk significantly through the use of prototyping and competitive concept definition contracts. Use of these approaches was also strongly recommended in the ASD(C^3I) study[34].

In the area of ECS acquisition standards, a good deal of progress has been made by the Joint Logistics Commanders toward a consistent, up-to-date DoD-wide set of standards. However, the JLC activity's progress is hampered by its lack of funding and its heavy reliance on volunteer effort. The Task Force believes that standardization activity needs to be emphasized and provided with appropriate resources to do so. This would not be a large burden.

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[34] Final Report of the Software Acquisition and Development Working Group, July, 1980.

5.5.2 Recommendations

The following specific recommended additions to DoD Directive 5000.29 would cover the ECS concept validation and acquisition standards problems:

1. Paragraph D.3(g): "Prototyping and competitive concept definition contracts shall be major considerations in the acquisition process."

2. Paragraph D.11: "A consistent set of DoD-wide ECS acquisition specifications and standards shall be developed, emphasizing life-cycle planning, life-cycle supportability and recognition of hardware-software differences."

Some additional recommendations of the nature and development of the standards are:

1. Standards should specify functional objectives rather than development practices (e.g., "ensure configuration identification, control and status accounting by routine, version and release" rather than "use a program Support Library with the following Job Control language statements").

2. Standards should recognize the differences between hardware and software development (e.g., the differing role and nature of Critical Design Reviews).

3. Standards should provide for tailoring in situations where it is cost-effective (e.g., tailoring deliverable documentation requirements to planned support needs).

4. Responsibility for the standards effort should reside within OSD. Steps have recently been taken to improve this situation[35] The Task Force believes this is an important and necessary first step.

5. The defense acquisition process should reemphasize and monitor the incorporation of detailed software plans in system contractor selections.

---

[35] Embedded Computer Resources Standardization Area Plan, draft dated October 1981.

5.6 Management and Oversight of DoD's Computer Acquisition Process

5.6.1 Discussion

Much senior management, and not only within the Department of Defense, is clearly not comfortable about computers -- they are especially uncomfortable with software and its inherent problems. There is not a consistent approach across the OSD staff to the issues of automation. This may be due, in part, to the way the technology has been exploding and to the difficulty of hiring and retaining knowledgeable personnel in the face of the private sector demand for the same scarce personnel resources.

OSD has attempted to manage this ever-growing portion of its business through an ad hoc committee approach. The magnitude of the complex and interrelated issues to be resolved in this area have clearly outgrown this approach. We feel it is time to recognize the need for a meaningful approach which places responsibility in a line function.

During our deliberations, we came to the conclusion that a specific designation of the Under Secretary of Defense, Research and Engineering as Senior Policy Official for activities covered by the provisions of Section 908 of the FY1982 Defense Authorization Act, i.e., computer acquisitions "exempt" from the Brooks Act would be desirable. Further, we believe he must have the clear decision authority as to which process should be followed in any given case. That designation has been accomplished[36].

5.6.2 Findings

We believe that the importance of computers, or perhaps better put, the use of computers, has outgrown the committee management approach still being used at the OSD level.

OSD management and oversight is not at a high enough level to clearly signal the appropriate level of management concern to the Components and to assure the Congress and the Oversight Agencies that DoD has adequate control.

Programs of DoD-wide importance being conducted within the Components lack sufficient coordination at the OSD level to assure joint use of the results and products.

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[36] Deputy Secretary of Defense Memorandum, Acquisition of Automatic Data Processing (ADP) Equipment and Services, February 1, 1982.

5.6.3 Recommendations

The USDRE has been designated the Senior Policy Official for activities covered by P.L. 97-86 and since he has the responsibility for the Tech Base, he should develop an organizational approach which best meets the needs we and others have identified.

5.7 On the Implementation of P.L. 97-86

Section 908 of Public Law 97-86, the FY1982 Defense Authorization Act, provides an opportunity for DOD to acquire and manage the computer resources needed in defense systems both more efficiently and more effectively. At the same time, DoD must avoid serious management mistakes which would inevitably result in the reimposition of onerous controls. This discussion is intended to provide a framework of concepts and terms within which appropriate acquisition or procurement decisions about computer resources can be made.

Of all the computer resources within a given defense system, some will be mission-critical in the sense that successful performance of the intended mission will depend upon them daily. All mission-critical resources will be embedded in the sense that they are considered within the "boundary" of the system and immersed in its proper operational functioning. Of these, some will be directly involved operationally in the system mission-operational, but others will be mission-support in terms of providing (say) specialized forward or base-level maintenance and logistics. There may be other non-embedded computers which are also mission-support in the sense that they are concerned primarily with a given mission for (say) supply or rear-area maintenance. Outside every system will be a variety of general support systems providing standard logistical functions, financial management, personnel records and movement, etc.

The computer resources for general support are likely to be commercial-soft machines -- soft in the sense that they have been designed for installation and use in fixed, well-controlled physical environments and intended for general marketing by their vendors. The mission-support computers might well be commercial-soft, for example minicomputers incorporated in fixed-site, rear-echelon automatic test equipment, but they might also be commercial-military machines -- ones which are militarized versions of soft designs or are especially designed ones for a severe military environment. Examples would include automatic test equipment mounted in vans or shipboard, or van-mounted inventory and item-issue systems. Finally, mission-operational machines might be either commercial-soft (e.g., installed in forward-area vans or in aircraft) or they might be mission-specially-designed for a very particular purpose (e.g., a guidance computer in a missile). Not every system can be expected to have every category of computer resource, but the construct must allow for all possibilities.

The DoD has several options for obtaining computer resources:

1. Via the established procedures implementing Public Law 89-306, the Brooks Act, and heretofore referenced for data automation applications or as ADP resources;

2. Via the usual systems acquisition process in which prime, sub- or associate contractors make the decisions; or

3. Via procedures yet to be established which are wholly within the DoD and are in the spirit of the system acquisition process, but

would use the machine-selection methodology of data automation applications, but probably modified to acknowledge a mission-critical status.

A senior DoD official should be responsible for determining in each defense system (probably above some size threshold):

1. The boundary of the system to define what mission-critical computer resources are part of the system.

2. The interfaces between the system and other general support systems, and the support expected from the latter.

3. The status of each computer system within the boundary -- mission-support or mission-operational.

4. The appropriate means for obtaining each of the computer hardware and software resources.

Historically, some senior DoD official was thought of in a weapon-system context; but, given the proliferation of computers within systems which are not directly connected with weapons per se plus the responsibility now implied by P.L. 97-86, it would seem desirable that he should become the "senior official for defense systems."

In his deliberations about the computer resources of a given system, he would have to consider such collateral aspects as:

- Operational vs. support

- Mission-critical vs. mission-support

- Mission-support vs. general support

- Field vs. Depot maintenance

- Specialized vs. general logistic support

- Life-cycle support of software

- Forward vs. rear-area software support

He would also have the opportunity to identify other kinds of resources -- not presently regarded as computer resources but which really are -- such as:

- Specialized personnel

- Software development facilities for life-cycle support

- Other special facilities such as for forward-area hardware maintenance

- Specialized training requirements

These considerations are shown in Figure 5-1. The intent of the framework and procedure outlined above is two-fold:

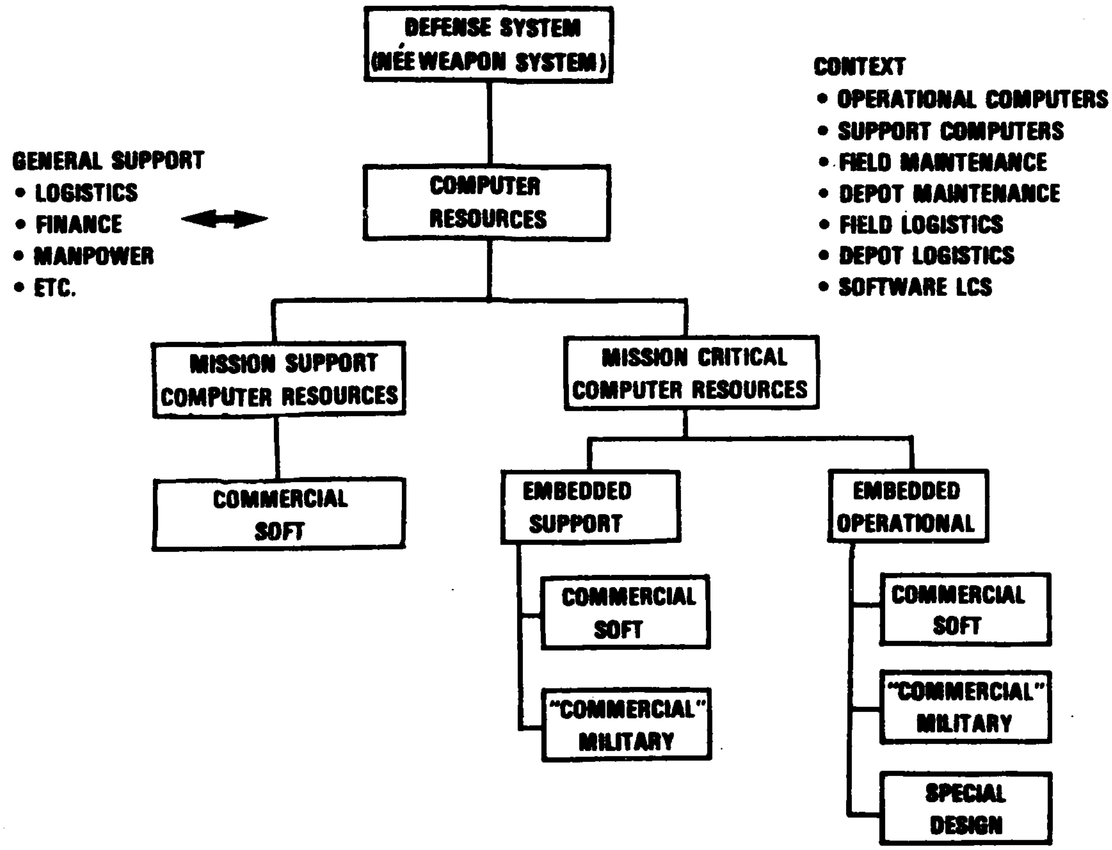

Figure 5-1: Acquisition Decision Tree

1. To provide a mechanism for deciding between P.L. 89-306 and P.L. 97-86 procedures for computer resources needed in each system.

2. To assure adequate front-end planning for <u>all</u> computer-resource aspects of defense systems.

There are a variety of possible implementations on which the Task Force does not take a position:

1. The Senior DoD Official could exercise the authority himself and, with his staff, issue the appropriate direction;

2. He could delegate, wholly or in part, to corresponding officials in the Military Departments or Defense Agencies for all decisions; or

3. He could require the Component advocating a given system to incorporate appropriate recommendations in its planning documents for his review.

Since commercial-soft computers can function as either an embedded or non-embedded mission-support role, it is important to note that the general process described above allows for obtaining them by whatever procedures are best for a given application in a given system.

This can mean that the same model computer -- and perhaps even precisely the same configuration -- could for one system be acquired under one set of procedures but for another system, under the other procedures.

Appendix A. TERMS OF REFERENCE

THE UNDER SECRETARY OF DEFENSE

WASHINGTON, D C 20301

RESEARCH AND ENGINEERING

20 August 1981

MEMORANDUM FOR THE CHAIRMAN, DEFENSE SCIENCE BOARD

SUBJECT: Defense Science Board Task Force on Embedded Computer Resources (ECR) Acquisition and Management

You are requested to organize and convene a Defense Science Board (DSB) Task Force to review, evaluate and make recommendations concerning the acquisition, management and utilization of digital computers and associated technology to support the military mission of the Department of Defense.

BACKGROUND

Practically every significant, modern defense system relies upon a digital computation element or subsystem for either its native operation, its integration into the tactical, strategic or C3I environment or for its support.

Traditionally, there have been problems in defense system software, at least as great as those faced by the commercial sector in their large-scale computer-based systems. These problems include schedule slip, cost overrun, and lack of acceptable performance of the delivered product. The lack of transportability of software has constrained system upgrades based upon the sheer magnitude of the sunk investment.

DoD management policy for embedded computers is contained, principally, in DoD Directive 5000.29, "Management of Computer Resources in Major Defense Systems." This Directive established a Management Steering Committee for Embedded Computer Resources (MSC-ECR) to improve the management of computer resources in major defense systems, and other purposes. Secondary policy issuances include DoD Instruction 5000.31, "Interim List of DoD Approved High Order Programming Languages (HOL)" and proposed DoD Instruction 5000.5X, "Instruction Set Architecture (ISA) Standardization Policy for Embedded Computers."

A study was recently conducted under the aegis of the Assistant Secretary of Defense (C3I) which concluded that all facets of the software development and acquisition process need varying degrees of improvement. The Senate Armed Services Committee included Language in the FY1982 Defense Authorization Bill which will clearly exclude the acquisition of digital equipment for intelligence activities, cryptologic activities, weapons and weapon systems, command and control of military forces, and in direct support of systems for these applications from Brooks Act (P.L. 89-306) provisions. There is also an extensive effort under the Joint Logistics Commanders' Joint Policy Coordinating Group for Computer Resource Management (JPCG-CRM) addressing the implementation of policy through specifications, standards, and other management tools. At least four industry associations--NSIA, ADPA, AFCEA and EIA--have ongoing studies. This review should provide recommendations to the DoD taking into account, to the extent possible, all the factors considered in the other studies.

SPECIFIC OBJECTIVES

Critical questions which the Task Force should address include:

1. Are the management policies enunciated in DoD Directive 5000.29, DoD Instruction 5000.31 and proposed DoD Instruction 5000.5x appropriate to the present? If not, how should they be modified for the upcoming generation of technology? What are the costs and benefits of these policies and to what extent can they be quantified? Is the implementation of these policies within the DoD Components adequate?

2. Are the key embedded computer programs of the Department--Ada, NEBULA, NECS, MIL-STD-1750--properly constituted and supported? What changes can and should be made to afford maximum benefits to the Department as a whole? To what extent should these programs and the policies of 1., above, be considered for near-term programs such as the WWMCCS upgrade?

3. Does the Management Steering Committee for Embedded Computer Resources serve a useful role? How could it be improved or is there a better mechanism to provide oversight and policy guidance? Are there other organizational issues of consequence and, if so, what recommendations can be advanced for improvement?

4. What is the effect of the Legislative and Regulatory Environment upon the ability of the Department of Defense to make adequate use of Digital Technology? Consideration should be given to Public Law, Defense Acquisition Regulations, Component regulations, business practices and appropriate policies, both central and local.

ORGANIZATION

The Task Force should begin its work as soon as possible and should deliver a final report not later than January 31, 1982. Interim reports should be submitted as issues are resolved to the satisfaction of the membership.

This Task Force will be sponsored by Mr. Robert F. Trimble, Acting Deputy Under Secretary of Defense (Acquisition Management). Mr. Thomas Crowley has agreed to serve as the Chairman. Mr. H. Mark Grove, Deputy Director, Embedded Computer Resources and Electronics Policy, OUSD(R&E)ECR, will be the Executive Secretary.

Appendix B. MEMBERSHIP OF THE TASK FORCE

Chairman	Present Position
Dr. Thomas H. Crowley	Executive Director, Computer Technology and Design Engineering, Bell Laboratories
Executive Secretary	
Mr. H. Mark Grove	Director, Embedded Computer Resources OUSDRE
DSB Liaison	
Col. Wayne B. Davis, USA	Defense Science Board, OUSDRE
Members	
Dr. Barry W. Boehm	TRW, Defense and Space Systems Group
Dr. James C. Fletcher	University of Pittsburgh
Mr. Joseph M. Fox	Chairman, Software Architecture and Engineering
Dr. George H. Heilmeier	Vice President, Corporate Research, Development and Engineering, Texas Instruments
Dr. Walter B. LaBerge	Assistant to the President Lockheed Missiles and Space Co.
Dr. Edith W. Martin	Executive Director, Atlanta Operations Control Data Corporation
Mr. Alan J. Roberts	Vice President, Strategic Systems Mitre Corporation
Dr. William R. Sutherland	Sutherland, Sproull and Associates
Dr. Willis H. Ware	Corporate Research Staff The RAND Corporation
Dr. John G. Weber[37]	TRW, Military Electronics Division

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[37] Now with VERAC, Inc., San Diego, CA.

Military Observers

LtGen Hillman Dickinson, USA	Director, C^3 Systems, OJCS
MGen Emmett Paige, Jr., USA	Commanding General, U.S.Army Electronics Research and Development Command
RAdm James R. Lewis[38], USN	Deputy Chief of Naval Material
MGen D. L. Evans, USAF	Joint Program Manager WWMCCS Information System

Assistants to the Task Force

Mr. Owen C. Holleran	Headquarters, Department of the Army
Mr. William R. Smith	Office of the Assistant Secretary of the Navy, RE&S
Maj David A. Herrelko, USAF	Headquarters, USAF
LCol John M. Selzer, USAF	OJCS, C^3 Systems

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[38] Deceased.

Appendix C. DEFINITIONS

The Instruction Set Architecture (ISA) of a computer is the set of instructions (e.g., add, store-into-memory) used to program a computer, augmented by other minimal information available to a programmer (e.g., interrupt capability).

Each computer has an ISA which is the logical basis for its physical structure.

An ISA may be implemented in many different ways since its specification is independent of hardware.

An alternative definition of Instruction Set Architecture is:

> "An ISA is the specification of the interface between software and hardware. It includes the attributes of a computer as may be seen by a machine [assembly] language programmer or the target code generator of a compiler for a high-order language (HOL). It describes the conceptual structure and functional behavior of a computer as distinct form the organization of the data flow and controls, logic design or physical implementation."

MIL-SPEC Computers are specially designed for the military environment. The performance required is delineated, usually, in a Military Specification (MIL-SPEC) or Military Standard (MIL-STD) which form an integral part of the contract for the acquisition of the specific materiel. MIL-SPEC equipment is generally not available "off-the-shelf" and must be designed and fabricated "to order" to meet a set of performance and/or environmental requirements, including the form factor of the equipment. Examples are space-borne equipment; airborne weapons-delivery, navigation or flight-control computers.

Embedded Computers are those computers incorporated as an integral part of, dedicated to, or required for the direct support of, or for the upgrading or modification of, major or less-than-major systems. Thus this term refers not only to those computing devices buried deeply within subsystems as radars, radios, missiles and the like but more generally to computers which are used to perform a portion of a larger task such as fire-control, automatic testing, navigation, and threat warning. The key discriminator is whether the application is computation alone or whether computation is merely a subtask to be performed as a part of a larger activity. In the industrial realm, "embedded" computers would be found managing process control in a steel mill or a chemical plant or as the automation element in an automobile. In a hospital or research laboratory, computers are embedded in CAT scanners, in scintillation counters, in gas chromatographs, in EKG or EEG equipment -- they perform specialized and dedicated tasks and are not, in general, available to support the general computational or data processing needs of the organization and hence are subject to a more specialized selection process than classical Automatic Data Processing Equipment (ADPE).

Embedded Computer Resources include the totality or resources required for the support and operation of "embedded computers." Thus, the term includes, but is not necessarily limited to:

- Computer Data
- Computer Hardware
- Computer Programs
- Documentation
- Personnel
- Supplies
- Services
- Training
- Software

    * Support Software
    * Utility Programs
    * Test Software
    * Operational (Applications) Software
    * Training Software

Tactical Computers are those used in the tactical, strategic, intelligence, cryptologic or command and control environments of military operations. Generally this would mean deployed equipment on ships, aircraft or with the fielded army or dedicated to the training and support of military personnel as a part of their military assignments as contrasted to the CONUS administrative support of the Department, the Services or the Agencies. The term is even less precise than "embedded" and, so, we prefer not to use it.

Ruggedized Computers are those which are specially designed and tested to ensure resistance to such environmental hazards as shock, vibration, humidity, sand, salt, temperature, operational and storage extremes, altitude and explosive hazards without the requirement for redesign or change of the computer itself. That is the protection is provided through shock mounting, enclosures such as transit cases, or other means to isolate a fundamentally commercial instrument from an environment it was not basically designed and produced to withstand. Some consider that a complete mechanical redesign holding the electrical design constant constitutes "ruggedized" equipment; however that would be the extreme case and would require different production lines and techniques so one is talking about a completely separate product in this case and the "learning curve" is broken, support requires differing parts and training, etc.

Commercially Available Computers are those available to the general public from the equivalent of a published catalog at preestablished prices and requiring essentially no design effort. Clearly, options may be required and adaption or configuration to the customers needs may be required but this tailoring should be a small portion of the final selling price. It would also be expected that the equipment would be supported by existing field service personnel and commercial logistics systems. This class would generally exclude "ruggedized" equipment although equipment for steel mills, chemical plants and petroleum fields may be both commercially available and ruggedized.

Commercially available computers are frequently delivered with software which may have application to common business, technical or educational needs. Software associated with MIL-SPEC, MIL-STD or special purpose computers designed for tactical, strategic, intelligence, cryptologic or command and control environments is generally unique to the special military application.

Mission Critical Computer Resources (MCCR) could include all of the above categories. The test here is the application and whether it is on the critical path to the fulfillment of the military mission of the Department, either defensive or offensive. The test is the application of the equipment and not its source. All computers and related equipment destined for the "excluded" applications of 10 U.S.C. 2315 are included in this general description, i.e., "...if the function, operation, or use of the equipment or services--

1. "involves intelligence activities;

2. "involves cryptologic activities related to national security;

3. "involves the command and control of military forces;

4. "involves equipment that is an integral part of a weapon or weapons system; or

5. "...is critical to the direct fulfillment of military or intelligence missions."

Not included in the fifth excluded application area is equipment and services "...for routine administrative and business applications..." Interim guidelines for acquisitions under 10 U.S.C. 2315 maintain this gray area under case-by-case oversight to assure that the legislative intent is preserved. The definition will be modified as we gain experience in this area.

Computers in Direct Support of Mission Critical Computer Resources may include all of the above described categories. More particularly, they are those computers which remain under exemption five when the ..."routine administrative and business applications including payroll, finance, logistics, and personnel management applications)" are excised. There are systems in these applications areas which fail the "routine" test as they are on the critical path toward the fulfillment of the "military mission." Automatic test equipment, deployable logistics systems such as the Combat Support System, NALCOMIS, Global Weather Service systems, the Satellite Control System, the NORAD system, Avionics Intermediate Shop equipment, and shipboard machinery monitoring systems are examples of this area of application.