AD-A126 641 A SURVEY OF COMPUTER RESOURCE UTILIZATION IN ESD (ELECTRONIC SYSTEMS DIVI..(U) MITRE CORP BEDFORD MA J A CLAPP FEB 83 MTR-8740 ESD-TR-82-406 1/1

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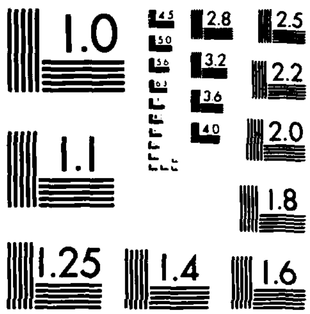

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ESD-TR-82-406 MTR-8740

A SURVEY OF COMPUTER RESOURCE UTILIZATION IN ESD WEAPON SYSTEM ACQUISITIONS

By
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FEBRUARY 1983

Prepared for

DEPUTY FOR TECHNICAL OPERATIONS AND PRODUCT ASSURANCE
ELECTRONIC SYSTEMS DIVISION
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
Hanscom Air Force Base, Massachusetts

Project No. 5220
Prepared by
THE MITRE CORPORATION
Bedford, Massachusetts
Contract No. F19628-82-C-0001

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REVIEW AND APPROVAL

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER ESD-TR-82-406	2. GOVT ACCESSION NO. AD-A126641	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) A SURVEY OF COMPUTER RESOURCE UTILIZATION IN ESD WEAPON SYSTEM ACQUISITION		5. TYPE OF REPORT & PERIOD COVERED
		6. PERFORMING ORG. REPORT NUMBER MTR-8740
7. AUTHOR(s) JUDITH A. CLAPP		8. CONTRACT OR GRANT NUMBER(s) F19628-82-C-0001
9. PERFORMING ORGANIZATION NAME AND ADDRESS The MITRE Corporation P. O. Box 208 Bedford, MA 01730		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project No. 5220
11. CONTROLLING OFFICE NAME AND ADDRESS Deputy for Technical Operations and Product Assurance Electronic Systems Division, AFSC Hanscom Air Force Base, MA 01731		12. REPORT DATE FEBRUARY 1983
		13. NUMBER OF PAGES 23
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

HOL STANDARDIZATION
SOFTWARE DEVELOPMENT
SOFTWARE ACQUISITION
COMPUTER RESOURCE ACQUISITION
ISA STANDARDS

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

As a part of AFSC's High Level Standardization Plan, the Computer Resource Management Technology Program ~~(PE 64740F)~~ sponsored a survey of embedded computer system acquisitions at ESD in June 1981. The purpose of the survey was to determine the impact on ESD programs of proposed military standards for computer Instruction Set Architectures and standards for programming languages. The survey shows a proliferation of computer tapes among ESD programs but uniformity in choice of high order programming language. Other data about the

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

20. Abstract (concluded)

practices in procurement of computer resources are also presented.

ACKNOWLEDGMENT

The survey was conducted by Len LaPadula who was assisted by Laura Anderson. A preliminary version of the results was published with the help of Tom Connors. Marilyn Pyne tabulated much of the data presented in this report. The work was performed as a part of Air Force Program Element 64740F, Computer Resource Management Technology under the direction of ESD/TOEE. William Letendre is the Project Officer.

This report has been prepared by the MITRE Corporation under Project No. 5220. The contract is sponsored by the Electronic Systems Division, Air Force Systems Command, Hanscom Air Force Base, Massachusetts.

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SECTION 1

INTRODUCTION

As part of Air Force System Command's High Level Standardization Plan, in June 1981 MITRE conducted a survey of ongoing and upcoming embedded computer system acquisitions at ESD. The survey was funded by Program Element 64740F, Computer Resource Management Technology. The purpose of the survey was to determine the impact on ESD programs of impending military standards defining computer Instruction Set Architectures and of policies mandating their use. At the same time the questionnaire requested information which might show the impact of a prior standard and policy for the JOVIAL programming language and a more recent standard and proposed policy for the use of the Ada programming language.

The responses to the questionnaires do not, in themselves, provide detailed information about use of computer resources in ESD programs. It was not possible to carry out interviews to expand on and to validate the responses. Consequently, the following analysis should be used to indicate general practices at ESD. Although the numbers given are not completely accurate, they do allow some observations to be made which may be useful in shaping policy or in planning future in-depth studies.

BACKGROUND

Within the Air Force and across DoD there is a movement to introduce standards for the acquisition of computer resources for embedded computer systems. These standards would specify the allowable choices of programming language and Instruction Set Architecture (ISA). A MIL-STANDARD would define the language or ISA and a policy would indicate the conditions under which the language or ISA must be used. Four such standards are currently in existence, and the accompanying policy documents are issued or in draft form. The standards define two Instruction Set Architectures, developed by the Air Force and by the Army respectively. The language standards are for JOVIAL, developed by the Air Force, and Ada*, developed on a DoD-wide basis.

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*Ada is a registered trademark of the U.S. Department of Defense.

An Instruction Set Architecture for a computer defines its behavior from the point of view of a machine language programmer. The set of instructions, their format, and the interrupt structure are included, but the ISA does not define execution speed, internal organization and the technology which is used to manufacture it. In other words, two computers have the same ISA if the same software will run on each and produce the same results, except for timing. The computers may differ in size, weight, and internal components. Standardization at the ISA level is intended to allow compatibility among computers without freezing the technology used to construct them.

The Air Force intends to use a single standard ISA for 16-bit computers and another standard ISA for 32-bit computers in embedded computer systems. The advantages of these restrictions include the reuse of support and operational software among computers with the same ISA; upgrade of hardware for a system without replacement of software; lower per unit cost because of competitive sources to produce equivalent computers; and lower logistics, maintenance, and training costs. The two MIL-STANDARDS for ISAs are MIL-STD-1750A which defines a 16-bit computer ISA now used in Air Force avionics applications, and MIL-STD-1862A which defines a 32-bit architecture called NEBULA, which has been under development by the Army with Air Force participation. NEBULA defines a family of computers ranging from a minicomputer to a singleboard machine. The NEBULA architecture was widely reviewed by military, academic, and industry representatives. The architecture was frozen in late 1981. Initial implementations will undergo evaluation in 1983. Production of NEBULA computers for the Army is not scheduled until 1986. A draft policy, DODI 5000.5X, "Instruction Set Architecture (ISA) Standardization Policy for Embedded Computers", which would mandate the use of these standards, has not been approved due to both government and industry concerns about its effect on competition.

There are also two standards with respect to High Order Programming languages (HOLs). The first is MIL-STD 1589B which defines the JOVIAL J73 language. The second is MIL-STD 1815 which defines the Ada programming language. For both languages, there are organizations which control changes to the language. There are a number of policies which govern the use of programming languages. At the DoD level, DoDD 5000.29, issued in 1975, mandated the use of HOLs instead of assembly language in weapon systems in order to reduce life cycle costs. DoDI 5000.31, issued in 1976, specified an interim list of approved HOLs which might be used for embedded computer systems. The Air Force has long had a policy for use of JOVIAL, in its various dialects. The Ada programming language is the outcome of a DoD effort to select or develop a single HOL for all DoD applications. The language Ada has been defined through a series of stages in which there was broad participation and review by government, industry, and academia on an international level. Along with the Ada language is a programming environment containing tools for compiling, testing, debugging, documenting, and maintaining Ada programs. The Ada Programming Support Environment (APSE) is undergoing an initial implementation as the Ada Language System, under Army sponsorship. Delivery of the initial system is scheduled for early 1983. The Air Force is also sponsoring an implementation of the APSE called the Ada Integrated Environment (AIE), which will support primarily the coding and maintenance phases initially. Application of Ada for an operational capability in an embedded computer system is expected in 1985. The current Air Force policy directs J73 for avionics and air launched missile applications with Ada to be the standard for all embedded computer systems when it is ready.

SECTION 2

RESULTS OF THE SURVEY

Selected data from the responses to the questionnaire have been summarized. Results have been grouped to give a picture of the kinds of programs which are represented, general impressions about the results, specific data about hardware selection, and then specific data about software selection. Not all of the information requested by the questionnaire was supplied on each response, so many of the results below are based on the subset of responses that supplied the specific information.

For purposes of this survey, it is useful to analyze the characteristics of major subsystems as well as systems. These subsystems are often distinctive in function, in phase of acquisition, and in choice of computer resources. Hence, they represent decision points at which standard computer resources can be or might have been considered. Most of the statistics and other observations in this paper will be based on subsystems, or systems for those programs which have no subsystems. The latter will also be referred to as "subsystems" for convenience.

ESD PROGRAMS IN THE SURVEY

A total of forty-eight responses were received, representing information about thirty ESD programs. Tables 1, 2, and 3 summarize their characteristics. The programs responding ranged from large C3 programs, consisting of many subsystems using different computers, to systems buying many copies of a single device, such as a radio, within which there is a microprocessor or computer. There are airborne, mobile tactical, strategic, space, and ground-based systems represented. While the largest category of mission area designated for the systems was C3, a wide diversity of other mission areas is represented. Among these are surveillance, navigation and control, and simulation and training. Three-fourths of the programs were described as "new developments" rather than upgrades. Ninety percent of the programs plan for or use organic maintenance support.

About 65% of the subsystems in the survey were in phases of their life cycle prior to production or deployment. About 42% of these subsystems, or 28% of the total set responding, had not yet decided on the computers to be used in Full Scale Engineering Development. This amounts to twelve pending decisions when the survey was made about a year ago. This is a rough indicator of the number of ESD programs in a position to adopt new standards in the next several years. The estimated number of systems to be procured by these twelve programs is at least 340.

GENERAL IMPRESSIONS

The survey results deal with practices used by ESD Program Offices in selecting computer hardware and software. In general, these practices indicate that both standard Instruction Set Architectures and High Order Language standardization can be beneficial to ESD programs. Although there is little commonality in the selection of computer hardware for ESD acquisitions, there is a surprisingly large amount of commonality in the choice of programming language. There are several possible explanations. The technology for hardware has been improving much more rapidly than that for programming languages. Each time a computer is selected for a program, the choices of available hardware are probably different, whereas the most popular high order programming language (HOL) among ESD subsystems has been Fortran, one of the oldest HOLs still in use. The choice of programming language appears to be based less on capability than on the availability of a compiler. The commonality of programming language in the absence of common computer hardware may also indicate that the need for a common computer architecture is mitigated by a common programming language, which can serve as the primary interface for programmers to a computer provided assembly language is not used. The language can then mask ISA differences among computers as long as compilers are available. The survey indicated a need for a complete set of support software by most programs but there is no record to show if this requirement was met.

HARDWARE SELECTION

A 1980 GAO study cited the proliferation of different kinds of computers, and stated: "Most of these computers were acquired on a project-by-project basis in which military project officers and contractors were given the flexibility to independently select the computers for their particular tactical systems." (1) This contention is borne out by the results of the survey, as shown in Tables 4 and 5. Over 50 different computer types have been selected

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(1) "The Department of Defense's Standardization Program for Military Computers - A More Unified Effort Is Needed", General Accounting Office, LCD-80-69, June 1980.

by programs which responded. Of these, only 10% are used in more than one system, so there is very little commonality of computer type among systems in the survey, although in some cases there are computers which are members of a family of software-compatible computers. The maximum commonality among subsystems is one computer type which is used in three subsystems of the same large program.

In addition to showing the lack of commonality among programs in choice of computer type, the survey shows greater commonality of computer types within a single program or subsystem of a program. These results are summarized in Table 5. For those programs which had made a computer selection, about half have only one type of computer. At the subsystem level, about 74% use only one kind of computer.

The survey also supports the GAO claim that the choice of computer was often made by the contractor. There are indicators in the data that those choices might be consistent with policies requiring the use of standard ISAs, if such policies had existed. Most of the computers are commercially available, or have military equivalents; very few are special purpose. About 17% have military nomenclature, indicating that they are equivalent to military standards. Among the two most frequent reasons given for the selection of the computers were availability off-the-shelf, and compatibility with previously selected computers in the same or other systems with which a system must be interoperable (see Table 6). A policy on standard ISAs can provide greater compatibility among systems and for upgrades within systems. The implementation of that policy should also ensure the availability of computers if it is to succeed.

A strong motivation for the Army's support of a standard Military Computer Family has been the reduction of logistics support costs. While there is little data in the survey results to show logistics support costs, the survey asked about the number of systems to be procured, and the number of each type of computer per system. The responses seem to be inconsistent in assigning values to each answer, as there may be one system with many computers or many systems with one computer each, when they ought to be equivalent. Furthermore, the number of systems was specified in ranges, as shown in Tables 7 and 8. Therefore, it is not possible to calculate the number of units of each computer being procured. Over half the programs were buying ten or fewer systems, while 96% of the systems have 10 or fewer computers. More than half the systems have only one computer. The largest number of units being purchased for a system was 3,000, followed by 800 for the next largest. For this sample, one might conclude that ESD usually buys a small number of computers per program or subsystem. If this is the case, it may not continue to be true as systems become distributed, with collections of computers performing functions previously executed in a single computer.

The information from the survey was not complete enough to examine commonality in functional or performance characteristics of the computers selected. However, it is possible to distinguish computers by word length. Since proposed ISA standards provide for a 16-bit and a 32-bit computer, ESD programs can be compared with this aspect of the standards. Table 9 shows that 85% of the computer types selected are either 16-bit or 32-bit; about 62% were 16-bit and about 23% were 32-bit. The other choices ranged from 8 bits to 54 bits. There did not seem to be any division of word length choices by application area or based on environmental requirements such as mobility or weight. It appears likely that ESD program requirements could be met with the two proposed standard word lengths, with the possible exception of 8-bit microprocessors for some embedded applications.

SOFTWARE SELECTION

When the DoD High Order Language standardization program was formulated in 1975, it was stated that most embedded computer system software was being written in assembly language, and where a HOL was used, very large portions were still written in assembly language because high order languages were inadequate. In many ways, the results of the survey for ESD programs contradict these claims, as shown in Tables 10 and 11. Perhaps the passage of time since 1975 has changed awareness of the importance of using HOLs, and the issuance of Air Force and DoD policies requiring HOLs has also affected the results. The information in the survey does not show when the language decisions were made, so it is not possible to assert that there is a trend toward greater use of HOLs. What the survey does show is that only one-third of the systems use assembly language exclusively. The remainder are almost equally divided between a mix of HOL and assembly language within a subsystem (possibly on different machines) and exclusively HOL. Only nine different HOLs are represented, five of which are approved interim languages in DoDI 5000.31. Over half the systems or subsystems use one of these interim languages. Fortran is the de facto HOL standard, used in almost every system or subsystem which uses a HOL. Where HOL and assembly language are both used, the amount of assembly language is surprisingly small, as shown in Table 12. In half the subsystems for which data were provided, less than 10% assembly language was used in combination with HOL.

With any policy mandating use of a specific HOL, one can expect waivers. The questionnaire asked whether JOVIAL J73 was required. Table 13 shows the responses. Three fourths of the answers indicated that J73 was not required. It is not clear whether language decisions antedate the requirement, or some other criterion was used. Of those responses which said J73 was required, only 25% had not sought a waiver. However, only 30% of the waivers granted were for use of assembly language. The other 70% all chose Fortran instead of JOVIAL. The reasons for waivers were not provided in the survey, but general reasons for language selection were selected from a list in the questionnaire, as shown in Table 14. The most frequent reason, given by 60% of the systems, was the availability (or lack) of a compiler. The choice of assembly language as well as the choice of Fortran were justified by compiler availability. As in the case of hardware standardization, it appears that successful adoption of a HOL standardization policy will depend on its causing compilers to be available. Other popular reasons for language selection, cited by about half the responses, were "suitability to application" and "standard language", which are compatible with the objectives of the Ada and JOVIAL standardization efforts. The reasons for choice of assembly language most often included "processing requirements" and "hardware selection" which might be interpreted to mean the real-time performance requirements of an application dictated the choice of computer, and the unavailability of a compiler or the assumed inefficiency of compiler-generated code then dictated the use of assembly language.

It is interesting to note the least frequently chosen reason for selection of a programming language as well as the most frequently chosen reason. In this survey, less than 10% of the responses indicated "maintainability/reliability" as a reason. One can only conjecture that decisions made by the developing organization at the front end of the system life cycle tend to favor minimizing startup costs and delays caused by compiler availability, rather than later costs associated with system operation and maintenance. In fact, the operation and maintenance of the system are usually the responsibility of a different organization than the one which makes the language selection. In this survey, this is confirmed by the frequent choice of language by the developing contractor, while the overwhelming number of systems plan for or use organic maintenance.

CONCLUSIONS

Before imposing new standards for hardware and software acquisition, it is desirable to determine what will be the impact on future programs. This impact can be felt as technical improvements or deficiencies caused by the standards. The impact can also be affected by the reaction of Program Offices and the ways in which they change their acquisition practices or continue to seek waivers.

The responses to the survey do not provide definitive answers to questions about impact. They are useful in showing what happens when there are no standards imposed for hardware. Proliferation of computer types has indeed resulted across programs, although the number of computer types within a program is small. There do not seem to be any serious technical impediments to adopting standard ISAs. The logistics savings may not be very large if the number of units purchased is small, which has been the case in the past. With the increased use of distributed architectures, that may change.

The issue of ISA standardization should not be considered independently of language standardization. The survey indicates a desire for commonality of HOL across programs. The use of a standard HOL is also preferred. The choice of HOL is dictated by the availability of the compiler. This would indicate that compilers must be available whether or not ISAs are mandated, or waivers will undoubtedly be sought as they have been for JOVIAL. The survey demonstrates that the issue of HOL versus assembly language is dying out with the acceptance of HOLs. A return to assembly language would probably occur if the compiled code for Ada is too inefficient to meet performance requirements. Reusability of software is not yet a major consideration in language selection.

Table 1

ESD Programs in the Survey

o Number of Programs Responding	30
o Number of Subsystems	48
o % of Subsystems in Pre-Production Phases	~ 65%
o % of Pre-Production Subsystems which have not selected a computer	~ 42%
o % of subsystems which are new developments (vs upgrades)	~ 74%

Table 2

Distribution of Programs by Mission Area

C^3	28%
Communication	17%
Surveillance and Warning	14%
Intelligence	11%
Navigation	10%
Control Radar	7%
Simulation and Training	7%
Weapon	3%
Telemetry	3%

Table 3

Program Maintenance Concept

Maintenance Support	% of Programs
Organic	74%
Organic and Contractor	16%
Contractor, then Organic	8%
Contractor	2%

Table 4

Commonality of Computer Types Among Programs

Number of Computer Types	~ 50
% of Computer Types Used in More than 1 Subsystem	10%

Table 5

Commonality of Computer Types Within Programs and Subsystems

Number of Computer Types Per Program/Subsystem	% of Programs (approximate)	% of Subsystems (approximate)
1	50%	73.7%
2	9.1%	10.5%
3	18.2%	5.3%
4	13.6%	5.3%
5	4.5%	5.3%
6	___	___
7	4.5%	___

Table 6

Major Reasons for Hardware Selection

Reason	% of Responses*
Service Selected	9%
Contractor Selected	29%
Available Off-the-Shelf	32%
Compatibility	21%

*Responders were asked to fill in reasons. Answers are not well defined.

Table 7

Number of Systems to be Procured

Number	% of Responses
1	16%
2-5	29%
6-10	10%
11-100	39%
101-1,000	4%
1,001-10,000	2%

Table 8

Quantity of Computers per System*

Quantity	% of Systems
1	55%
2	23%
3-10	18%
11-100	2%
101-1,000	2%

*Quantities are for one type of computer

Table 9

Distribution of Computer Types by Word Length

Word Length (bits)	%
16	62%
32	23%
36	5%
18	4%
8	4%
54	2%

Table 10

Use of HOL and Assembly Language

Type of Language	% of Subsystems
Assembly Language Only	~ 34%
HOL Only	~ 28%
HOL and Assembly	~ 38%

Table 11

Choice of High Order Language

Language	% of Subsystems
Approved Standard*	53%
FORTRAN	48% [98% of Subsystems using HOL]

*According to DODI 5000.31

Table 12

Percent of Assembly Language Used with HOL

Percent Assembly Code	% of Subsystems with ASM and HOL**
1	9%
5	18%
10	28%
20	9%
30	18%
90	9%
95	9%

**A small sample provided data

Table 13

JOVIAL Language Requirement

J73 Requirement not applicable	**75% of Programs**
% of Programs which received a Waiver	**~ 20%**
% of Waivers which selected FORTRAN	**70%**
% of Waivers which selected Assembly	**30%**

Table 14

Reasons for Language Selection

Reason for Language Selection	% of Subsystems
AVAILABILITY/LACK OF COMPILER	61
SUITABILITY FOR APPLICATION	55
STANDARD LANGUAGE	49
PROCESSING REQUIREMENTS	39
HARDWARE SELECTION	39
OFF-THE-SHELF APPROACH	36
USER EXPERIENCE	33
OVERALL SYSTEM DESIGN	27
PROGRAMMER TRAINING	21
SOFTWARE TRANSPORTABILITY	21
SOFTWARE ENGINEERING SUPPORT & ENVIRONMENT	21
COMPATIBILITY/REUSABILITY WITH EXISTING SOFTWARE	15
MAINTAINABILITY/RELIABILITY	9

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