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Navy Computer Accreditation Study

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Navy Computer Accreditation Study

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LIST OF ACRONYMS

ARINC	-	Aeronautical Radio Incorporated
BITE	-	Built In Test Equipment
CPU	-	Central Processing Unit
ECP	-	Engineering Change Proposal
EDM	-	Engineering Development Model
F^3	-	Form, Fit, and Function
HOL	-	High Order Language
ILS	-	Integrated Logistics Support
I/O	-	Input/Output
IROR	-	Internal Rate of Return
ISA	-	Instruction Set Architecture
KOPS	-	Kilo Operations per Second
LCC	-	Life Cycle Cost
LSI	-	Large Scale Integration
MSI	-	Medium Scale Integration
MTBF	-	Mean Time Between Failure
NECS	-	Navy Embedded Computer System
NRSU	-	Non-Recurring Start Up
O&M	-	Operation and Maintenance
O&S	-	Operation and Support
PC	-	Production Control
PLA	-	Programmable Logic Array
PMS	-	Program Manager, Sea
RAM	-	Random Access Memory
RIW	-	Reliability Improvement Warranty
ROI	-	Return on Investment
SSI	-	Small Scale Integration
TTL	-	Transistor - Transistor Logic
ULA	-	Unit Logic Array
VHSIC	-	Very High Speed Integrated Circuit
VLSI	-	Very Large Scale Integration
WRA	-	Weapons Replaceable Assembly

Section 1
INTRODUCTION

This report documents "The Navy Computer Accreditation Study" performed by the IBM Federal Systems Division for the Assistant Secretary of the Navy, Office of Naval Research, under Contract N00014-79-C-0986. IBM would like to thank Mr. W.R. Smith (Scientific Officer, Assistant Secretary of the Navy, Office of Naval Research), Messrs. D. Barry and P. Mankofsky (Naval Underwater Systems Command, NUSC/3551), and the two Navy review teams, whose comments and support data provided guidance for this study.

This study was initiated by the U.S. Navy in recognition that an examination should be performed of shipboard computer acquisition policies to meet future Navy needs and priorities as well as reflect the anticipated "environment" (technology, LCC, business costs, etc.) It should be noted that just the estimated initial acquisition costs for shipboard computers will be almost $1 billion over the next 10 years, thus emphasizing the importance of future effective acquisition policies.

The primary objectives of this study was for IBM to:

- Examine accreditation concept candidates
- Define a meaningful policy and management framework for future Navy needs
- Provide, where possible, specific details to put into the policy/management structure
- Support the proposed accreditation approach with rationale and analysis.

With these "objectives" in mind, IBM proceeded to develop a study methodology which could best examine the concept of accreditation.

1.1 THE ACCREDITATION CONCEPT

IBM's early analysis indicated that many variations of the accreditation concept existed, that these concepts were sensitive to priorities at hand (e.g., operational readiness, recruitment problems, cost, etc.), and, finally, that it was not reasonable to expect a precise definition of accreditation as it is still evolving and the study would further that end.

As a departure point for the study, it was established that accreditation is

> "A set of future Shipboard computer acquisition policies and practices that will allow the U.S. Navy to

- Most effectively utilize advancing technologies
- Be responsive to operational readiness needs and weapon system requirements
- Be sensitive to ever increasing cost of ownership and manpower availability

- Provide adequate opportunities for industry competition with attractive market definition."

In other words, one can view accreditation as the next evolution of Navy acquisition policies deemed most effective and acceptable.

1.2 THE ACCREDITATION/STANDARDIZATION RELATIONSHIP

The benefits of standardization are well-known. Standardization of computers enables the DoD to effectively manage the proliferation of numerous computer hardware architectures/types, thereby providing

- Management of software proliferation, which is a significant cost contribution in the development and maintenance of systems
- Utilization of common support software tools and minimization of retraining of programmers
- Common logistics support (critical in shipboard applications), enabling lower O&M costs, maintenance training requirements, common test equipment, and a manageable spares situation
- Minimization of risk to the weapon system developer because of known, tested, and supported hardware
- Opportunity to procure on a large commodity basis, providing production cost leverage.

However, there can be come significant disadvantages to "rigid standardization", such as

- Inability to take advantage of advanced technology, which precludes the benefits of lower cost and more reliable and testable hardware
- Lack of competition, which can inhibit potential innovations and system alternatives that would provide the DoD with either a better product or lower production cost.

There are also "degrees of standardization", which range from identical hardware from a single source for an extended period; to standardized ISAs with hardware procured to the ISA on a form, fit, and function basis; to numerous "approved" "off-the-shelf computer standards", from which Navy Program managers pick and choose. Examples of standardization programs currently in DoD are summarized and compared in Table 1-1. Note that each standardization program is geared to each service's priorities and weapon development situation. This is a reasonable approach to standardization.

There is also another dimension to standardization: that of a higher-order language (HOL) standard. Given that all operational/applications software were written at the HOL level, and it was a matter of compiling toward a target machine, that might be a factor in determining the rigidity of the "computer hardware standards policy." IBM's study of accreditation, however, did not address this, on the basis of an initial study groundrule exempting software considerations.

Table 1-1. Current DoD-Service Standardization Approaches

Specified Standard	Principal Objective	Comments	Reduced Software Development Cost	Lower Hardware Acquisition Costs via Competition	Lower Hardware Logistics Cost	Ease of Technology Insertion	Investment Incentive
Air Force - 1750 ISA & J-73 HOL	Software cost; technology insertion, hardware costs	Box-dependent speed, timing. (F^3) procured by platform (Multiple suppliers)	++ Standard ISA	+	- Only by platform	+ (No serious constraints)	+ (Frequent recompetition possible. Large potential volume)
Navy UYK-7/20 hardware & CMS-2 HOL	LCC reliability & maintainability, Software cost reduction	Rarely second sourced. Minimal technology evolution. (Standard ISA by history)	++ Standard ISA	- (+W/dual source)	+ (Fewer module types)	(Sunk cost slows technology insertion)	+ (Limited recompetition. Large volumes.)
Army-MCF Nebula ISA & ADA HOL	ADP survivability, LCC maintainability reliability	Box F^3, winner take all production, standard ISA	++ Standard ISA	+	+	+ (No serious constraints)	+ (Multiple developments, large production commitment)

Accreditation, as determined by this study, is a concept which embodies the benefits of standardization, addresses some of the potential disadvantages of too repressive a standardization concept, and provides a policy framework which permits more flexibility through

- More frequent but timely redevelopment
- Standardization of ISAs, but hardware development at the F^3 level
- Goverment-funded development that will enable "competition" without undue financial risk to industry as well as undue sensitivity to market projection inaccuracies
- Consolidated procurement to more effectively take advantage of quantity leverage, provide a focal point for computer procurement policy as a function of an evolving environment, and provide centralization of government cost
- Periodic concept formulation studies to revalidate or revise the accreditation framework.

1.3 STUDY REPORT CONTENTS

To provide a further characterization of the accreditation concept, Section 2 discusses acquisition scenario considerations and key issues that must be considered in the formulation of an accreditation concept. The study methodology is organized to address these key factors.

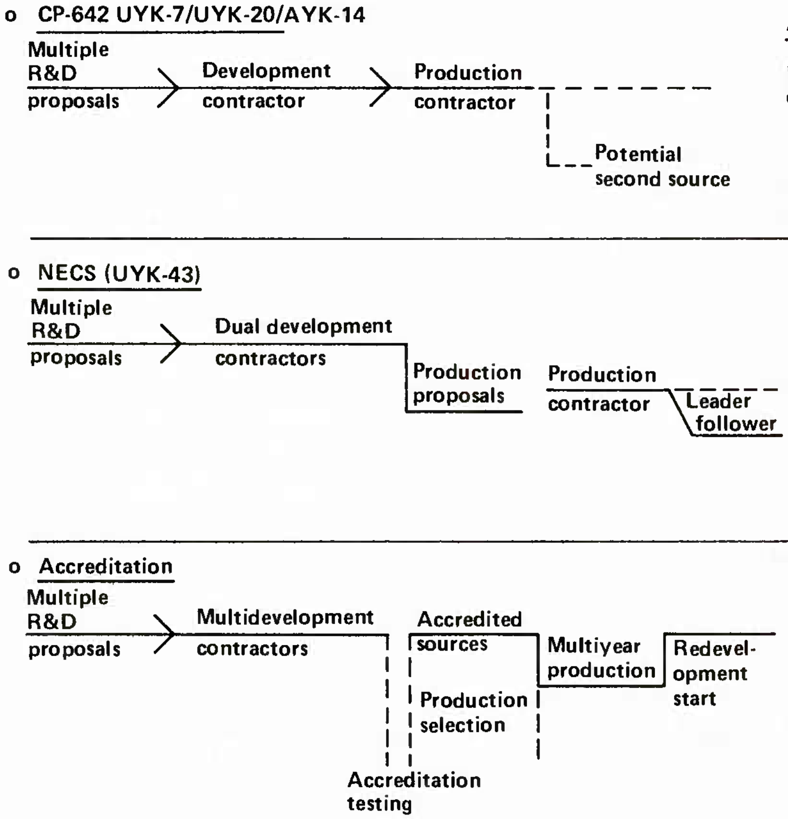
Section 3 examines technology trends and defines cost/performance and reliability rates of improvements. These rates of improvement are then used as data for input to the Life Cycle Cost analysis of Section 4. The market size, defined in Section 4, coupled with the spares data resulting from the Life Cycle Cost model, are used by the profitability analysis in Section 5.

Section 6 discusses computer acquisition strategies. Section 7 is a collection of additional issues, and discusses the level of standardization (build-to-print vs. form, fit, and function), the architecture certification process, and the relevance of commercial developments. Finally, Section 8 summarizes the results, and Section 9 summarizes the future recommendations of the Accreditation Study.

CURRENT NAVY POLICIES

The Navy was the first service to exploit the aspect of computer standardization out of the practical aspect of common hardware and software on multiple ship platforms. The Navy's Acquisition policies for shipboard computers is an evolving one, as characterized and analyzed in Figure 2-1. Whereas the CP-642, AN/UYK-7, AN/UYK-20, and AN/AYK-14 computers were single-source development and production items with the described disadvantages and advantages of such an approach, the upcoming NECS procurement is characterized by dual development and anticipated leader/follower production competition.

A potential step beyond this in future procurements might be the accreditation concept, characterized by multiple developments, optimized production sources, and then another redevelopment placing emphasis on F^3 to allow for integration of advanced technology. There are many variations of this postulated concept of accreditation that also solicit questions and identify factors to be considered; these are discussed in the following subsections.



	Advantages	Disadvantages
CP-642 UYK-7/UYK-20/AYK-14	Minimum government development cost o Procurement o Supplier Interface Minimum logistics support	Limited control production costs o Single supplier o Technical immobility
NECS (UYK-43)	Development alternatives Parallel competition throughout development Minimum logistics cost	Development affordability Technology insertion versus redevelopment Follower NRSU Production reprocurement to preferred source only
Accreditation	Multiple development approaches Maximizes competition Reduced production costs Technical innovation promoted Redevelopment for LCC and technical infusion	Development affordability Logistic cost analysis required Definition of management structure difficult

Figure 2-1. Evolution of Acquisition Strategies

2.1 ACCREDITATION SCENARIO CONSIDERATIONS

To effectively establish a framework for accreditation, it was necessary to postulate the key elements/participants in such a concept and then analyze the interrelationships between these key elements to determine what issues in accreditation the study should focus on and integrate into its methodology.

The key concept elements/participants were considered first as depicted in Figure 2-2:

- Weapon systems developer(s)
- Platform managers
- Computer development manager(s)
- Procurement manager
- Certification facility
- Industry computer sources.

Consider the potential relationships between each of these key elements which begin to formulate the framework for accreditation and which lead to these "factors" which must be defined to solidify this framework. One can begin by asking some questions in terms of what role these key players have in the accreditation process:

- How are the industry computer sources selected?
  - Competition?
  - Off-the-shelf products?
  - Other?
- What is the role of the Weapon System developer?
  - Computer developer?
  - Requirements generation?
  - Integration?
  - Funding source?
- How are platform managers involved?
  - Integration?
  - Logistics commonality?
  - Weapon system validator?
- How are computers developed and by whom?
  - Government funded?
  - Certification process?
  - Industry products?
- Should computers be procured via a "centralized" commodity manager concept?

Given the roles of the key players, we must evaluate the Accreditation Scenario Alternatives to identify key factors that can be integrated into the accreditation framework. In other words, the identification of key factors which will structure the study methodology must be derived

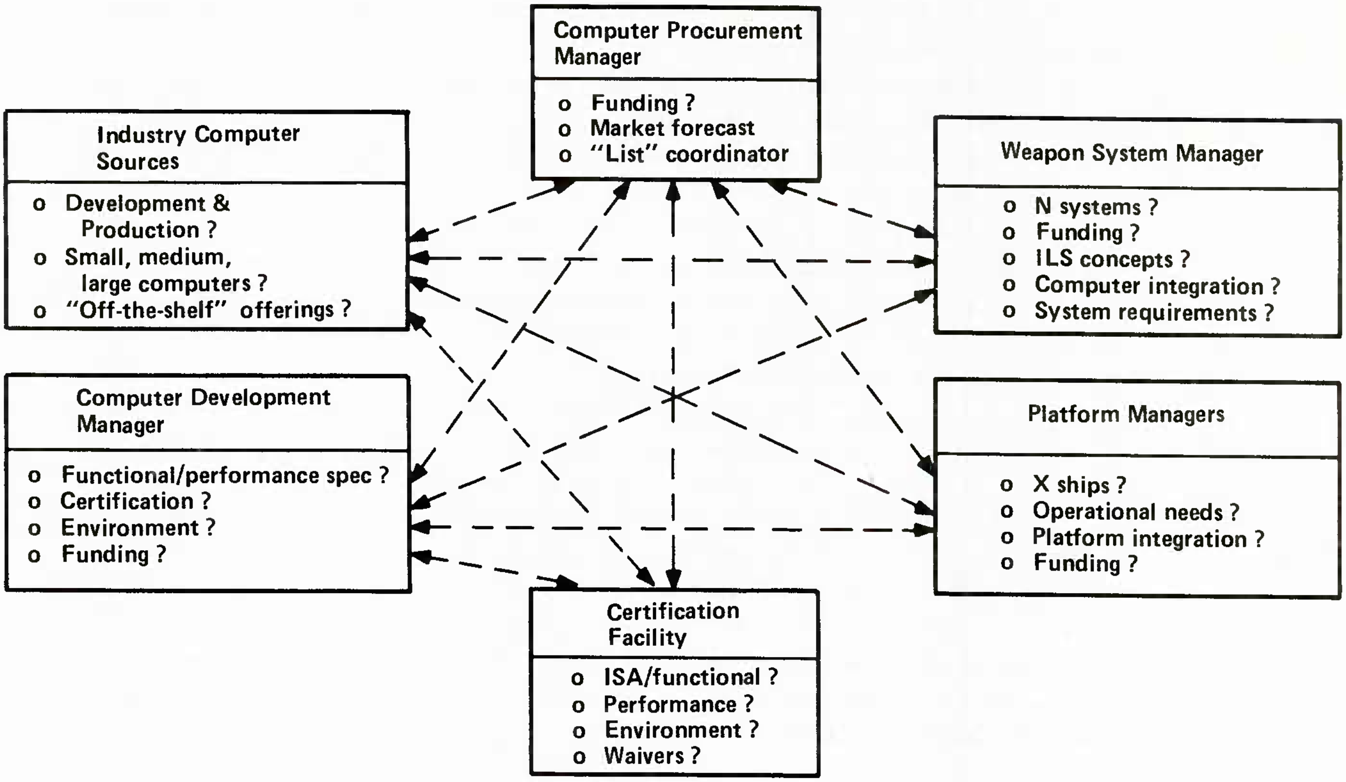


Figure 2-2. Accreditation Participants

by examining candidate accreditation scenarios. The following are examples of what were potential considerations:

- Scenario considerations - Proposition A
  - — The Navy lets multiple development contracts through a development manager/office.
  - — X developers qualify for EDM phase to compete for production.
  - — Other developers may, on their own, submit their computers for Navy evaluation.
  - — All developers certify their hardware to an ISA standard and MIL-SPEC requirements.
  - — A procurement manager compiles all weapon system managers' computer requirements.
  - — The platform manager inputs the logistics considerations to the procurement manager.
  - — A single producer is chosen for production, with potential second source options.
  - — This now becomes the standard until the next development cycle.

- Scenario considerations - Proposition B
  - — A Navy development office releases a "general" set of requirements, intended applications, projected market size.
  - — A certification process is established to ensure that the "general requirements" are met.
  - — Industry computer sources review requirements and submit their candidates for certification.
  - — X producers are certified by the Navy, and a "list" is formulated for the procurement manager.
  - — The list is frozen for X years and then reopened for new candidates; no "exception process" is provided.
  - — Weapon system and platform managers review the "list", select a producer's computer that best fills their needs, then fund and procure the computers themselves.
  - — Where possible and on a timely basis, the procurement manager would try to consolidate computer buys for PMSs and PARMs.
  - — After X years, the total process is repeated.

The eventual solidification of an accreditation process and policy will probably consist of elements described in examples of both scenario propositions, and other considerations. The examples were not meant to be all encompassing, but rather they were derived to elicit factors that should be studied for the concept of accreditation. The following sections discuss those factors identified by IBM that would best help in the analysis and definitization of accreditation.

2.2 ACCREDITATION STUDY FACTORS

The study factors identified were divided into three major categories:

- roles of accreditation players
- certification considerations
- acquisition process.

They were then integrated as outputs of the suty to be performed. The study factors are as follows:

- Certification process
  - — What specifications will be established for industry?
    - ISA functions only
    - Performance specs/operational needs
    - Environmental considerations.
  - — What are the general characteristics of the computers to be developed (small, medium, large)?
  - — What approach to logistics compatibility is required?
    - Box F^3
    - Module F^3
    - Build to print.
  - — How often is the list regenerated; i.e., what is the basis for deciding when to redevelop computers?

  - What are the pertinent technology trends; how are they measured?
  - Should the development process leading to certification be funded by the Navy?
  - How many developers are required or to be allowed?
  - What should be the actual certification process?
- Acquisition process
  - Quantity guarantees to producers
  - Procurement for production
    - Multiyear funding
    - Requirements contract
  - How many producers should be established?
  - What influence should the parameters of LCC, reliability and maintainability, and hardware cost play in ILS concepts, development, production, and acquisition priorities?
  - What must be structured to promote a competitive environment?
    - Market size/commitment
    - Multiple funded developments
  - What are the elements of "standardization" critical to accreditation?
    - Policy mandates
    - ISA standard.
- Accreditation roles
  - Funding process/responsibility
  - Integration of operational needs from users
  - Planning process
    - What basis? LCC?
    - Integration of requirements for market size projections
    - Who manages development versus production?
    - Commodity procurement process?
    - Who certifies the computers?

2.3 STUDY METHODOLOGY

Having defined those factors that a study of accreditation must address, the study methodology depicted in Figure 2-3 was established. The methodology focused on three major analyses:

- Life Cycle Cost - represents measured benefit to the Navy
- Profitability - represents risk and return of investments to industry
- Acquisition policies - key elements necessary to the concept of accreditation.

Thus, the study methodology examines elements necessary to develop a viable accreditation policy acceptable both for the Navy and to Industry.

As a basis for the three analysis areas, input data was gathered on

- Computer technology trends/projections
- Processor configurations (small, medium and large)
  - Physical/performance characteristics
  - Development cost
  - NRSU costs vs. production rate
- Government costs
  - Production management
  - Development management
- Market definition for Navy shipboard computers
- Navy computer procurement policies
  - Past and present
  - DoD standardization programs.

Then, as shown in Figure 2-3, three analyses were performed resulting in a framework for accreditation that addresses the factors identified from the scenario considerations examined. Section 3 discusses the first of the input data areas — technology trends and projections for LCC.

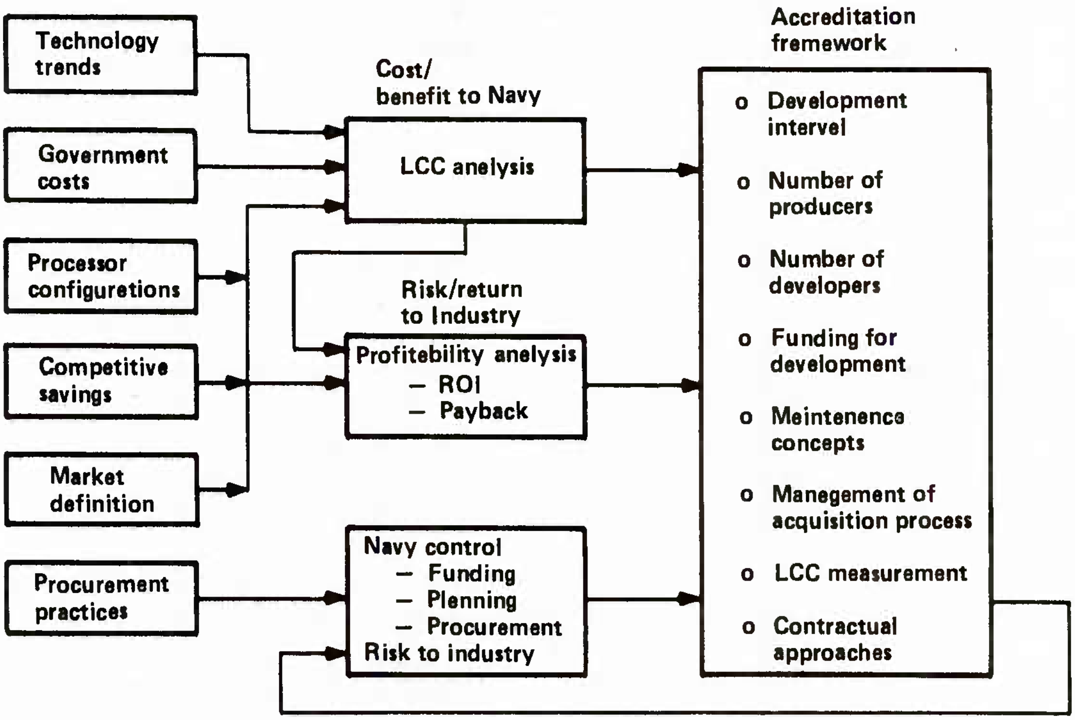


Figure 2-3. Study Methodology

Section 3
TECHNOLOGY CONSIDERATIONS

The rapid advances in digital electronic technology are widely recognized. Hand-held calculator price trends are indicative of price/performance improvements in digital technology. Current calculator price trends potentially reflect that "discard" could be a cost-effective means of maintenance.

An understanding of these dramatic digital technology improvements leads to an obvious question: How can the Navy capture the benefits of advancing digital technology (while considering the constraints of logistics, budget, etc.)?

An answer to this question dictates an assessment of the rate of technology improvement. Caution must be exercised, however, because there are really two rates of technology growth: device improvements and military computer improvements. While specific devices are experiencing tremendous rates of improvement in terms of reliability and price/performance, computers, which are effectively a mixture of "old" and new technology, are improving at a lesser rate. The use of the wrong rate could yield erroneous conclusions.

This section examines both device trends and computer trends. The computer trends are used by the Life Cycle Cost analysis (in Section 4) to examine the concept of periodic redevelopment. In addition, these same trends are used to examine various possibilities for future maintenance concepts.

3.1 DEVICE TRENDS

Processing improvements, geometric scaling, design innovation, market demands, and business enthusiasm have provided a growth rate in the semiconductor integrated circuits industry that is unparalleled by any other. Memory devices, high-function devices, microprocessors, and gate array/masterslices have been improving in gate density at approximately 40% per year, a doubling of density every 2 years. The results of this growth are reflected in cost and reliability improvements. Costs have been declining at 20% to 30% per year, and reliability has been improving at a rate proportional to the gate density growth; i.e., 40% per year.

The gate density growth rates are illustrated in Figure 3-1. Note that random logic TTL (transistor-transistor logic) functions have not improved as dramatically. The apparent reason for this is attributed to the lack of functional growth due to packaging pin restrictions. E. F. Rent of IBM empirically described the relationship between chip gate density and I/O pins.

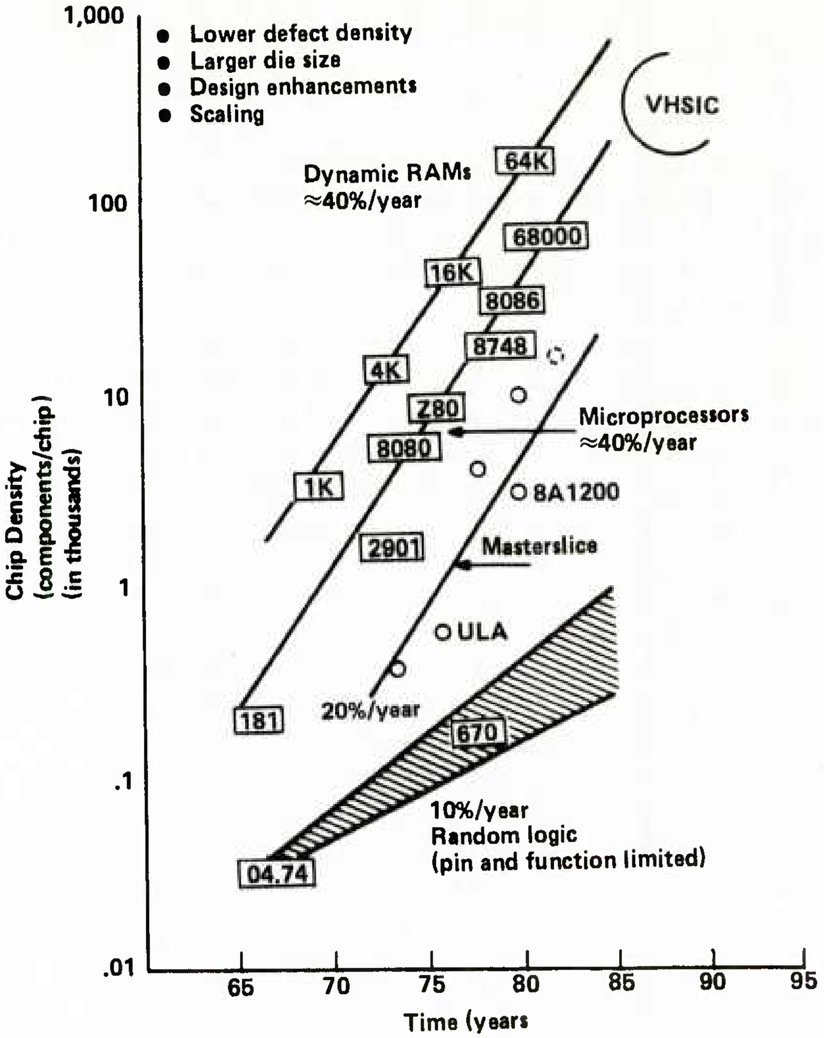


Figure 3-1. Device Density Trends

$$\text{No. of I/O} = (\text{Constant})\ (\text{No. of circuits})^{\beta}$$

By empirical determination

$\beta = 0.5$ to 0.75

Constant = 2.5 to 3.5

From this it is possible to determine the average functional gate density for a 16-pin package to be 12. The IC industry now recognizes this as a problem, and is pursuing 20- and 24-pin packages for random logic functions. This will allow a two times improvement in density. For example,

Constant = 3.0

$\beta = 0.625$

No. of usable I/O = 14, No. of gates = 12

No. of usable I/O = 22, No. of gates = 25

Cost and reliability improvements are a consequence of increasing the gate density per chip and improving manufacturing methods. Cost experience for IBM FSD's military logic circuits has indicated approximately a 20% price decline per year. This is illustrated in Figure 3-2.

Reliability per gate has improved with the density growth. By using RADC MIL-HDBK-217C and Notice 1, the curve illustrated in Figure 3-3 was generated. The reliability shown is for a referenced Navy shipboard application. Changes in environment will alter this curve. More severe environments (higher temperature, corrosion, vibration) will decrease the reliability of circuits and shift the curve up.

Three points are shown on the curve of Figure 3-3 to represent various integration levels. They are the average level currently used in box-level designs, the 2901 4-bit CPU slice, and the 68000 16-bit microprocessor. From this chart, it can be concluded that designs incorporating LSI will be greater than three orders of magnitude more reliable than those using SSI.

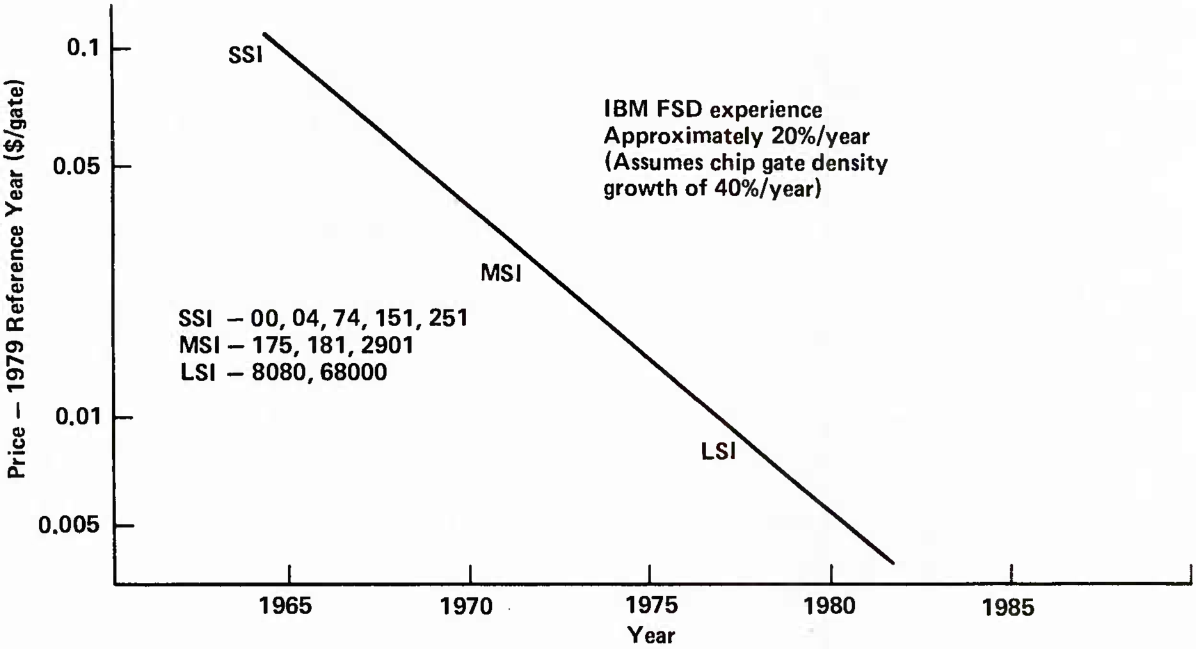


Figure 3-2. Device Cost Trends

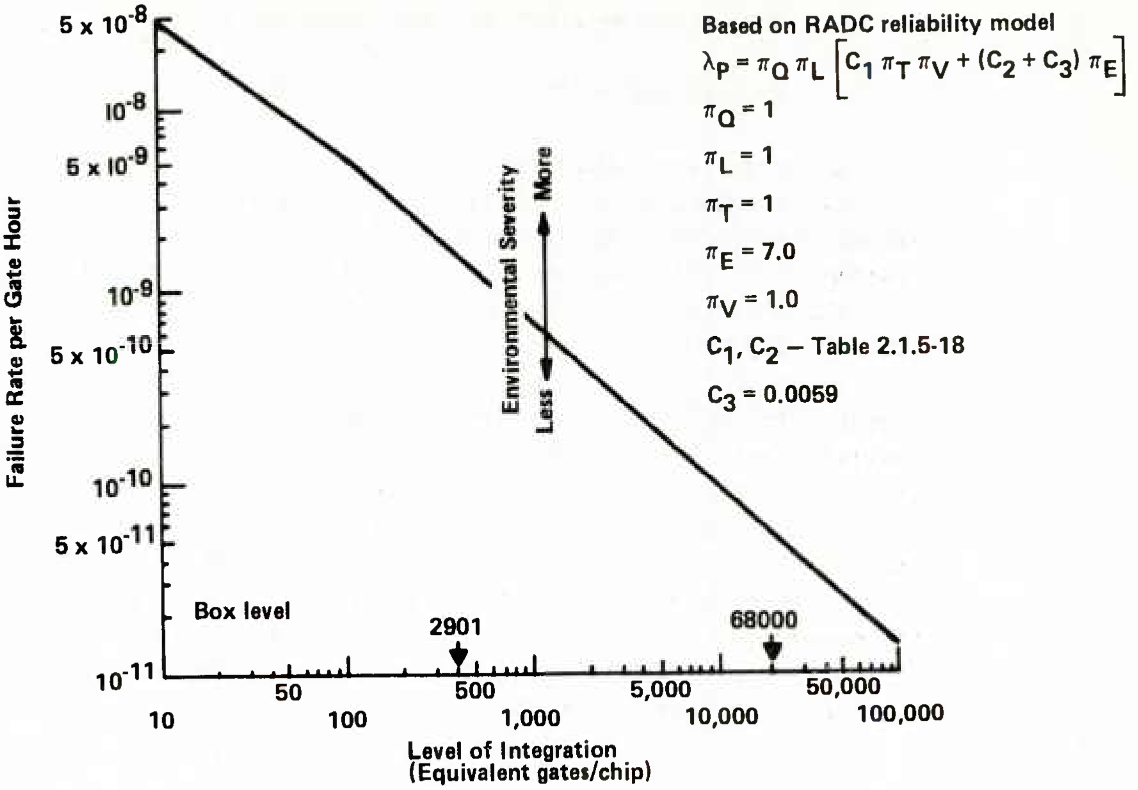


Figure 3-3. Chip Integration as a Function of Reliability

3.2 COMPUTER TRENDS

Technology improvements at the device level will be reflected in the design of new computers. While the maximum cost and reliability benefits would be attained by using the highest chip integration level practical, several factors can force computer designers to use lower integration levels. They include the demands of higher performance, use of multiple qualified sources for devices, and short production runs.

The relationship between cost, performance, and integration is illustrated for commercial computers in Table 3-1. Trends of price/performance, performance, and reliability for military computers are illustrated as Figures 3-4, 3-5, and 3-6, respectively. Note that performance has been improving at approximately the same rate that price/performance has been declining, which implies a relatively flat price trend. Note the opposing factors of performance, integration level, cost, power, etc. This implies that a balanced processor design is required by the developer. The implications of this are that performance does indeed dramatically affect cost.

Reliability improvement of 6% to 14% per year has been realized for IBM FSD's military computers. The growth of 6% per year represents the observed growth of computers, which includes increasing memory, performance, and function. The 14% per year growth is for computers

Table 3-1. VLSI and Computer Implementation Spectrum

Examples of computer/technology implementations

MOSTEK 8870	INTEL 8086	LSI-11	Burroughs 380	11/34 (FP11-A)	Raytheon RP 16	IBM 370	VAX 11/780	Cray I
INTEL 8048	INTEL 8080A	Fairchild F8	National IMP 16		IBM Series/1	Amdahl 470 /6	HP 1000	CDC 5500
	Zilog Z80						11.70	
	Motorola 68000						DG Nova	
Microcomputer	Microprocessor	Two-to-four-chip microprocessor	Multichip microprocessor	TTL bit slice	TTL gate arrays	ECL LSI custom	MSI TTL	ECL SSI

(0.1 mips) Lower performance ◄──► Higher performance (100 mips)

MOS intensive ◄──► Bipolar intensive

VLSI ◄──► SSI

Lower cost ◄──► Higher cost

Note: LSI memories span whole spectrum of computer implementations

REF: R.F. Spencer, Jr., "VLSI and Minicomputers," Compcon 78, February 1978, p. 20.

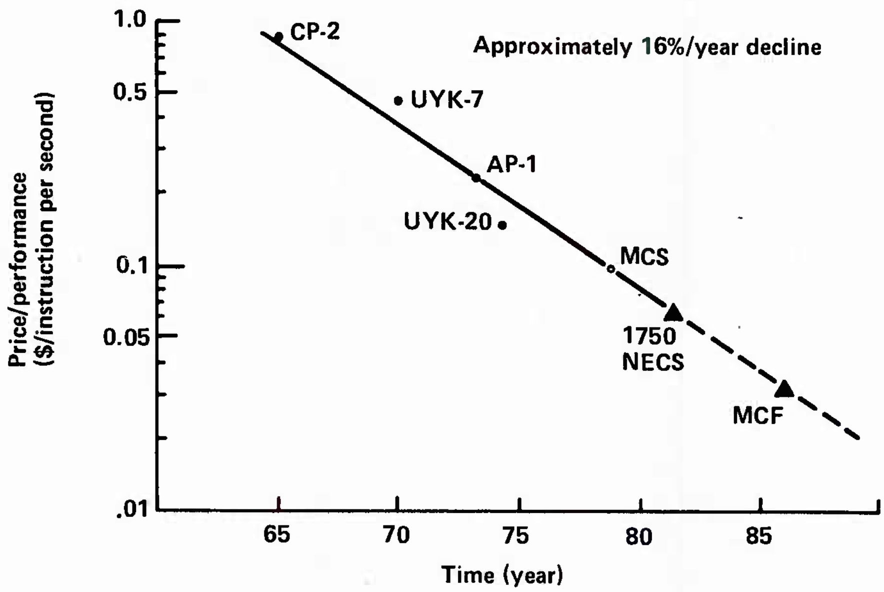


Figure 3-4. Military Computer Price/Performance Trends

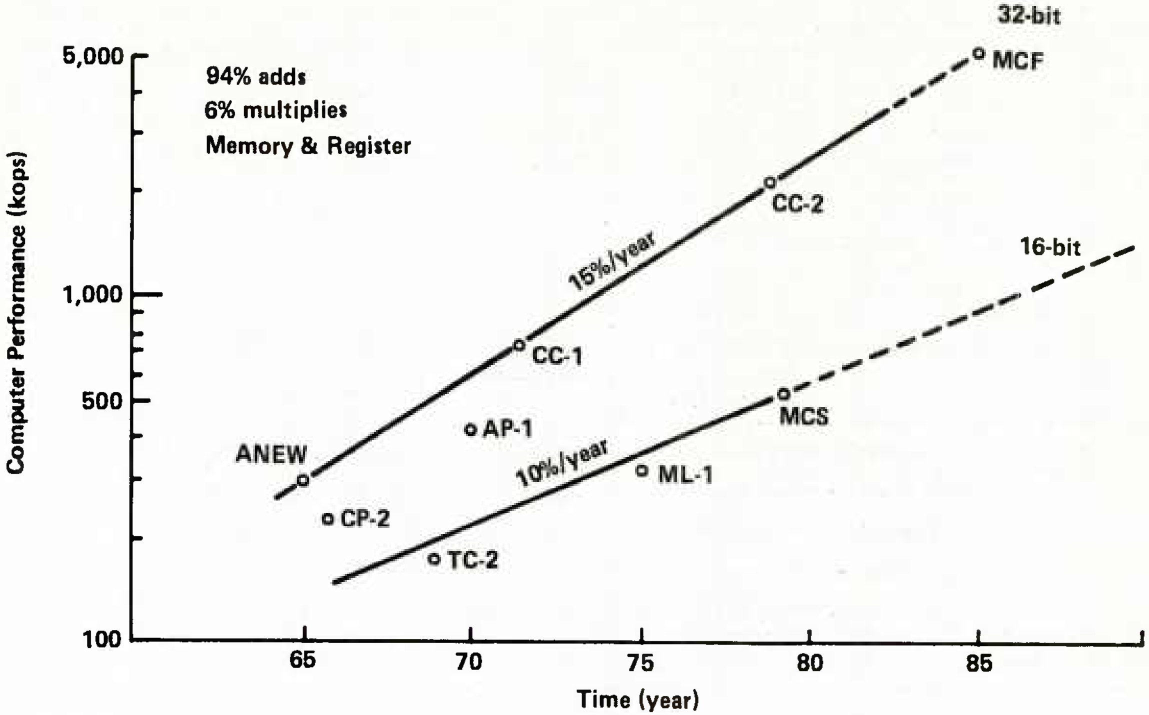


Figure 3-5. Military Computer Performance Trends

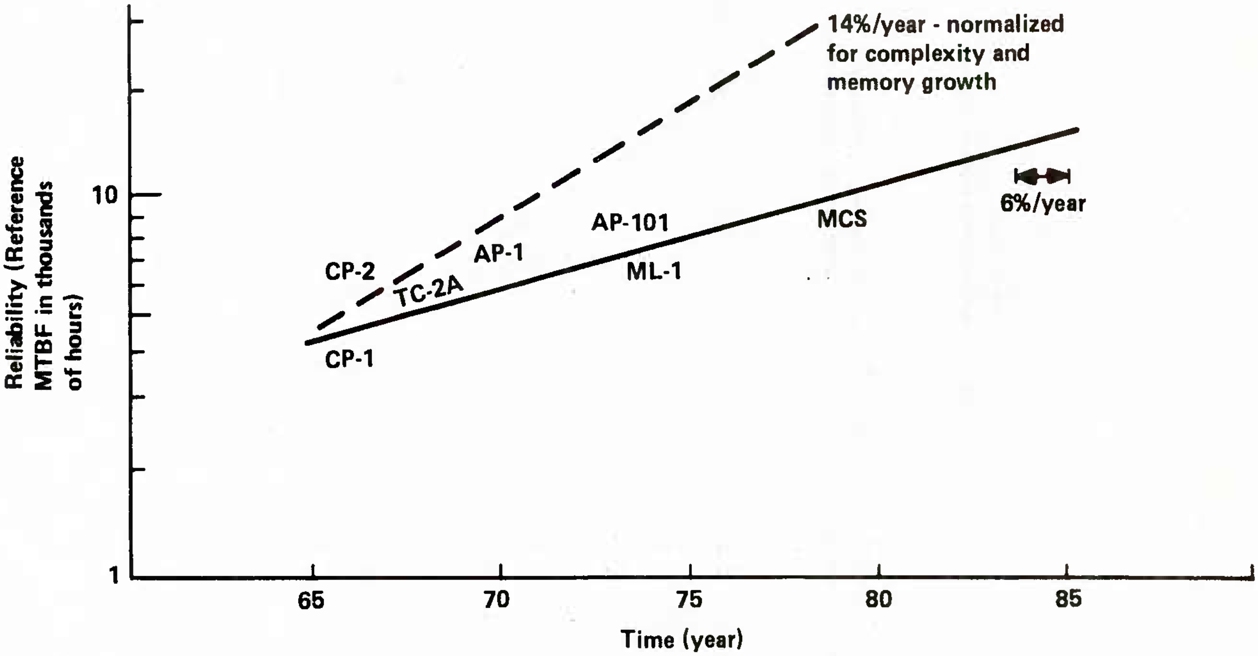


Figure 3-6. Military Computer Reliability Trends

normalized for constant function and memory, which was based on an analysis to determine the factors which influence computer reliability. The basic elements of a computer can be identified as CPU, I/O, memory, power supply, and miscellaneous (backpanels, harness, switches, connectors, etc.).

Table 3-2 identifies a 'typical' computer mix with its associated reliability contributions. This data is representative of IBM avionics computers, using SSI and MSI vendor TTL logic functions. Within each subgroup lies the reliability associated with either the semiconductor or the interconnection system.

The failure rates of pins and PC board plated-through holes have essentially remained constant with time, whereas the reliability of semiconductors on a per gate basis has improved directly as a result of the integration level. (Refer to Figure 3-3.) This results in a reliability improvement for the CPU, I/O and memory, as shown in Table 3-2, which is highly dependent on the circuit integration design. The power supply is relatively unaffected because of the discrete nature of the designs. The miscellaneous items represent mechanical interconnections, which also tend to be constant with time. Consequently, the estimated weighted effects have provided a 14% per year growth of reliability.

The two computer growth rates of price/performance and reliability have been used in a Life Cycle Cost model to determine the influence of periodic redevelopments to the accreditation concept. These growth rates, of 16% and 14% per year, respectively, are based on historical trends and were linearly extrapolated for the next 10 years. (These rates assume fixed functions.) These future extrapolations seem reasonable because an order of magnitude in geometric device scaling by itself is yet achievable. The Life Cycle Cost analysis of these trends is treated in Section 4.

Table 3-2. Estimated Failure Distributions for a General Purpose Military Computer (Assumes Typical I/O Memory, CPU Mix)

Basic Computer Elements	Estimated Reliability Growth/Year (%)	% of System Failure Rate*
CPU	8, random logic	26
I/O	8, random logic	20
Main store	40, RAM	24
	8, random logic	10
Power supply	Constant = 0	11
Miscellaneous (backpanels, harness, etc.)	Constant = 0	9

*14%/Year Reliability Growth for GP Computers. Normalized for Functionality and Per BIT of Memory.

Section 4
LIFE-CYCLE COST ANALYSIS

The previous section identified significant trends in computer reliability growth and cost/performance improvement. Clearly, the Navy would like to capture these benefits through new technology infusion. However, these benefits must be viewed in the light of potentially offsetting logistics costs.

This section uses a Life Cycle Cost (LCC) analysis model to examine several aspects of a new accreditation policy. The answers to these questions are helpful in the formation of new accreditation policy.

The first area examined involves the frequency of technology introduction. Specifically, is there an "optimal" redevelopment period? If so, are the savings significant compared to a policy of no (or infrequent) redevelopment?

Next, competition and various acquisition strategies are reviewed. The number of developers and the number of producers are varied to see if a preferable combination exists.

Finally, various analyses are performed to test the sensitivity of the conclusions to basic model assumptions; i.e., rates of cost and reliability improvement, levels of logistics support, the amount of competitive savings, and learning curve effects.

4.1 LIFE-CYCLE COST METHODOLOGY

The LCC methodology is based upon establishing a Total Program Cost for the various accreditation alternatives. The Total Program Cost includes Contractor and Government development costs (multiple costs if multiple developments), logistics acquisition costs (dependent upon number of suppliers) and the operation and support costs incurred across a 15-year use period. The methodology assumes that under each accreditation alternative, computer delivery requirements for 10 years would be met.

The methodology used in the LCC analysis is shown in Figure 4-1. It begins with the establishment of baseline configurations for three classes of machines, defined as small, medium, and large. The small machine is a single card, under-the-covers processor. The medium machine is roughly of the AN/UYK-20 class. The large machine is roughly of the AN/UYK-7 class. Further detail on these processor configurations appears in Appendix A.

The Total Program Cost was established for a development program starting in 1979 for each of the three classes of machines. This program cost was established based upon an acquisition approach reflecting a single developer/producer. (Other model assumptions appear later in this section and in Appendix A.)

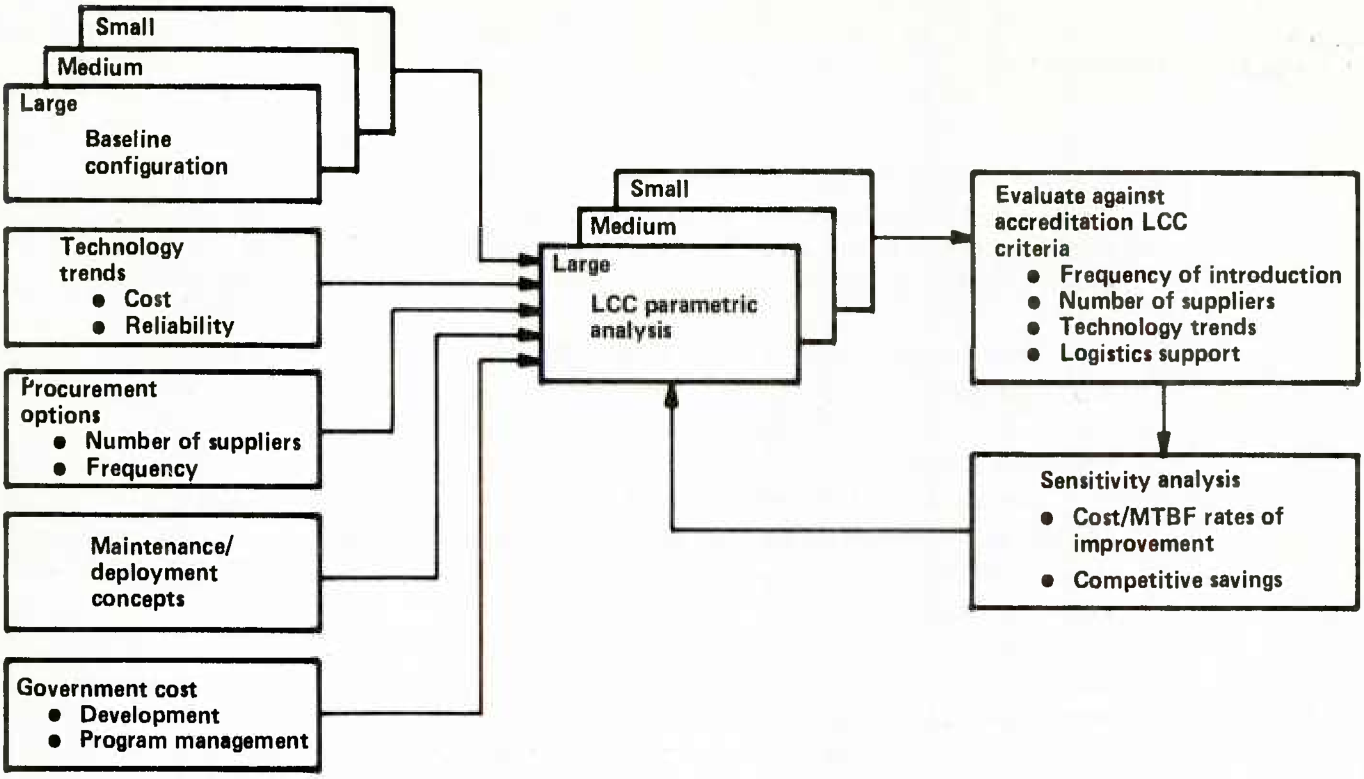


Figure 4-1. LCC Analysis Methodology

The technology effects were then integrated into the cost model. (These effects were summarized in Section 3 as a cost reduction of 16% per year and a reliability improvement of 14% per year.) This is depicted in Figure 4-2. The reduced cost and improved reliability results in significant overall program savings if the program start is delayed to capture the technology trends.

Figures 4-3, 4-4, and 4-5 summarize the Total Program Cost for each of three classes of computer. These figures show the percentage of program cost vs. the year of start of the development activities. For each configuration, the cost elements are summarized as follows:

- Production Hardware - Reducing with the rate of cost improvement
- Spares - Reducing with the combined effects of cost and reliability improvements
- Recurring Logistics - Reducing with the rate of reliability improvements
- Other Program Costs - Costs assumed to be fixed, including development, etc., as subsequently identified.

For example, the cost commitment made for production hardware and operation and support in 1989 would be 20% of the value required in 1979 for the medium-class computer if the procurement was delayed for 10 years. Although delaying the procurement is impractical, it does, however, point to the question of whether enough savings can be realized

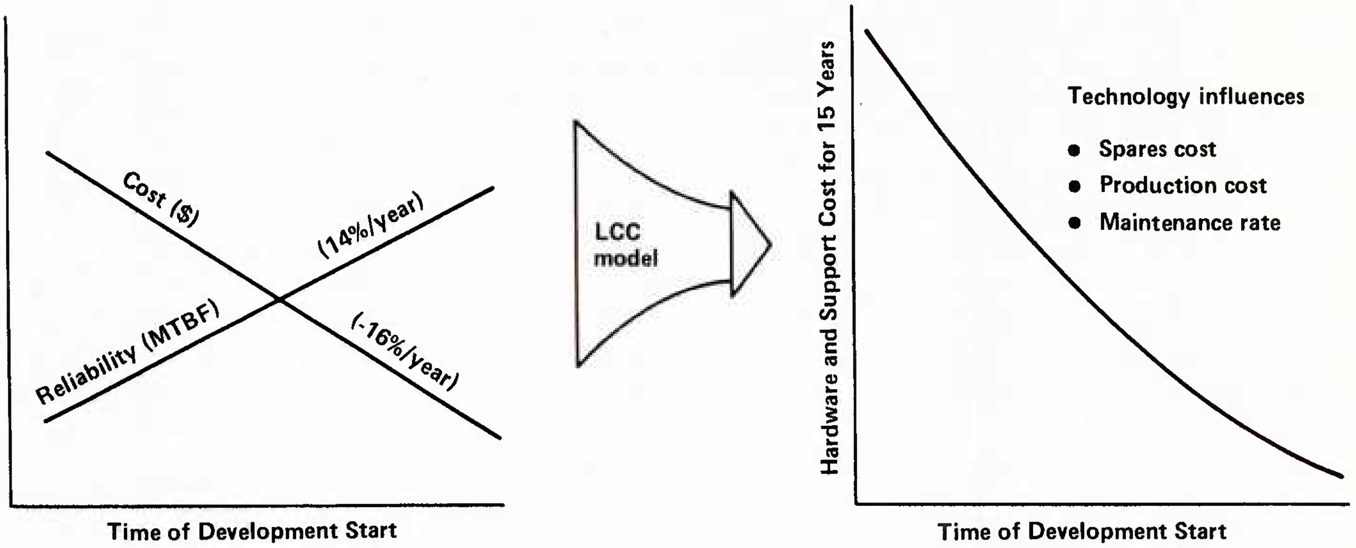


Figure 4-2. Projected Reliability and Cost Trends Used in LCC Analysis - Function Held Constant

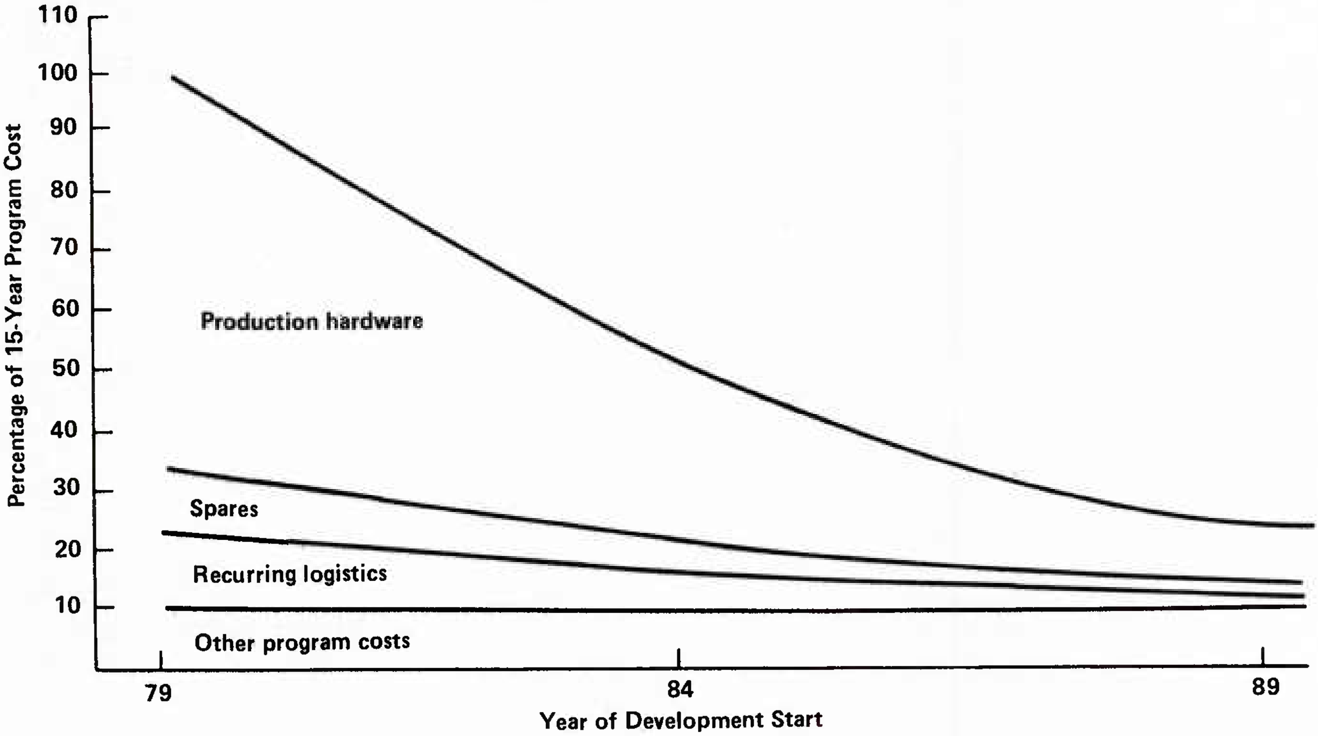


Figure 4-3. Total Program Cost Components - Small Machine

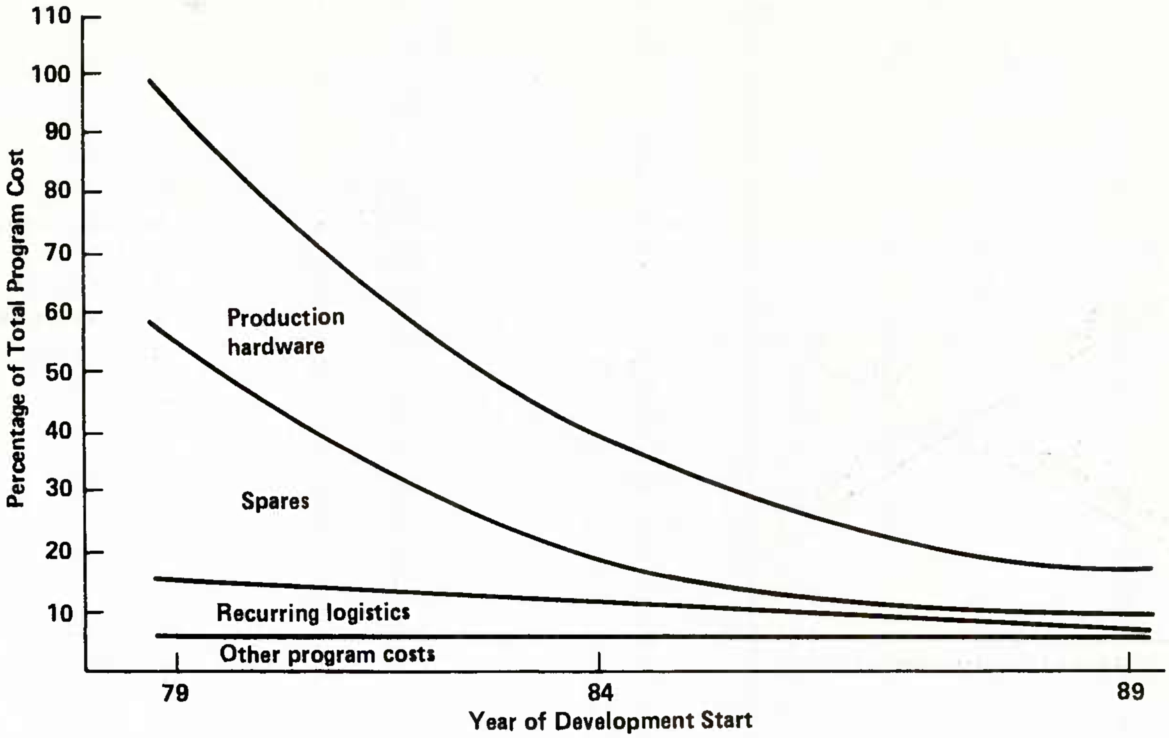


Figure 4-4. Total Program Cost Components - Medium Machine

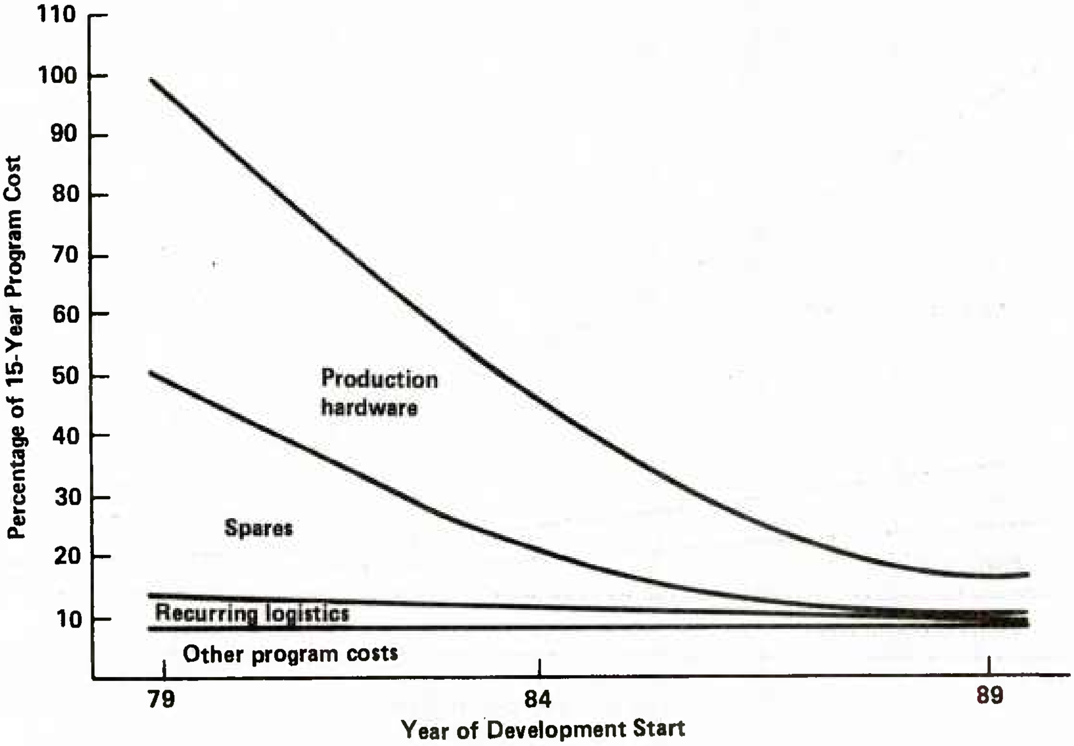


Figure 4-5. Total Program Cost Components - Large Machine

to offset multiple development costs if redevelopment is utilized during the 10-year production cycle. If so, a viable technique is to define a fixed hardware baseline (standard) for a shorter production run and then, on a scheduled basis, incorporate the latest technology within form, fit, and function constraints at the computer level.

Thus, the concept of periodic redevelopment is examined to evaluate the advantage of adopting a new procurement policy of introducing the latest technology hardware without changing the form, fit, or function of the computer. The basis for the evaluation of the redevelopment program cost is depicted in Figure 4-6. When the development program is initiated, the total cost commitment reflected by the available technology base is made, including operation and support costs. If no redevelopment takes place, and the total production program is 10 years, this commitment is equivalent to a 10-year period between redevelopment and is indicated as such on Figure 4-6.

The logistics costs are represented by the production hardware, spares, and recurring logistics costs. When redevelopment is applied, the one-time costs (development related) are incurred again, and the logistics costs become an average of the newer and older technologies.

Therefore, in Figure 4-6, the Total Program Cost is depicted as the sum of two functions: (1) the development investment incurred - a cost decreasing with the years between application of new technologies

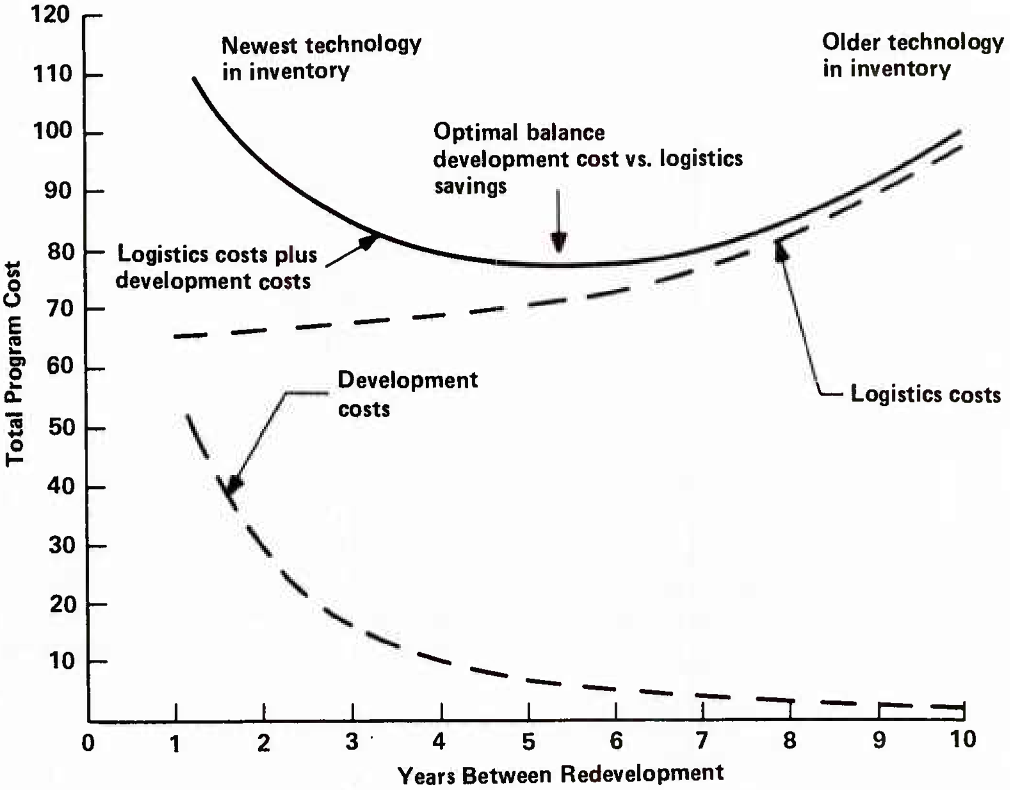


Figure 4-6. Redevelopment Effect on Total Program Cost

(number of developments required decreasing); and (2) the hardware and 15-year operation and support cost commitment made in satisfying the total acquisition requirements - a cost increasing with years between application of new technologies because cost/reliability benefits are not realized.

Next, procurement options, in terms of the number of developers and the number of producers, are analyzed. Finally, sensitivity analyses are performed. The sensitivity of the conclusions to variations in technology trends and competitive savings is tested.

4.2 LCC MODEL AND ASSUMPTIONS

The LCC model computer is based upon a model equivalent to MIL-STD-1390B, Appendix C and the Life-Cycle Cost Guide for Equipment Analysis prepared for the Naval Material Command by NWESA. It is composed of three constituent elements: development, investment, and support costs. These cost elements are as follows:

- Development
  - Contractor
  - Government
- Investment
  - Prime equipment acquisition
  - Initial hardware nonrecurring start-up support
  - Acquisition of:
    - Support equipment
    - Supply support
    - Training
    - Technical data
  - Government program management
- Support
  - Corrective maintenance
  - Support equipment maintenance
  - Supply support
  - Data management
  - Packaging and shipping

The development costs consist of Contractor and Government cost. A Contractor development cost figure was established for each class of machine and was maintained as a fixed cost independent of year of development. Government development cost was estimated at one-half of contractor development costs.

The investment cost is comprised of four major elements: acquisition of prime equipment hardware; nonrecurring start-up (NRSU) costs; Government program management; and acquisition of support equipment, training, supply support, and technical data. The unit hardware cost was established for each class of machine. The cost was modified during redevelopment cycles to reflect the technology and cost improvements projected during that time period.

The support costs encompass five major areas: corrective maintenance, support equipment maintenance, supply support, data management, and packaging and shipping. To compute these costs, a maintenance concept and operational criteria were defined. The recurring costs were computed for the discard and repair alternatives for the different classes of machines. The cost for the large- and medium-scale computers was based upon a cost-effective discard concept, while the small-scale computer was repaired at depot.

In this study, a 10% competitive savings in acquisition cost from multiple developers/producers was assumed, and the cost elements were summed in constant dollars.

No software effect was included in this study because it was assumed that, in all redevelopment cases, the computers would remain completely software compatible and no new functions would be added. Table 4-1 highlights some of the acquisition cost and reliability parameters used. Appendix A provides further detailed definition of how the assumptions and inputs were derived for this study.

Table 4-1. Acquisition Cost/Quantity Summary

Class / Parameter	Small	Medium	Large
Initial Acquisition Cost	$5k	$50k	$250k
Projected Quantities	(10,000)	(7,600)	(2,020)
Total Acquisition Cost	$50M	$380M	$505M
Initial Reliability (MTBF)	50,000 h	2,000 h	1,400 h

4.3 REDEVELOPMENT ANALYSES AND RESULTS

Five major analyses were performed to assess the effect of the periodic redevelopment concept on the Total Program Life Cycle Cost:

- Effect of periodic redevelopments
- Effect of acquisition strategy on redevelopment
- Sensitivity of the cost/reliability projections
- Effect of competitive savings
- Effect of learning curve.

4.3.1 EFFECT OF PERIODIC REDEVELOPMENTS

The first analysis determines the effect upon the overall program costs of varying the years between redevelopment. The result is that, based on a 15-year program and the assumptions that reliability improvement will increase at a 14% annual rate and costs will decrease at an annual rate of 16%, it is most attractive to redevelop every 3-5 years for the medium and large computers and every 5-7 years for the small computer. This is shown on Figure 4-7.

The optimum number of years between redevelopment is determined by the net programs savings that result from periodic redevelopment. For example, for the medium-scale computer, the development cost, if incurred once in the 10-year period, represents 5% of the Total Program Cost. With two developments, the development costs represent 12% of the Total Program Cost, but the hardware and support savings result in a net decrease of 25% in the Total Program Cost.

The optimal period for redevelopment of the medium-scale computer is approximately 3 years. At this point, the development costs rise to 18% of the Total Program Cost, but the savings result in a decrease of 29% in the Total Program Cost.

Figure 4-8 and Tables 4-2 through 4-4 summarize how these results were obtained. Figure 4-8 illustrates the candidate time lines associated with the multiple redevelopments. Tables 4-2, 4-3 and 4-4 show the quantitative values of the program cost elements for the three machine classes for discrete (one, two and three) developments. The cost savings and the sensitivity of the results to the cost assumptions can be obtained from these figures and tables.

It can be seen that hardware costs are reduced as a direct result of introducing newer technology at a lower procurement cost. Spares costs are reduced due to the combined effects of increased reliability and lower procurement costs. Other support cost are reduced as a result of improved reliability. The remaining costs stay constant and are considered as development costs.

The variation in the optimal point between the three classes of computers is a function of the development cost and savings realized. For the small, medium, and large classes of machines, the ratio of development cost to Total Program Cost was 12%, 5%, and 8%, respectively. Because the medium class has the lowest relative cost ratio, the greatest LCC savings results for this class of computers.

4.3.2 EFFECT OF ACQUISITION STRATEGIES

The effect that the number of developers and producers has upon the Total Program Costs was analyzed to determine an optimal accreditation approach. The acquisition strategies evaluated included (1) one developer, one producer; (2) two developers, one producer; (3) two developers, two producers; and (4) three developers, three producers.

These acquisition strategies are depicted in Figure 4-9. While these strategies are shown with a 10-year redevelopment period, other redevelopment periods were also evaluated.

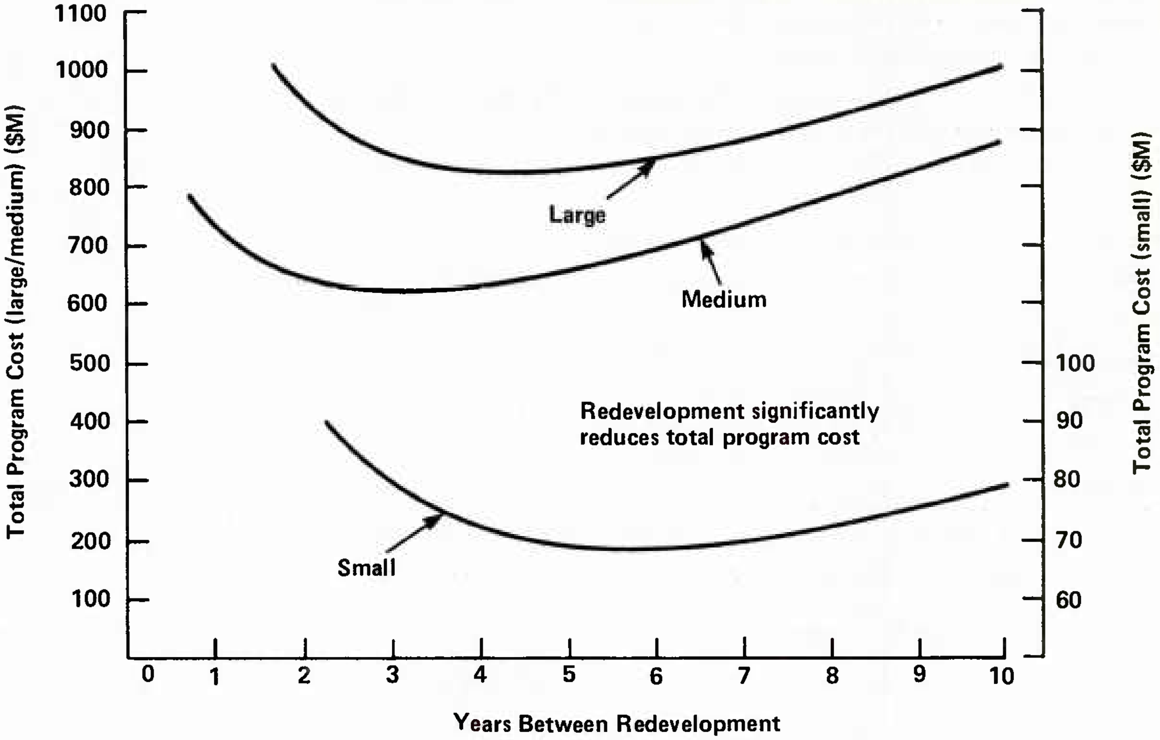


Figure 4-7. Effect of Years Between Redevelopment

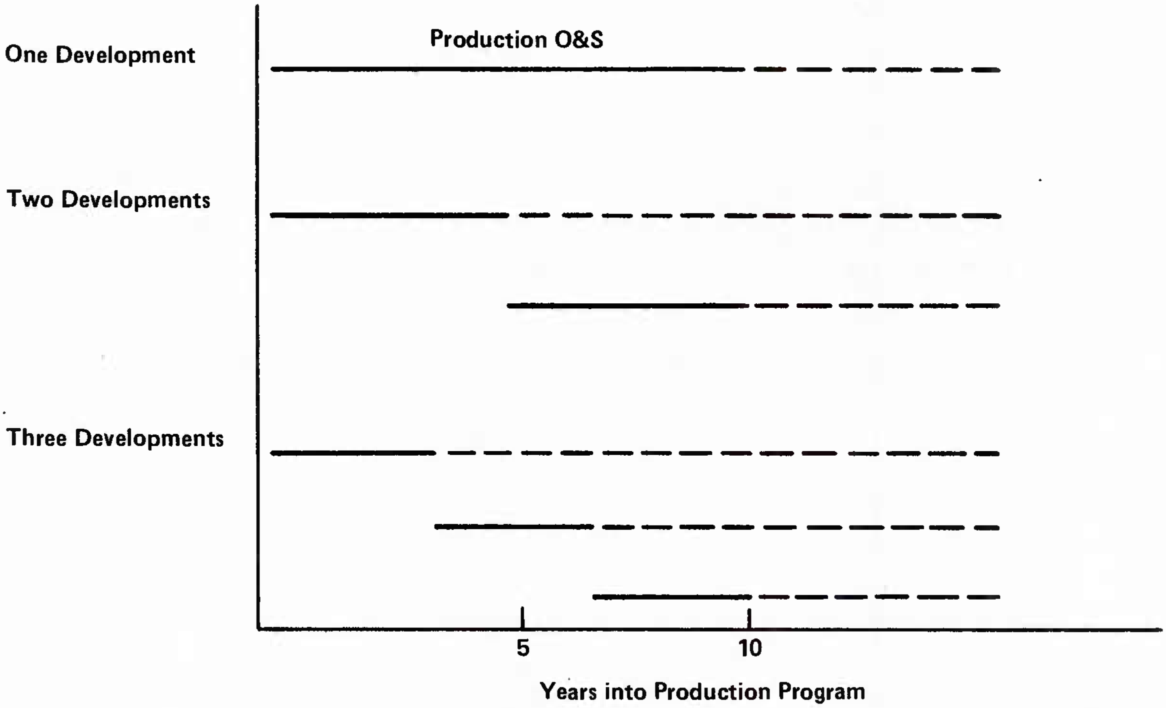


Figure 4-8. Redevelopment Time Line

Table 4-2. Small-Scale Computer Effect of Redevelopment One Developer, One Producer, Constant Function

	One Development	Two Developments		Three Developments		
	($ millions)	1st Year ($ millions)	5th Year ($ millions)	1st Year ($ millions)	3rd Year ($ millions)	7th Year ($ millions)
Hardware	50.0	25.0	10.5	16.7	9.3	5.3
Spares cost	7.4	3.7	2.0	2.5	1.6	1.1
Other support cost	13.0	6.8	3.9	4.7	3.4	2.5
Development cost	1.5	1.5	1.5	1.5	1.5	1.5
Production NRSU	1.3	1.3	1.3	1.3	1.3	1.3
Government Development	0.8	0.8	0.8	0.8	0.8	0.8
Government Program Office	6.0	4.8	3.8	4.2	3.6	2.8
Total/acquisition	80.0	43.9	23.8	31.7	21.5	15.3
Total program cost	80.0	67.7		68.5		

Table 4-3. Medium-Scale Computer Effect of Redevelopment One Developer, One Producer, Constant Function

	One Development	Two Developments		Three Developments		
	($ millions)	1st Year ($ millions)	5th Year ($ millions)	1st Year ($ millions)	3rd Year ($ millions)	7th Year ($ millions)
Hardware	377.6	188.8	79.3	125.8	70.5	40.3
Spares cost	362.7	191.7	42.5	134.9	49.5	18.6
Other support cost	94.8	50.8	27.0	34.5	22.7	15.1
Development cost	10.0	10.0	10.0	10.0	10.0	10.0
Production NRSU	15.0	15.0	15.0	15.0	15.0	15.0
Government development	5.0	5.0	5.0	5.0	5.0	5.0
Government program office	15.0	12.0	9.5	10.5	9.0	7.0
Total/acquisition	880.1	473.3	188.3	335.7	181.7	110.0
Total program cost	880.1	661.6		628.4		

Table 4-4. Large-Scale Computer Effect of Redevelopment One Developer, One Producer, Constant Function

	One Development	Two Developments		Three Developments		
	($ millions)	1st Year ($ millions)	5th Year ($ millions)	1st Year ($ millions)	3rd Year ($ millions)	7th Year ($ millions)
Hardware	511.1	255.6	109.9	171.3	95.9	54.8
Spares cost	360.2	216.5	46.1	173.0	62.7	23.2
Other support cost	70.4	36.6	20.3	25.4	17.5	12.3
Development cost	30.0	30.0	30.0	30.0	30.0	30.0
Production NRSU	18.0	18.0	18.0	18.0	18.0	18.0
Government development	15.0	15.0	15.0	15.0	15.0	15.0
Government program office	15.0	12.0	9.5	10.5	9.0	7.0
Total/acquisition	1,019.7	583.7	248.8	443.2	248.1	160.3
Total program cost	1,019.7	832.5		851.6		

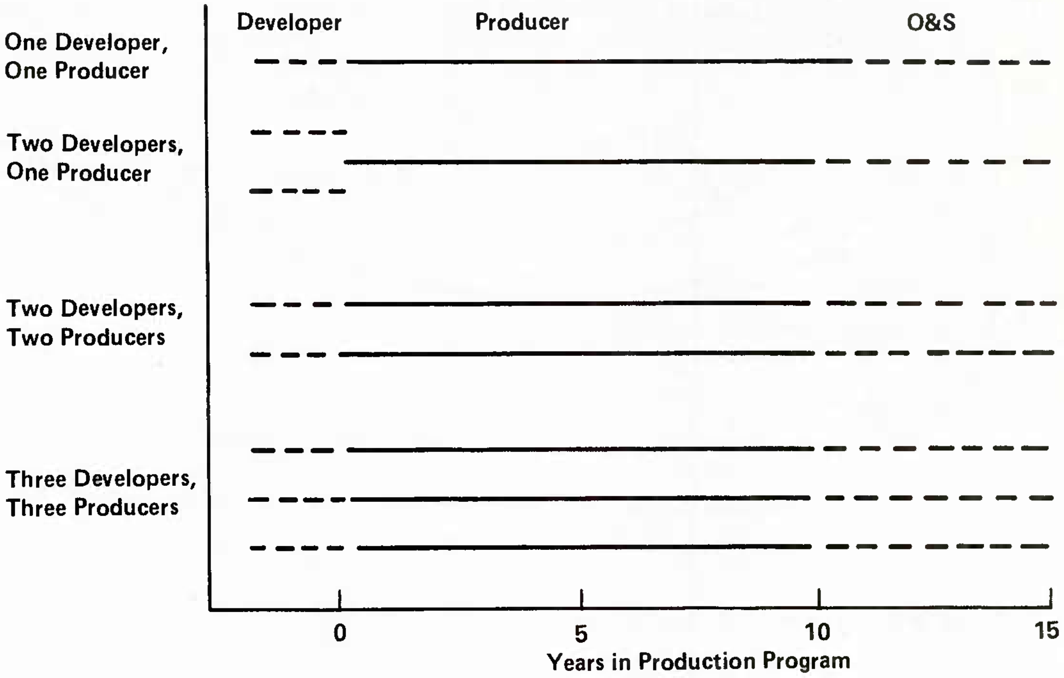


Figure 4-9. Acquisition Strategies Evaluated

The effect on total program cost of the various acquisition strategies is shown on Figure 4-10 for the medium-class computer. The results indicate that, with redevelopment every 5 years (near the optimal point) only small program savings are achievable by varying procurement strategies. The Total Program Cost for one developer, one producer closely matched that of two developers, one producer with redevelopment. This relatively small difference (less than 5%) in savings results, even with an extended redevelopment period. This indicates the greater importance of redevelopment as compared to procurement strategy.

Total Program Costs increase when two developers, two producers are introduced into the model. The competitive savings realized from competition is offset by the duplicate NRSU cost required to bring on an additional production facility. Additional Government support is also required to support the second producer, which further offsets the competitive savings. When three developers, three producers is evaluated, the increases more than offset the savings. Therefore, more than two developers, two producers is not considered in the rest of the analyses as a viable acquisition alternative.

The medium-class computer results are shown in Figure 4-10. The other classes of computers have similar results, and are reviewed in the summary.

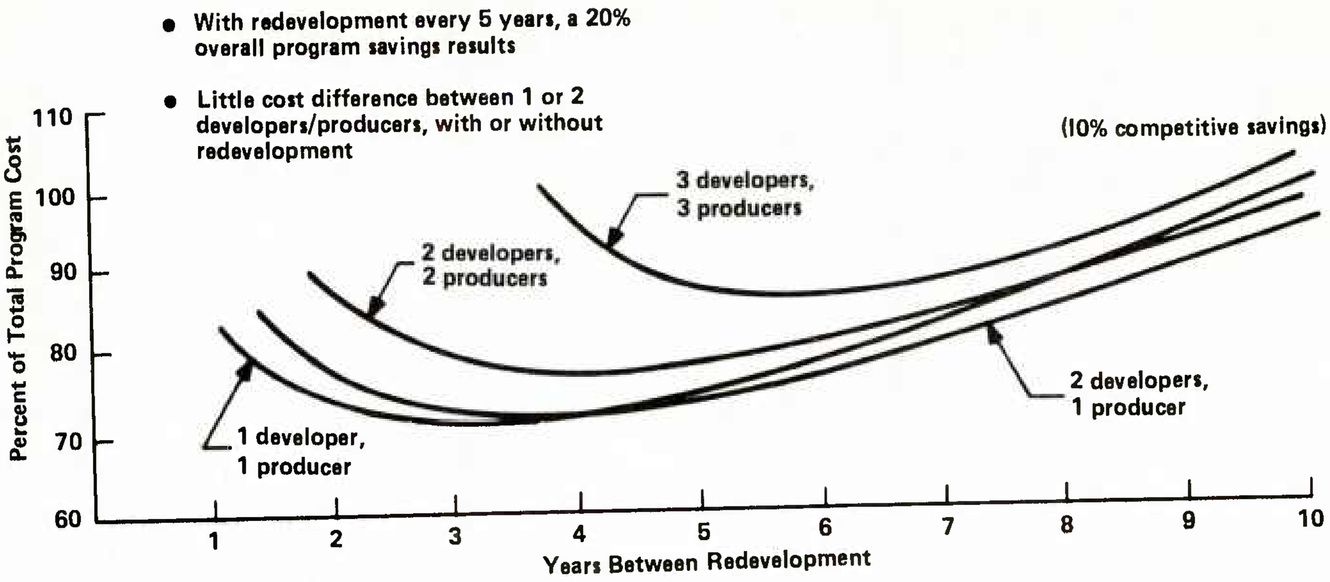


Figure 4-10. Effect of Number of Producers and Redevelopments, Medium-Scale Computer

4. 3. 3 SENSITIVITY OF COST/RELIABILITY PROJECTIONS

The results of the previous analysis (the benefits of periodic redevelopment) were based on capturing the projected technology growth in cost and reliability. In this section, a sensitivity analysis is performed to determine what effect a 50% reduction in cost/reliability projections would have on periodic redevelopment costs. The rate of reliability improvement is reduced from 14% per year to 7% per year. This reduction would be indicative of either the technology projections not being realized or, alternately, a growth in machine function or performance. The previous analysis assumed fixed function in the three machine classes.

Figure 4-11 portrays the effect on hardware and support costs of the various rates of reliability improvement and cost reduction. Decreasing the rate of reliability improvement has less of an effect upon total cost than decreasing the projected rate of cost reductions. The increased cost is reflected in the production hardware and spares, which represent the major program cost. By reducing the reliability growth improvement, one increases the quantity of spares required to support the operational program as well as the recurring maintenance costs to effect the additional repairs. The decreased rate of cost reduction affects the total cost at twice the rate of reducing reliability growth.

The effect of simultaneously reducing reliability and cost savings rates is greater than the sum of the individual items. This results because the spares increase in both quantity and cost. The sensitivity analysis is performed utilizing this combined rate.

Results of the analysis show that redevelopment with reduced reliability growth and cost reduction still provides significant overall savings and that one producer still provides the lowest total program cost. This is shown in Figure 4-12.

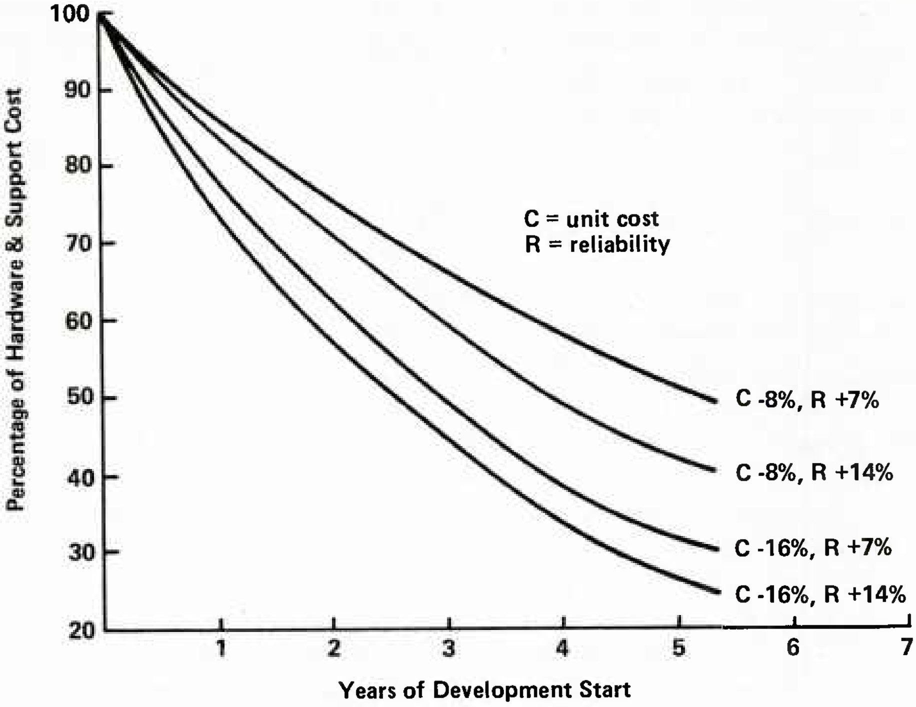
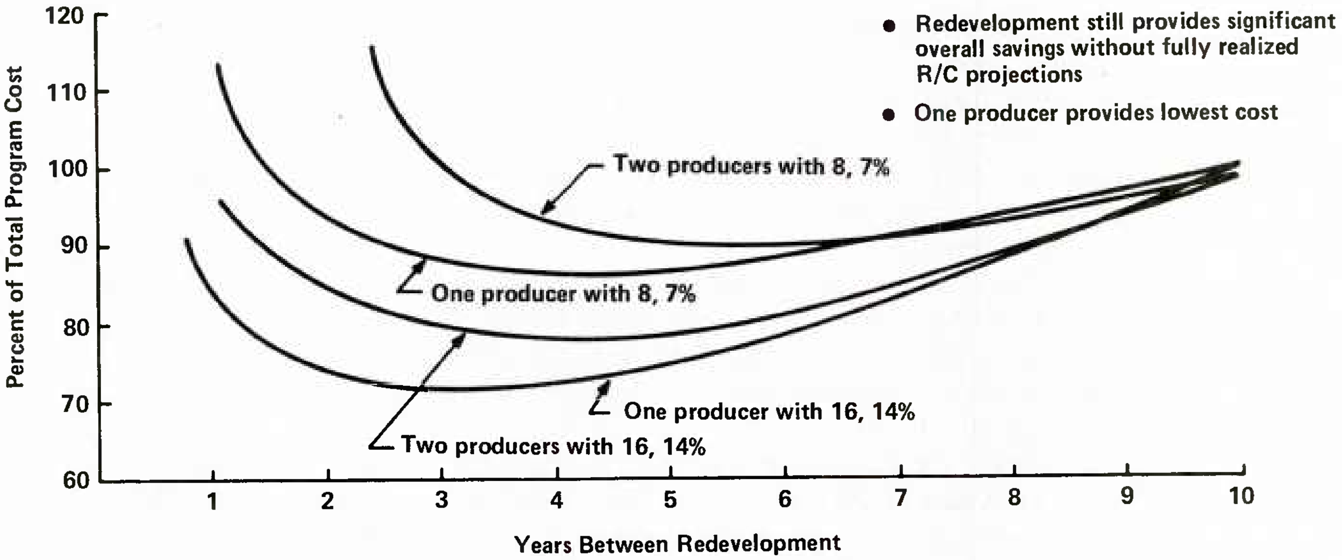


Figure 4-11. Cost and Reliability Sensitivity Analyses



- Redevelopment still provides significant overall savings without fully realized R/C projections
- One producer provides lowest cost

Figure 4-12. Sensitivity Effect of Realized Cost/Reliability Growth, Medium-Scale Computer

The prior analyses on redevelopment assumed the functional capability of the computer was held constant. As stated earlier, the reduction in technology trends could be representative of increased functional capability and performance, which would lessen the technology advantage realized. Therefore, even with some functional growth, the sensitivity analysis indicates that a policy of redevelopment can provide program savings.

4.3.4 EFFECT OF COMPETITIVE SAVINGS VARIATION

This section investigates the effect of varying competitive savings. Although the exact savings from competition is unknown, a 10% savings in acquisition cost resulting from either competitive developments or competitive production was assumed and used for the previous analysis, then parametrically changing this savings to 20%.

The effect of varying the competitive savings from 10% to 20% for multiple developers is shown in Figure 4-13. The basic redevelopment conclusions remain unchanged. The second analysis evaluates the effect of competitive savings for two producers. Results of this analysis are summarized in Figure 4-14. The competitive savings of multiple producers are offset as a result of the additional nonrecurring startup costs required to support a second production line and the additional Government program management needed to support the second producer. Again, periodic redevelopment remains viable.

4.3.5 EFFECT OF LEARNING CURVE

The effect that the learning curve effect has upon the total program cost (given multiple producers) was also analyzed. A 90% cumulative cost improvement curve was projected for the total production quantity. To obtain the maximum benefit of cumulative learning, one producer for the total production quantity is required. If multiple producers are introduced, the effects of the cost improvement curve would not be fully realized.

Dividing the production quantity among two producers results in the last half of the production savings not being realized. Based on a 90% curve, this amounts to an increase in the average production unit cost of 10% when two producers are utilized over the projected production quantity of 10,000.

Thus, the competitive savings for multiple producers is offset by a 10% increase in average cost because cost improvement is not realized from using a single producer for the total production quantity. This is summarized in Table 4-5. When the learning curve effect is added to the assumed competitive savings, the effect is to reduce the attractiveness of multiple producers, as is quantitatively defined in the "Net" column of Table 4-5.

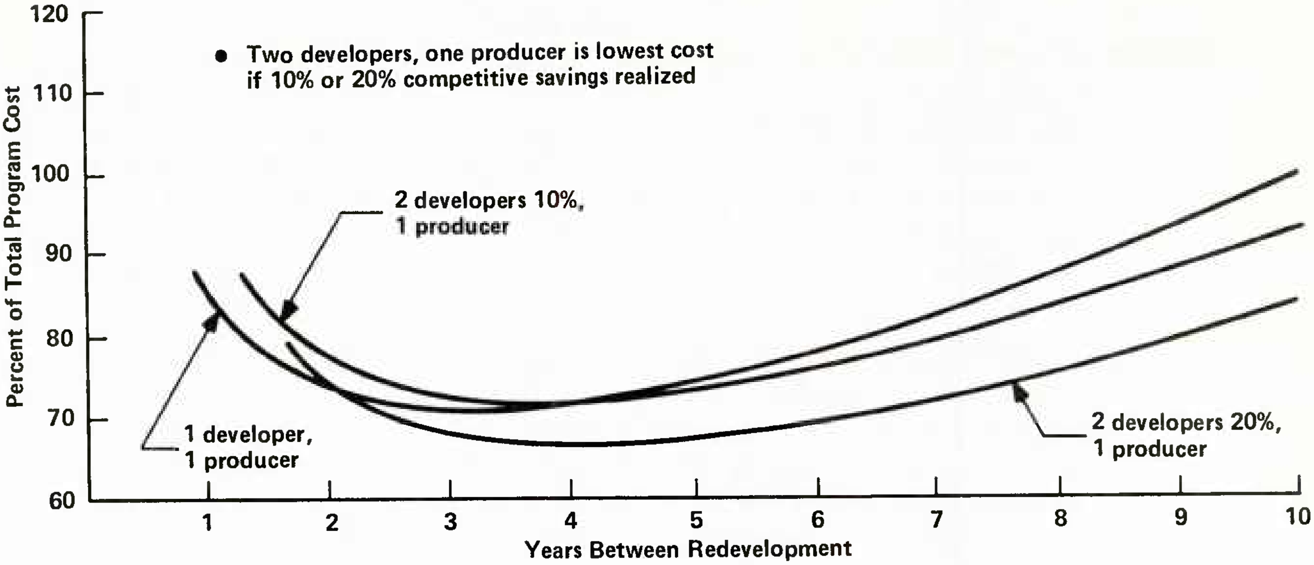


Figure 4-13. Sensitivity Effect of Competitive Savings, Medium-Scale Computer, Number of Developers

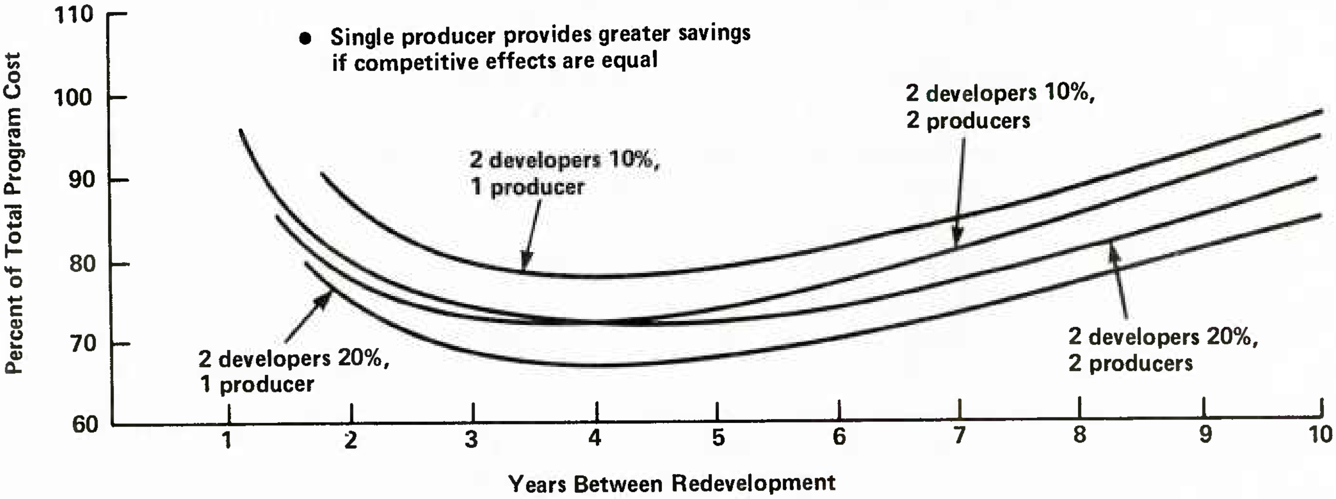


Figure 4-14. Sensitivity Effect of Competitive Savings Medium-Scale Computer, Multiple Producers

Table 4-5. Learning Curve Effect

Number of Developers	Number of Producers	Assumed Competitive Saving	Learning Curve	Net
1	1	0	0%	0
2	1	-10%, -20%	0%	-10%, -20%
2	2	-10%, -20%	+10%	0%, -10%

4.3.6 SUMMARY OF ANALYSES

The quantitative results of the five major analyses are summarized in Tables 4-6 through 4-9. These results have been evaluated for one redevelopment at the 5-year point, which is near optimal for the three classes of computers.

For all three classes of computers, the following observations are made:

- Redevelopment is very desirable under all procurement strategies (Table 4-6). The effect of redevelopment for the three classes of computer are graphically depicted in figures 4-4 and 4-9. Table 4-6 summarizes these figures in tabular form. The effect of redevelopment between the 5-year point (one redevelopment) and the 10-year point (no redevelopment) is depicted by the delta column in Table 4-6, reflecting the savings realized with redevelopment under each of the various procurement strategies. In all cases significant savings resulted.
- Redevelopment provides the greatest Total Program Cost savings: acquisition strategy can provide additional savings potential, depending on competitive savings (Table 4-7). The effect of redevelopment in combination with each of the procurement strategies is summarized in Table 4-7. The objective is to evaluate the savings realized by the procurement strategy adopted. This is presented as the difference between the savings realized at 5 years for each of the strategies vs. that realized by a single developer/producer. Figures in parentheses represent negative savings (or) increased costs. The sensitivity analysis results on the effect of competitive savings are also presented to show the potential savings of 20% vs. the 10% reflected in the baselines. These are also depicted in Table 4-7.
- Two developers with one producer provides the largest total program savings. Table 4-7 summarizes the savings potential for each of the procurement strategies, with the largest potential being 22%, 33%, and 23% for the small, medium, and large computers, respectively, when a two developers, single producer strategy is utilized and the combined savings of redevelopment and competitive savings of 20% are realized.
- A 5-year redevelopment period provides a manageable time period with near optimal total program savings (Table 4-8). The summary was presented by evaluating the results at the 5-year redevelopment interval. The effect of using this interval instead of the "optimal" interval is a reduction in the total savings realized. This effect is shown in Table 4-8, where the percentage reduction nonrealized is presented. The year's shift in the redevelopment interval is also summarized. Comparison of the savings realized at the 5-year redevelopment interval vs. the savings not realized indicates that the significant advantage of redevelopment is not dependent upon selection

Table 4-6. Summary of Analysis — Redevelopment

Acquisition Strategy	Percent Savings in Total Program Cost								
	Small Computer			Medium Computer			Large Computer		
	With Redevelopment	Without Redevelopment	Δ	With Redevelopment	Without Redevelopment	Δ	With Redevelopment	Without Redevelopment	Δ
1 developer, 1 producer	17%	0%	17%	25%	0%	25%	18%	0%	17%
2 developers, 1 producer	16%	4%	12%	27%	7%	20%	16%	4%	12%
2 developers, 2 producers	4%	(3)%	7%	21%	2%	19%	3%	(5)%	8%
3 developers, 3 producers				12%	(4)%	16%			

Observation: Redevelopment is very desirable under all procurement strategies.

Table 4-7. Summary of Analysis — Acquisition Strategy, Competitive Savings

Acquisition Strategy	Percent Savings in Total Program Cost								
	Small Computer			Medium Computer			Large Computer		
	With Redevelopment Every 5 Years	Delta for Acquisition Strategy at 10% Competitive Savings	Delta for Acquisition Strategy at 20% Competitive Savings	With Redevelopment Every 5 Years	Delta for Acquisition Strategy at 10% Competitive Savings	Delta for Acquisition Strategy at 20% Competitive Savings	With Redevelopment Every 5 Years	Delta for Acquisition Strategy at 10% Competitive Savings	Delta for Acquisition Strategy at 20% Competitive Savings
1 developer, 1 producer	17%	--	--	25%	--	--	18%	--	--
2 developers, 1 producer	16%	(1%)	5%	27%	2%	8%	16%	(2%)	5%
2 developers, 2 producers	4%	(13%)	(5%)	21%	(4%)	3%	3%	(15%)	(4%)

Observations: Redevelopment provides greatest savings, with acquisition strategy providing some additional savings potential, depending on competitive savings.

Two developers, one producer provides largest potential for savings.

Table 4-8. Summary of Analysis — Five-Year Redevelopment vs. Optimal

Acquisition Strategy	Variations from Minimum with 5-Year Redevelopment								
	Small Computer			Medium Computer			Large Computer		
	% Savings Realized (optimal)	Δ From Minimum		% Savings Realized (optimal)	Δ From Minimum		% Savings Realized (optimal)	Δ from Minimum	
		% Cost	Years		% Cost	Years		% Cost	Years
1 developer, 1 producer	17	0	0	25	(4)	-2	18	(1)	-1
2 developers, 1 producer	16	0	0	27	(2)	-1	16	0	0
2 developers, 2 producers	4	(2)	+1	21	(1)	-1	3	(1)	+1
3 developers, 3 producers				12	(2)	+1			

Observation: Five-year development period provides qualitatively manageable period with near optimal total program savings.

Table 4-9. Summary of Analysis — One Half of Technology Rates

Acquisition Strategy	Percent Savings								
	Small Computer			Medium Computer			Large Computer		
	With Redevelopment Every 5 Years	Without Redevelopment	Δ	With Redevelopment Every 5 Years	Without Redevelopment	Δ	With Redevelopment Every 5 Years	Without Redevelopment	Δ
1 developer, 1 producer	6	0	6	13	0	13	6	0	6
2 developers, 1 producer	7	4	3	16	7	9	4	4	0
2 developers, 2 producers	(6)	(3)	(4)	10	2	8	(11)	(5)	(6)

Observation: Redevelopment desirable for viable acquisition strategies even if projected technology benefits are not fully realized.

of the optimal point. For example with the medium-class computer, 29% (25% + 4%) savings could have resulted if the 3-year (5-2) redevelopment period was adopted. With the 5-year redevelopment interval, 86% of the savings are realized (25 ÷ 29).

o Redevelopment is desirable as a viable acquisition strategy, even if projected technology benefits are not fully realized (Table 4-9). The effect with or without redevelopment when the total technology benefits are not realized was depicted graphically for the medium class computer in Figure 4-11. This is summarized in tabular form for all three classes of computers in Table 4-9. The small- and large-class computers are more sensitive to achieving the projected technology improvements than the medium.

4.4 QUALITATIVE ASPECTS OF PROCUREMENT STRATEGY

The results of the Life Cycle Cost analysis show that the procurement strategy is far less important than redevelopment in terms of the savings realizable. There are many considerations and approaches in terms of the procurement strategy that cannot be reflected in the quantitative analysis performed which could significantly affect the overall attractiveness of a particular procurement strategy.

Although a concept which provides for redevelopment clearly provides significant overall program savings, the best procurement strategy (number of developers, number of producers) to implement the concept is less apparent. In fact, the different procurement strategies only differ by 5% of total program costs; a factor of the order of the accuracy of the analysis. Therefore, the exact procurement strategy should be selected by other than quantitative analysis. This section summarizes the qualitative aspects for the various strategies considered.

4.4.1 SINGLE VS. MULTIPLE DEVELOPERS

The first consideration is the number of developers. The results of the Life Cycle Cost analysis indicate that for all classes of computers, either one developer or two developers with a redevelopment period of 5 years is attractive on an LCC basis, but there is no cost advantage in considering more than two developers.

The advantages of two developers over one include:

- More realistic fixed price production competitions can be completed following the completion of the development program.
- Technology risks can be taken in the development phase, enabling competitive technology advantages to be assessed prior to the production decision by the Contractor and the Navy.
- Performance achievements between designs can be evaluated, particularly from the standpoint of reliability, maintainability and support features, which enables evaluation of the Life Cycle Cost targets established.
- Logistics support elements/requirements (e.g., technical manuals and spares provisioning), which are part of the production program, still retain the competitive influences, providing incentive for contractors to minimize these items and their cost.

These items appear to represent a significant savings potential to the Government, and offset the risks on the part of both industry and the Government.

The major advantage of a single developer is the minimization of Government administrative and development evaluation costs. This cost penalty can be recovered with the assumed 10% cost savings realizable from the competitive effects. Therefore, the recommendation to utilize two developers appears to have advantages.

4.4.2 SINGLE VS. MULTIPLE PRODUCERS

The questions regarding the number of producers is more complex. Three alternatives are identifiable:

- Single producer - analyzed previously
- Two producers - analyzed previously
- Leader/follower - not specifically analyzed.

The leader/follower concept for the production phase would fall between the single producer and two producer alternatives. Specifically, the cost for leader/follower would be more than for a single producer, because additional NRSU costs would be required, but it would be less than for two producers, because logistics resources would not be duplicated (because leader/follower implies identical support resource requirements build to print).

The advantages of a multiple producer strategy are

- Potential additional resources to expand production in the case of a national emergency
- Less sensitivity of national security to the success (technologically or business posture) of a single company
- Potential additional competitive savings as a result of head-to-head competition following the initial production award.

These advantages (achieved through either two producers or leader/follower) are offset by

- Potential increased cost in production due to learning curve effects (particularly with leader/follower, where technological differences cannot offset learning effects)
- Additional Navy support resources required (e.g., training of data system technicians, Navy management, technical supervision) particularly with multiple producers, where simultaneous delivery and support requirements would occur for two different computers
- Duplication of initial startup and schedule problems in R&D (due to introduction of a new machine as a result of simultaneous producers)
- Reduced investment recovery, de-emphasizing to some extent additional industry capital investment.

The results of the analysis performed indicated that a single producer strategy was slightly preferable from a cost standpoint. From an evaluation of the qualitative factors, the increased burden on DS personnel may be of critical importance. If so, multiple developers and a single production supplier appear to be preferable.

4.5 QUALITATIVE ASPECTS OF MAINTENANCE CONSIDERATIONS

One of the limitations of Life Cycle Cost analyses is the necessary assumption that the trained people required for maintenance are available. As identified in the final report of the Navy Embedded Computer Review Panel (NECRP), Appendix D, the requirements for data systems technicians are projected to exceed the available quantities of personnel, as reflected in Figure 4-15. These projections were based upon the distributable manning projected into the future to reflect the increasing complexity of new and complicated equipment requiring highly trained maintenance expertise due to the introduction of UYK-7s and UYK-20s into the fleet. The results of the NECRP study clearly indicate that:

1. Effective operational utilization of deployed equipment will be severely impacted if the required maintenance levels are in fact required and not available.
2. Incorporation of technology advances to the level required to mitigate the potential problem hasn't occurred. If maintenance simplification were achieved through technology advances, then the manpower requirements with the additional equipment being fielded might remain constant.

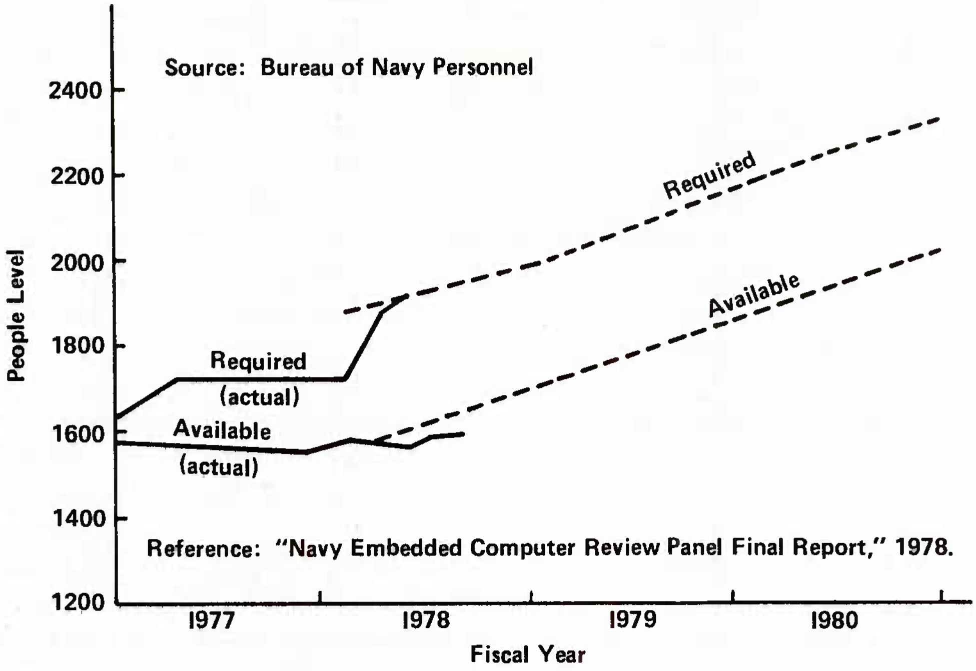


Figure 4-15. Data Systems Technician Distributable Manning

Computers, by themselves, do not dictate the personnel level loading required into the future, but the host systems utilizing the embedded computer installations may. Because of the expressed concern by the Navy about data systems technician requirements, the following paragraphs review the results of the study as applicable to computers, and suggests some other areas of consideration.

One approach to reduce the need for skilled maintenance personnel onboard ship is to design the equipment with such a high reliability that it does not fail during the length of the mission. The need for any onboard maintenance would thus be eliminated. Any maintenance would be deferred to the end of the cruise. Qualified Navy or contractor personnel could then provide required maintenance at a central location.

To achieve an absolute failure-free equipment, of course, requires a design with infinite reliability. A design point was arbitrarily selected as a 0.95 probability of completing the mission without a failure, i.e., 5% of the time, a failure would occur.

The required equipment reliability to achieve such a condition is shown in Figure 4-16. To achieve maintenance-free equipment for a 90-day mission requires an equivalent MTBF of 43,000 hours. This requirement is contrasted with the present MTBF of 2,000 hours, which yields a probability of success of 0.34. Projecting the current reliability of 2,000 hours forward with a reliability growth rate of 14% a year as determined, which is the military computer reliability history for fixed functions in Section 3, still does not provide the required reliability.

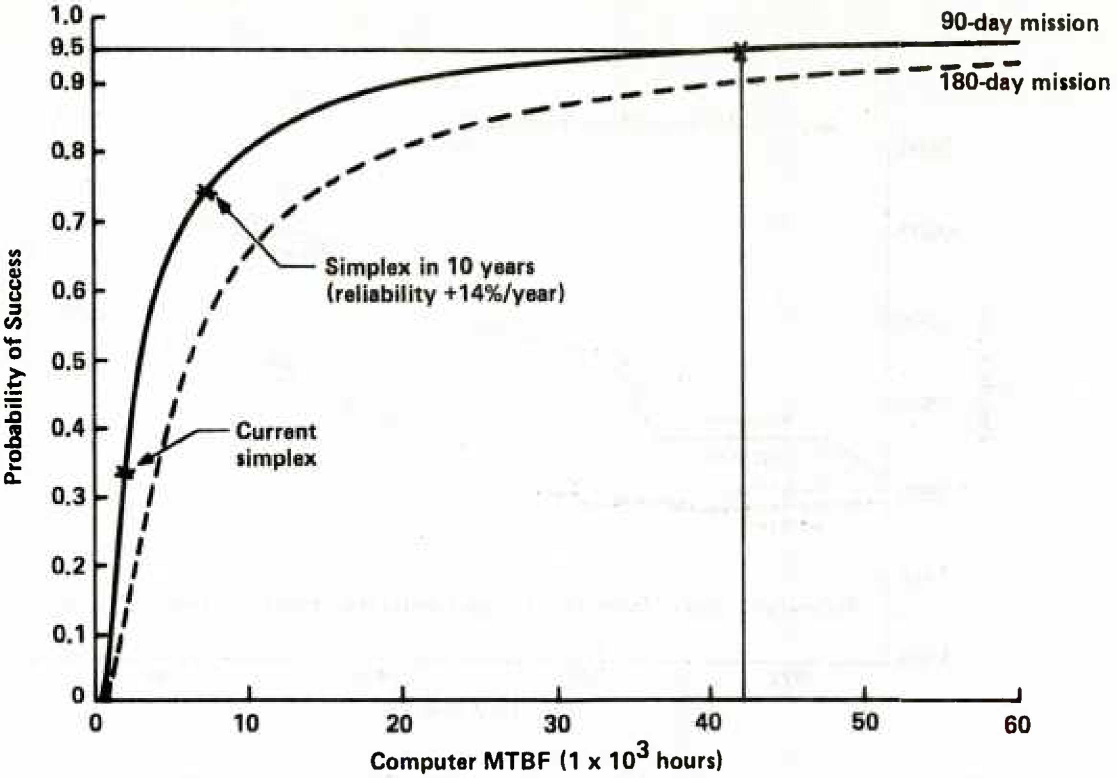


Figure 4-16. Mission Maintenance-Free Computer

As seen from Figure 4-16, a 0.75 probability of success is achieved in 10 years. Clearly a simplex (nonredundant) design is not available in the near future to achieve a mission maintenance-free design.

Some form of redundancy must be implemented to achieve a fault-tolerant design. Figure 4-17 parametrically examines, as a function of reliability growth rate, some redundant designs to achieve the 0.95 probability of success required for no on-board maintenance. Device reliability trends have improved at a significantly higher rate than the box reliability.

Even a duplex redundant design is not sufficient to achieve the requirement. Figure 4-17 suggests that the approach is to design redundancy at internally partitioned levels within the computer to achieve the requirement. In fact, the greater the partitioning, the lower the redundancy required. An effort of additional development and equipment cost penalties are incurred to implement redundancy. Test equiment and maintenance skills at the maintenance site will also be further complicated by a redundant design approach.

The effectiveness of this solution to the total problem is dependent upon more than just the computer, but also the reduced maintenance capability of the host system. Therefore, prior to specific recommendations, the host systems must be evaluated in terms of their ability to

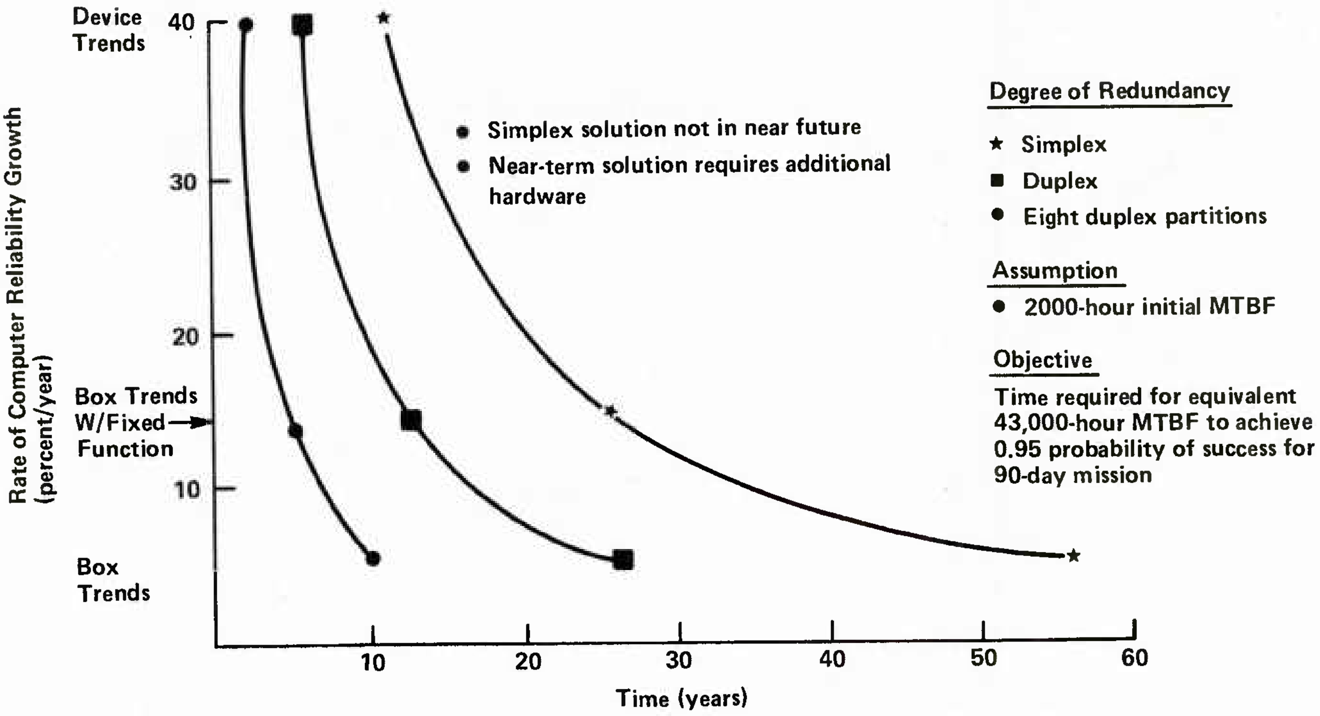


Figure 4-17. Time in Years Until Mission is Maintenance Free

be designed as fault tolerant. Such a study should consider the extent of potential shore maintenance requirements.

Another consideration to reduce maintenance skill levels is to evaluate various options for the level of repair. Alternate repair concepts, such as sparing at the box level, could possibly reduce the required maintenance skills. For the medium-class computer, the baseline configuration is evaluated against

- The computer being returned to depot (only computer unit spares on ship)
- The computer repaired through assembly level replacement, with the assembly returning to depot
- The computer repaired through assembly level replacement, with the assembly being discarded.

These various maintenance alternatives effects on total program cost as a function of the year of development start are depicted in Figure 4-18.

The results of the analysis for the medium-scale computer indicated that the most cost-attractive approach was discard of the module. The computer being returned to depot was the most costly, with the major cost being the number of computer box spares required. With the cost and reliability improvements projected, the cost penalty for the depot repair concept for the computers is significantly reduced. Therefore,

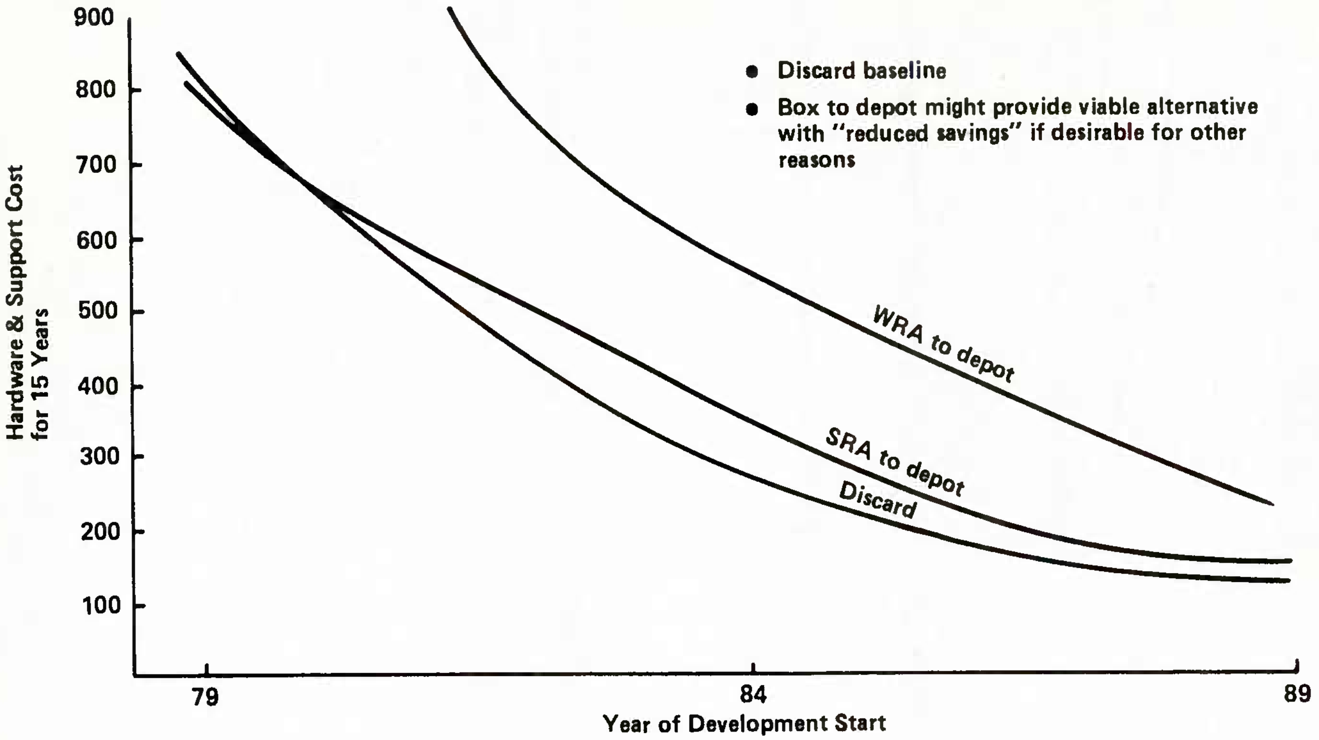


Figure 4-18. Alternate Repair (Medium-Scale Computer)

in the future (≈10 years) this higher level of maintenance might be feasible, and can provide a means for reducing the requirement of data specialist skilled personnel onboard ship.

The large-scale computer was also investigated for alternate repair concepts. A significant cost penalty is incurred by sparing this class machine at the box level, such that the concept is impractical. Future studies should investigate partitioning this machine into smaller replaceable units to make this repair concept more economically feasible.

The preceding consideration could encompass the use of a Reliability Improvement Warranty approach when the computer was returned to depot for repair. This approach has proven successful in the commercial airline industry and also on selected items in the Navy inventory. Usually, a higher level assembly is specified as the removable item with less sophisticated fault isolation techniques. This sealed assembly is then returned to a depot for subsequent maintenance activity.

A cost penalty is incurred for sparing more expensive assemblies in the inventory. However, this cost penalty is balanced by reduction in the procurement and training of qualified personnel. This approach reduces the incidence of induced failures and erroneously removed hardware. A significant rate of 60% of field returns has been attributed to this fact from field depot return history.

It is also recommended that the Navy undertake further study of fault tolerance through distributed systems or internal partitioning, not only at the processor but also at the host system level to determine if within the next 5 years, such a concept should be considered as a part of accreditation of embedded computers.

4.6 CONCLUSIONS

The results of the Life Cycle Cost analysis indicate that significant savings in the Total Program Costs for embedded computers could be realized if an accreditation approach was incorporated and periodic redevelopments were adopted. The Total Program Cost for future Navy shipboard computers was estimated to be about $2 billion, and if an accreditation approach based upon periodic redevelopments to accommodate technology changes were adopted, a savings of approximately 25% could result, reducing the estimated cost to $1.5 billion. Selection of an optimum procurement strategy, implied from the cost analysis to be two developers and one producer, would provide additional savings due to the additional competitive effects in the market. These savings were found to be less significant than the savings from redevelopment, but would further reduce the estimated program cost from $1.5 to $1.4 billion.

The conclusions were based on assuming a fixed function computer set, so that the technology benefits were not adding to the complexity of hardware in the field, but instead were directed at simplifying the currently planned program requirements. The integration of this accreditation concept into current Navy procurement policy is a significant departure from current practices, where the primary motivating factor for a change is enhancement of performance attributes. However, the results indicate that, even when allowing for performance enhancements or additional function, Total Program Costs could still be reduced to 1.8 billion dollars with redevelopment.

The significantly increasing effect of logistics support costs on Total Program Costs has been identified, and is an increasingly important input to development engineering for new designs.

The major areas not addressed in the analyses were software effects and the effects of personnel considerations beyond active maintenance time on the embedded computers. These issues are difficult to assess at the embedded computer level, and require that analyses be performed at the host system or platform level. Adopting an accreditation policy of redevelopment would not affect the support system, if adequately planned, and may in fact provide additional benefits, among which are increased fault isolation capability and increased reliability.

One may view the current standardization activities as a system that allows for a constantly changing base via ECP activity. The accreditation concept is viewed as a system with planned, competitively established, technological enhancements every 5 years. The overall effect is expected to be more manageable and beneficial to operational capability.

Section 5
PROFITABILITY INCENTIVES FOR COMPETITION

One of the objectives of the accreditation study was to induce competition in the Navy computer market. The preceding Life Cycle Cost analysis addressed the attractiveness of competition to the Navy. The attractiveness to the computer developers/producers of the business opportunities which arise from an accreditation policy must also be considered. Unless the policy can generate sufficient competitive interest, accreditation will not be effective.

The Navy has in its control a number of items that affect the profitability of shipboard computer procurements. These include development funding, the maximum permitted profit, and the degree of competition. While total computer requirements may be relatively fixed, the manner in which these requirements are divided between producers also affects profitability. This division can be both in parallel (the number of producers) and in serial (the period of redevelopment). A viable accreditation policy must create a proper balance of these considerations.

Just as the Navy has numerous decision criteria other than cost for evaluating a proposal (e.g., operational effectiveness, integrated logistics support (ILS), supplier risk), a potential developer/producer has numerous decision criteria other than profitability when evaluating a business opportunity. These include the availability of personnel, consonance of the opportunity with business goals, project risk (technical and schedule), the availability and cost of capital, follow-on potential, and the flexibility allowed to meet the contract requirements.

While all of these factors are of importance, their relative importance varies from one firm to the next, and, within a single firm, according to the current needs of the business. For these reasons, a firm may be willing to compromise on one factor to obtain a benefit in another. For example, faced with a surplus of engineering talent, a firm might consider a relatively unprofitable opportunity to be quite attractive. Or a firm might consider a relatively unprofitable opportunity to be an attractive entrance into a new market.

It is important to recognize, however, that the profitability aspect cannot be ignored indefinitely. In the long run, firms must work on a profitable basis or go bankrupt. For these reasons, this study analyzes the profitability aspects of future Navy computer procurements. In addition, these factors listed (e.g., availability of personnel) do not readily lend themselves to a priori analysis.

5.1 PROFITABILITY/INVESTMENT MODEL

Many models can be used to evaluate investment opportunities. For analysis of DoD business, these models are often complicated by considerations such as funding sources (e.g., the relative proportions of IRAD funds, investment dollars, capital). Because the future markets on which this analysis is based are only loosely defined, and because there is no insight into contract specifics, a simple model was required to deal with the problem on a cash flow basis only.

This analysis uses two simple measures of "profitability": the Internal Rate of Return (IROR), which is sometimes referred to as Return on Investment (ROI), and Payback. IROR is a percentage measure of the overal "profitability" of the investment; it is analogous to the interest earned on a savings account. The payback period is not truly a measure of profitability. Rather, it is a measure of risk, because it tells the investor how long it will be before he or she breaks even. Firms are clearly interested in both measures: a project that is highly profitable overall but that does not break even for 8 years may not be attractive.

The model treats investments and profits on a cash flow basis. Investment, in this case, is the computer development cost funded by the supplier. Profits are the markups on production, production nonrecurring startup (NRSU), and on that portion of the computer development funded by the Navy.

The internal rate of return considers the cash flows over the life of an investment:

$$\begin{array}{lccccc} \text{I} & \underline{\text{Now}} & \underline{\text{Year 1}} & \underline{\text{Year 2}} & & \underline{\text{Year N}} \\ & \dfrac{-A_0}{(1+i)^0} + & \dfrac{A_1}{(1+i)^1} + & \dfrac{A_2}{(1+i)^2} & \cdots & \dfrac{A_N}{(1+i)^N} \end{array}$$

where each A represents an annual cash flow. The negative sign of A_0 signifiies that A_0 is a cash outflow (investment).

The IROR is defined to be that value of i which causes the net cash flow line to sum to zero. The time value of money is taken into account in that a dollar received in year 2 is less valuable than a dollar received in year 1. This is simply because the higher exponent of the denominator for year 2 reduces the ability of a dollar earned in year 2 to offset the investment.

The Payback measure is simply the time period for which the profits exactly equal the initial investment. That is, the Payback period is that value of t such that

$$A_0 = A_1 + A_2 + \ldots A_t$$

If the cash inflows are equal, that is

$$A_1 = A_2 = \ldots = A_N + A,$$

then, the payback period is simply

$$\text{payback period} = \frac{A_0}{A}$$

The IROR and Payback are computed for various market scenarios. The data used for the total computer requirements and program costs is consistent with the data used for the Life Cycle Cost analysis. Because that analysis suggests that there is an optimum redevelopment interval of between 3 to 7 years, this analysis considers a 5-year market period and has cut the total 10-year Navy projected requirements in half. The spares percentages are derived from the LCC analysis. These data are shown in Table 5-1.

Table 5-1. Data Used in Profitability Analysis

Program Costs

Machine Size	Development Cost ($M)	NRSU ($M) Single Supplier	Rate (units/mo)	NRSU ($M) per Supplier, Two Suppliers	Rate (units/mo)
Small	1.5	1.3	90	1.2	45
Medium	10	15	60	10	30
Large	30	18	20	15	10

Total Requirements for 5 Years

	Initial Acquisition			Spares (%)	
Machine Size	Units	Unit Cost ($K)	Total Cost ($M)	Single Supplier	Two Suppliers
Small	5,000	5	25	15	25
Medium	3,800	50	190	65	100
Large	1,010	250	253	65	100

5.1.1 MARKET SCENARIOS

Four different market scenarios are considered in this analysis (see Figures 5-1 and 5-2). Each scenario begins with a proposal phase which is followed by two or three development awards. After development is complete, a competition is held to select one or two producers. In the two-producer scenarios, each producer has one-half of the total production requirements for 5 years; i.e., they produce in parallel.

At the time of proposal, each prospective bidder must make a bid/no-bid decision, based (in part) on a profitability assessment. To make this assessment, each bidder must estimate the expected portion of the total available production. Each bidder is assumed to have an equal probability of winning. The expected portion of the total available production is equal to the probability of winning times the expected

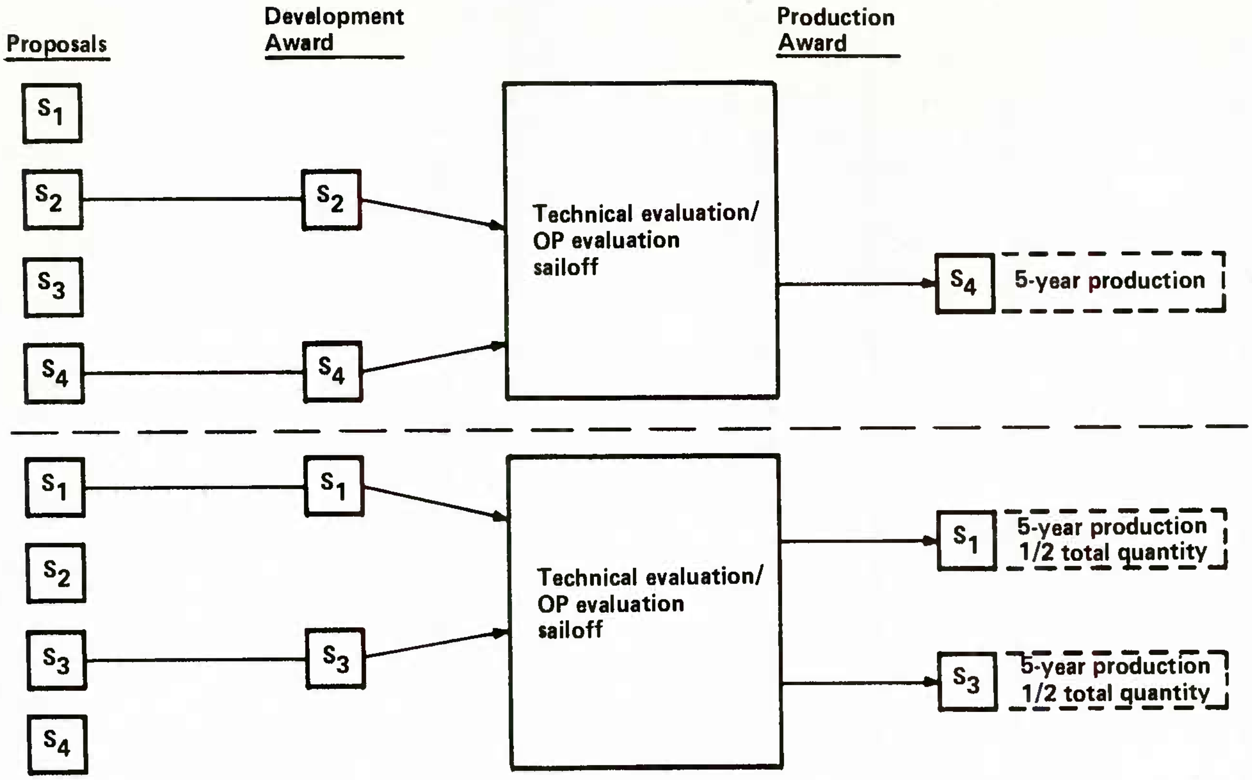


Figure 5-1. Candidate Acquisition Timelines, Two Developers

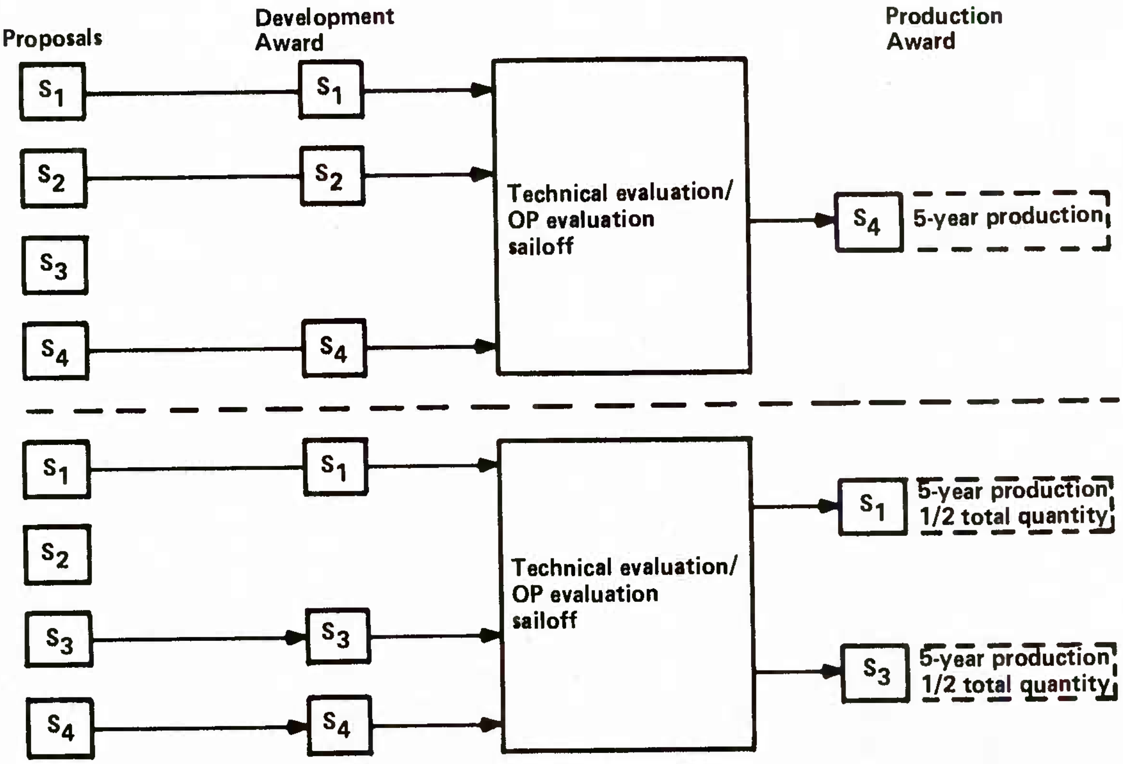


Figure 5-2. Candidate Acquisition Timelines, Three Developers

value of that win (either the whole production quantity or one-half of the total quantity). These calculations are shown for the four market scenarios in Table 5-2. These expected portions of the total available production are used in the profitability analysis. Note, however, that winners exceed their expectations and losers have a greater loss.

Table 5-2. Best Available Investment Information at Time of Proposal

Candidate Scenario

Number of Developers	Number of Producers	Pr (win)	x	E (win)		Expected Portion of Total Available Production
3	1	1/3	x	1	=	1/3
2	1	1/2	x	1	=	1/2
3	2	2/3	x	1/2	=	1/3
2	2	1	x	1/2	=	1/2

Assumptions

1. Proposers have equal probability of winning.
2. No investment until development awards are announced.

5.1.2 CRITIERIA FOR ACCEPTABILITY

To determine what constitutes an "attractive" business opportunity, it is necessary to establish cutoffs for IROR and Payback. There are no universally accepted cutoffs; "minimally acceptable" varies with business conditions, inflation, the risk-taking posture of the individual firm, and many other considerations.

For this analysis, 20% has been selected as the minimally acceptable IROR. This is based on an examination of the current lending rates. If a firm must pay 15% for investment funds, surely it must earn an expected return somewhat greater than 15% for bearing the risk of the investment.

A minimally acceptable Payback is more difficult to estimate, but it clearly must be based on an estimate of the technically viable lifetime of the product. If a computer were expected to be obsolete (i.e., non-competitive) in, say, 5 years, then reliance on revenues for many years beyond 5 is risky. This analysis assumes minimally acceptable payback periods of 3, 4, and 4 years for the small, medium, and large machines, respectively. The lengthening of the payback periods is based on the assumption that larger machines have a longer competitive viability (because of their increased development time and cost).

5.1.3 MODEL ASSUMPTIONS

The model used has a number of simplifying assumptions:

- All costs are incurred and all revenues are realized at the end of each year.
- Development costs are incurred in year 0.
- Production NRSU costs are incurred in year 1.
- Production revenue occurs in five equal, annual amounts.
- Multiple suppliers produce in parallel over the full 5-year time period and equally share the market.
- A hardware price reduction (to the Navy) of 10% or 20% will occur through competition, but the percentage will not increase as a function of the number of competitors. Both percentages are calculated in the model.

These assumptions are used to facilitate calculations.

Table 5-3 is an example of a cash flow scenario examined by the model. This table shows the cash inflows and cash outflows for the development and production of a large-class machine by two suppliers. It takes market and cost data from Table 5-1. It assumes a 10% price break to the Navy (resulting from competition) and an 8% markup (profit) by the suppliers. Spares are at the 100% level.

Cash flows are summed in this table to provide a yearly cash flow line. This cash flow line is used by the IROR and Payback formulas.

Table 5-3. Cash Flow Example

	Cash Flows Per Supplier, $M					
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Investment						
Development cost	(30.0)					
Revenues						
Production NRSU						
(8% of $15M)		1.2				
Production, initial acquisition						
(8% of $126M, less 10%)		9.1	9.1	9.1	9.1	9.1
Spares						
(@ 100%)		9.1	9.1	9.1	9.1	9.1
Net cash flow	(30.0)	19.4	18.2	18.2	18.2	18.2

Large machine, two producers, 10% price break, 8% markup, development funded by producers

5.2 PROFITABILITY/INVESTMENT MODEL RESULTS

This analysis has determined those combinations of Government funding for development and profit on production that will provide both a minimally acceptable Internal Rate of Return and a minimally acceptable Payback period. This was done for each class of machine and for a varied number of competitors and varied price break (resulting from competition). Because the exact amount of the price break resulting from competition is not known, both 10% and 20% price breaks were parametrically calculated.

The results of this analysis are shown in Figures 5-3 through 5-5 for the small-, medium-, and large-class machines, respectively. All of the points on each line represent acceptable business opportunities (i.e., they meet the minimally acceptable IROR and Payback criteria) to the supplier(s).

To help in understanding these curves, consider the two-developer band for the large machine (Figure 5-3) at 10% price reduction. Each producer requires both a 20% minimum IROR and a Payback period of no more than 4 years. The computer requirements (initial acquisition and spares), development costs, and production NRSU costs are as shown previously in Table 5-1. If the producers were to have an 8 percent profit, a Navy investment of approximately $30 million in development funding would be required to make this investment attractive. At a 16% profit, the scenario is attractive with approximately $18 million of Navy development funding.

Consider next the band for three developers and 20% price break. For this scenario, if the producers have an 8% profit, a total Navy investment in development funding of approximately $40 million is required to make the business opportunity attractive to two producers. This development funding is assumed to be split equally between the suppliers. At a 16% profit, approximately $25 million of development funding is required.

For three developers, even larger amounts of development funding are required. Similar interpretations apply to the small- and medium-machine scenarios.

5.3 PROFITABILITY/INVESTMENT MODEL CONCLUSIONS

The most important conclusion to be drawn from this analysis is that, in general, there is seldom sufficient return on investment to attract industry for unfunded development. Hence, the Navy must fund a portion of the computer development costs. The amount of this funding is reduced to the extent that higher profit rates are permitted. At profit rates of, say, 10%, funding of approximately $1.5 million, $2 million, and $35 million are required for the small, medium, and large machines, respectively, to provide adequate profitability to two developers.

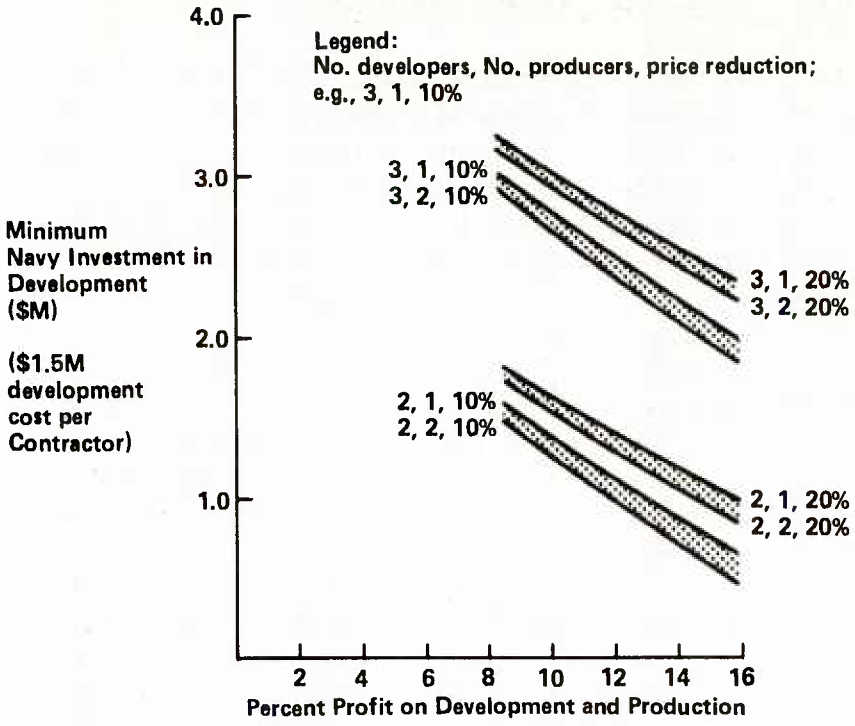


Figure 5-3. Small-Machine Scenarios Which Provide 20% IROR, 3-Year Payback

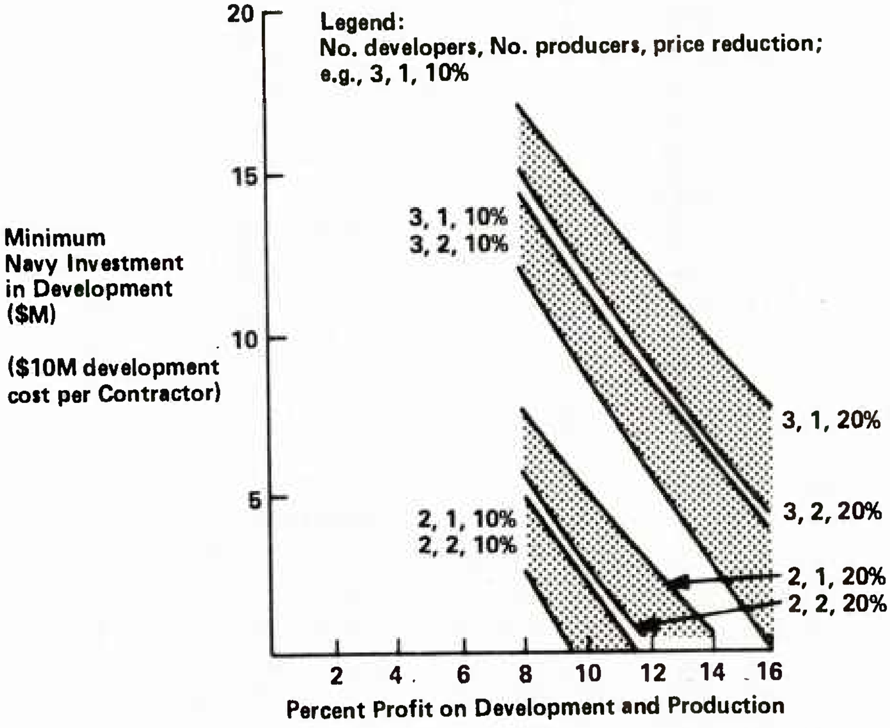


Figure 5-4. Medium-Machine Scenarios Which Provide 20% IROR, 4-Year Payback

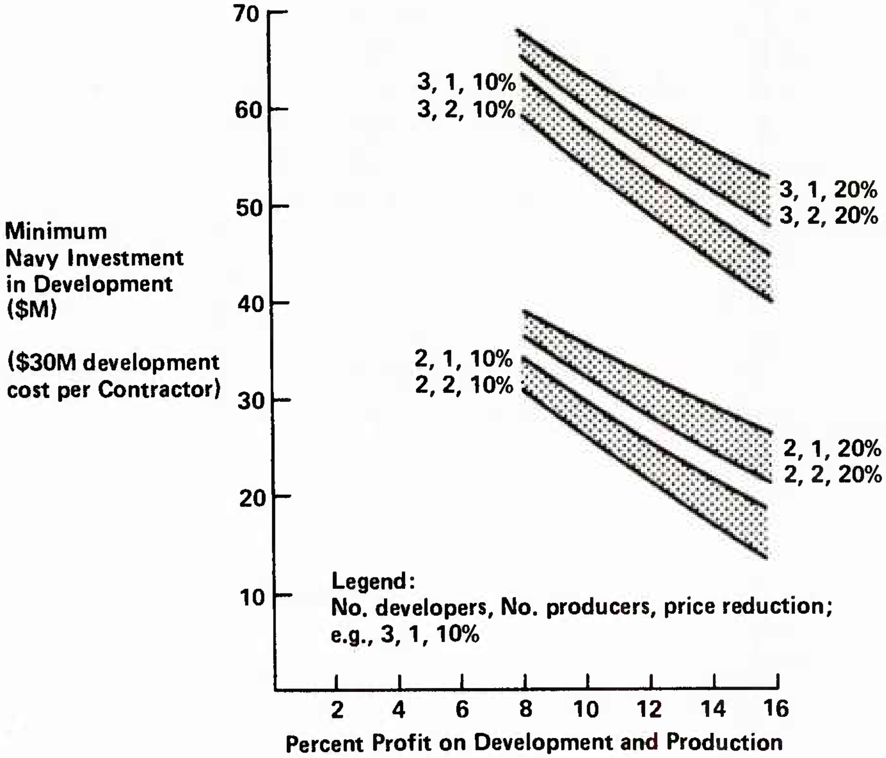


Figure 5-5. Large-Machine Scenarios Which Provide 20% IROR, 4-Year Payback

The foregoing analysis has assumed that there is no technical risk, no schedule risk, and no risk of cancellation. Clearly, adding these risk considerations of the Government market further diminishes industry incentive to invest. As a result, the Navy investments identified above must be even higher than stated.

It is important to recognize that the markets which are defined here are the total markets. They represent the total sales that the producer(s) can expect, including spares. At the end of the 5-year period, the accreditation cycle begins anew, and the existing computers will probably not have the proper technology base to viably compete. For this reason, producers cannot afford to take relatively unprofitable contracts with the hopes of additional future sales to enhance profitability.

5.4 COMPETITIVE PRICE REDUCTIONS VS. ADDITIONAL DEVELOPMENT COSTS

The addition of competition results in additional costs for development. Competition also is expected to provide a price savings on production to the Navy. It is desirable to examine the ability of competitive price savings to offset the additional development costs.

Table 5-4 provides a simple analysis to make this comparison. The additional costs of having more than one producer are shown, as are the assumed savings resulting from competition (for both 10% and 20%). Once again, the savings resulting from competition are arbitrary estimates; no insight as to the true value of those savings is inferred.

The price reductions due to competition can be seen to significantly offset the additional cost of multiple developments. Savings of 10% to 20% could fund between one and three developments, depending on Navy priorities.

Table 5-4. Payback Based on Competition

Production Revenue ($M)	Production Price Reduction 10% ($M)	Production Price Reduction 20% ($M)	Development Cost ($M)
25 (small)	2.5	5.0	1.5
190 (medium)	19.0	38.0	10
253 (large)	25.3	50.6	30

Section 6
COMPUTER ACQUISITION STRATEGIES

6.1 INTRODUCTION

The majority of the tactical shipboard computer systems deployed within the present-day fleet can be traced back to the development and acquisition concepts employed by the Navy since the late 1960's. The procurement practices employed range from noncompetitive selection of sole-source development and production suppliers to competitive selection of a development source, with follow-on production continuing with the same supplier. (See Figure 6-1.)

Current 1980 procurement plans call for the award of dual development contracts, following a multiple-source competition. The succeeding production phase of the procurement will introduce some form of the leader/follower procurement concept.

The AN/UYK-7, AN/UYK-20, and the AN/AYK-14 acquisitions illustrate the practices carried out throughout the preceding decade. The AN/UYK-7 computer development contract was awarded on a noncompetitive basis, and as a result of financial, technical, and time restraints, production follow-on contracts have continued to be awarded on a noncompetitive basis through the present time.

The AN/UYK-20, developed in the early 1970's, followed a similar procurement pattern. The single development contract resulted from a competitive procurement approach; noncompetitive production contracts followed. The sole source production concept remains in force today.

The AN/AYK-14 computer, a current standard for Navy avionics applications, was awarded to a single development contractor following a multiple-source competition. Preproduction requirements continue to be supplied by the development contractor. Current procurement plans for production requirements call for the early initiation of a leader/follower concept, wherein production requirements will be competed between two established sources. Annual quantity requirements would be shared between the two suppliers.

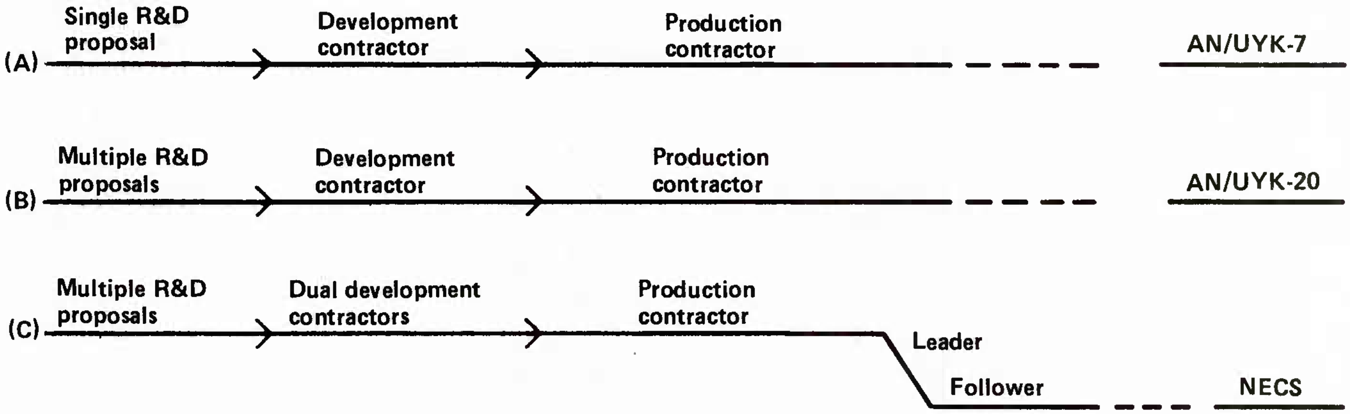


Figure 6-1. Evolution of Acquisition Strategies

The Navy Embedded Computer System (NECS), currently in the formulative RFP stage, has the specified goal of achieving increased operational capabilities and lower Life Cycle Costs while simultaneously avoiding logistic obsolescence. The acquisition plan projected would involve multiple development contracts. Preliminary plans indicate that the sponsoring agency will decide on a competitive production procurement, reflecting some form of the leader/follower approach.

The accreditation acquisition strategy to be described is a further evolution of the preceding procurement approaches. It is intended to enable the Navy to fulfill its computer needs, through a process of accreditation, provided a specified level of performance, reliability, sparing, and maintenance can be accomplished.

The acquisition strategy depicted in Figure 6-2 provides for the solicitation of development phase proposals from multiple industrial sources. The computer specifications prepared by the Navy would be at the highest functional level possible to allow technical innovation and alternate solutions by all potential development suppliers. A form, fit, and function (F^3) level requirement at the box level would be the goal. Realization of the F^3 principle would reduce development costs by providing sources able to accommodate their own design and manufacturing techniques.

Following a Navy selection procedure, multiple development contracts would be issued to the successful bidders. The results of the development program would be verified by an accreditation test program established by the Navy to determine the acceptability of the developed computers. Successful demonstration of all essential requirements would establish the development contractor as an accredited source and a viable contender for subsequent production contract awards.

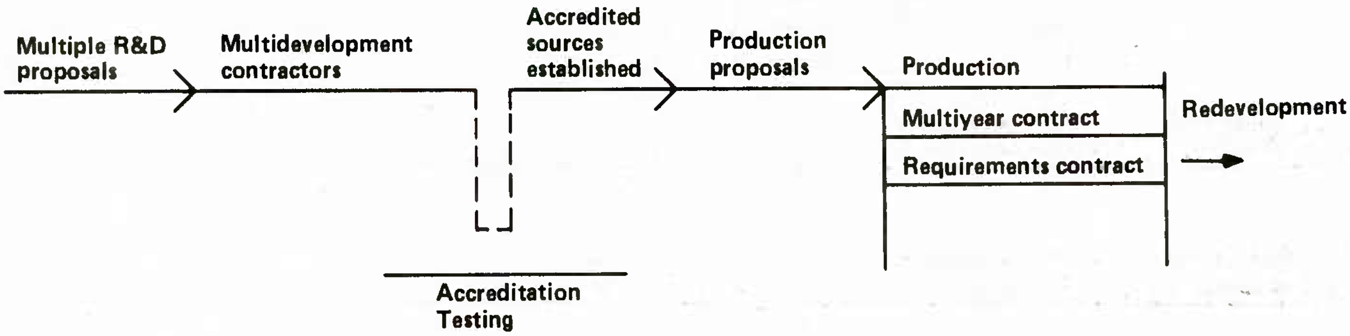


Figure 6-2. Tactical Computer Accreditation Strategy

6.2 CONSIDERATIONS

As stated in Section 2, a thorough and long-range planning function is necessary to establish an effective acquisition program throughout the development and production phases of computer accreditation program. The outcome of the planning stage must result in a procurement plan capable of operating within the bounds of acquisition regulations currently established within the U.S. Navy and Department of Defense.

To satisfy the preceding requirement, the procurement plan must provide

- A clear definition and understanding of technical requirements and operational needs
- An evaluation of Life Cycle Cost projections in relation to program affordability
- Realistic production commitments over a planned period
- Procurement policies for multiple sources.

6.3 THE ACQUISITION SCENARIO

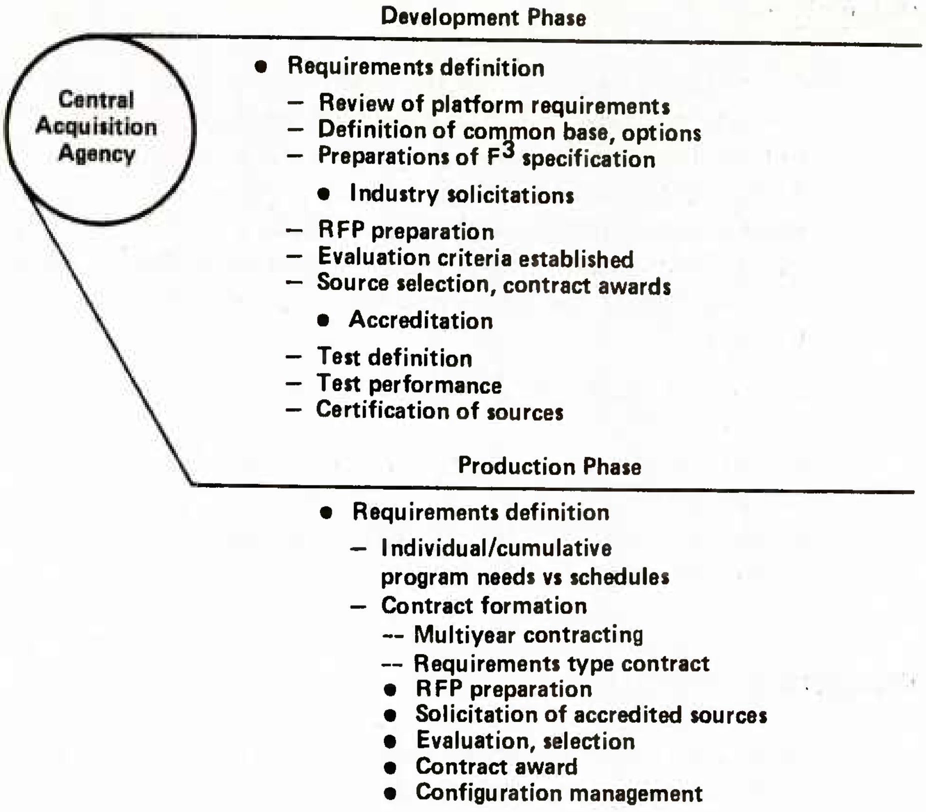
The acquisition structure depicted in Figure 6-3 should provide the Navy with a basic framework for future long-term computer development and production efforts. To ensure achievement of a common computer requirements base and a configuration level acceptable for carrying out many diversified applications, centralized control of the planning and procurement activity is a primary requisite.

The recommended vehicle for use throughout the embedded computer accreditation process is a Central Acquisition Agency to carry out the tasks outlined in Figure 6-3.

To provide an adequate focus on the accreditation program and to relieve the "computer" from competing for funding support with other elements of a designated system, appropriations for this vital element should be separated and controlled outside the individual system manager's function. The resulting autonomous status would relieve the Agency from the dependency on weapon system funding allocations. Undue influence by one user or potential user would be eliminated, enabling the Agency to structure a development and production program most beneficial to all.

The initial task of the Agency would be to identify all newly planned tactical computer applications within the fleet for a prescribed duration. A 10-year prospective in each performance class would satisfy this requirement. Operational specifications would be defined, along with reliability and operational goals.

The request for proposal would be prepared for the development phase(s) of the near-term efforts, utilizing existing Navy and Department of Defense acquisition regulations. Thorough planning in this area would be essential to ensure a wide range of interest with industry.



Development Phase

- Requirements definition
  - Review of platform requirements
  - Definition of common base, options
  - Preparations of F^3 specification
- Industry solicitations
  - RFP preparation
  - Evaluation criteria established
  - Source selection, contract awards
- Accreditation
  - Test definition
  - Test performance
  - Certification of sources

Production Phase

- Requirements definition
  - Individual/cumulative program needs vs schedules
  - Contract formation
    - Multiyear contracting
    - Requirements type contract
    - RFP preparation
    - Solicitation of accredited sources
    - Evaluation, selection
    - Contract award
    - Configuration management

Figure 6-3. Acquisition Approach

Industry should then be invited to review and comment on draft copies of the proposal request. Such preliminary reviews would provide the Navy an insight into the interest, recommendations, and ability of industrial sources to respond and eventually participate in the development effort. The final version of the request for proposal would include the pre-established Navy criteria to be used during the evaluation of all industrial submittals.

The selection process carried out by the Agency should result in multiple industrial development efforts. The scope of the multiple-source effort should allow the competitive process to continue between highly rated, competent sources during the development phase. The culmination of the development effort would be the demonstration and test of the development computer hardware to determine accreditation status.

The production program concept outlined in Figure 6-3 is intended to promote the use of a small number of computer types for system applications. The acquisition approach continues to emphasize the role of the Central Acquisition Agency in identifying and coordinating all computer requirements for the production phase. Source selection and contract formation continue at the Agency level.

Again, the Agency must determine the most viable approach to be used during the competition among the accredited sources. Current defense acquisition regulations provide guidelines for the alternate methods of contracting available and appropriate for use under the production accreditation concept. A competitive proposal and selection activity between all accredited development sources would result in the selection of a single production source.

A multiyear type contract is recommended for use in the production acquisition stage. This contract approach is suitable when a viable market has been established, along with definitive delivery schedules for computers (supplies) within a specified class. The elements of this contractual approach are outlined in DAR 1-322 and include the following:

- A projection of requirements covering a period of up to 5 years
- Contract provisions covering protection of the Contractor against loss resulting from cancellation
- Maintenance of the competitive environment among potential industrial sources.

The multiyear procurement approach provides an equitable contracting vehicle to all parties to the acquisition process. Industry is presented with a definitive production base under which management can determine reasonable investment and risk. The Government Procurement Agency realizes the advantage of better cost distribution by allowing nonrecurring costs to be distributed over large numbers of units. The multiyear funding approach is beneficial because it allows potential sources to consider committing capital investments that could result in decreased costs to the Government.

The current Defense Acquisition Regulation outlining the use of the multiyear procurement approach contains a specified limitation of $5 million as the maximum amount available in the event of contract termination, to cover contractor nonrecurring costs. Consideration should be given to a legal revision to increase the current dollar limitation covering the recovery of contractor nonrecurring costs. This, along with appropriate economic price adjustment provisions, would further strengthen the industrial source base available to future Navy accreditation programs.

An alternate production contractual approach is the requirement-type contract. This contractual approach, as described in DAR-3-409.2, would give the Navy a vehicle to enter the production phase when quantities and delivery schedules cannot be projected definitively. The requirements contract would provide

- Provisions for placement of "orders" under the base contract within the agreed upon contractual period
- Commitment of funds under each order as released.

The indefinite-type requirements contract provides the procuring agency with a vehicle to combine requirements where feasible into one quantity procurement, effecting a potential cost savings, while simultaneously maintaining inventories at a desired (nonsurplus) level. To be acceptable among the potential sources, the contract must provide meaningful minimum and maximum quantities to be acquired to allow industry to make fruitful management investment decisions.

6.4 ON GOING CONCEPT ANALYSIS

In addition to administering the specific development and production phases of a computer acquisition, an important function of the Agency will be to maintain currency within the computer environment. The dynamic evolution of computer technology, the influences of the economy, the performance to existing plans, all influenced by changes to mission needs and requirements, necessitate a continuing emphasis on the planning function. During the production phase, and in anticipation of redevelopment, the Central Agency must be tasked to review accomplishments to date and plan toward meeting the future Navy needs.

In reviewing accomplishments, the facts surrounding the planning efforts associated with the previous development cycle should be analyzed. What method could be improved? What steps could be taken to assure more accurate or earlier data? Was the technology concept sound and achievable? Were the proper resources sufficiently utilized? The answers to these questions should influence, in a positive manner, the planned redevelopment activity.

Simultaneously, the anticipated mission needs must be focused on as a continuing responsibility. What do the System Commands require, what is the commonality of these requirements, and, where needs differ, how or can they be brought together? This internal effort is crucial, but full benefit can only be derived when integrated with an understanding of technology availability.

The Agency must remain abreast of what will be available from industry during the redevelopment time period. This can most effectively be accomplished by initiating studies with industry. The study tasks should define the desired goals, and industry should respond with solutions for their achievement or definitions of what can be achieved in the various technological areas.

This concept definition activity will improve the future by building upon lessons learned. It will, through a broad base involvement, better define what is available from industry, which translates into achievable and affordable technology enhancement. It would also allow industry, in addition to the current producer, to remain involved, provide its expertise, and plan its own future business activities.

Section 7
ADDITIONAL CONSIDERATIONS

While factors like technology trends, redevelopment, the number of developers and producers, Life Cycle Cost optimization, and an acquisition framework are key to the concept of accreditation, a number of other factors should be integrated into a workable policy. These factors include (1) the level of standardization (e.g., build to print, module F^3, box F^3), (2) architecture certification, and (3) the significance of commercial developments are addressed in this section.

7.1 LEVEL OF STANDARDIZATION

If the Navy decides to have multiple developers and producers as part of an accreditation policy, then the level of identicality at which computers are to be standardized must be determined. The selection involves a tradeoff of numerous factors.

First, Navy objectives or requirements for standardization must be considered:

- Operational software transportability
- Support software compatibility
- Minimize LCC (e.g., hardware cost, spares requirement, and training)
- Maintain common test equipment
- Permit technology infusion
- Provide reasonable performance
- Maximize system availability.

The selection of a standardization level affects all of these objectives and, unfortunately, no one level of standardization solves all problems.

The basis for multiple-sourcing of computers could be summarized as follows:

> Obtain the greatest "functional" capability per dollar, and ensure that this functional capability will always be available (e.g., do not allow national security to hinge on the fortunes of one company).

Consider first the goal of achieving the greatest "functional" capability, which could be expressed in terms of KOPS of performance, bytes of memory, reliability, channels of I/O, etc. A periodic redevelopment cycle every 4 to 7 years will provide significant technology infusion, regardless of the level of standardization.

Standardizing on the Build-to-Print level, however, limits this functional improvement to a single new design and, to some degree, restricts competition. Giving suppliers the ability to meet a functional requirement on a module or box level, in the best way that they know, increases the probability of more effective designs. The higher the level of definition (box F^3, in this case) the greater the flexibility afforded a developer/producer. An F^3 level of standardization would permit the program manager to optimize functional capability on "performance" parameters (reliability, throughput, memory capacity, etc.) that are the most important. In addition, the higher the F^3 level of standardization, the greater the probability that more "functional" capability would be available.

7.1.1 COST VERSUS STANDARDIZATION LEVEL

Total LCC is highly dependent on the level of standardization and the number of producers. This study considers how cost is affected by the level of standardization by analyzing the major cost components (software, acquisition, and logistics) separately.

The most significant of these is software costs. The primary goal of computer standardization is the containment of software costs by standardizing on an instruction set architecture (ISA). This provides the benefits of support software compatibility and operational software transportability. Note that all three standardization levels provide a standard ISA. Test software used for diagnostic purposes is, however, unique to the particular hardware; thus, F^3 standardization would incur higher costs.

In the area of logistics costs, build to print and module F^3 have advantages. They provide minimum spares, common support equipment, and minimum training and documentation. This is not true of box F^3.

Acquisition costs must be divided into the components of design, NRSU and recurring costs to see the effects of a standardization level. A single final design under the build-to-print approach would apparently result in the lowest design costs. However, there is usually a development competition and a "fly-off" between competing designs, so more than one design is actually done. Also, the additional cost of generating and maintaining adequate documentation so that a second manufacturer can build the first's product is significant. Therefore, it is not clear which standardization level offers the lowest design cost.

The manufacturing NRSU costs are clearly the lowest under the box F^3 approach because the producers have the flexibility to use their own processes and tools. Module F^3 would require additional tooling and test equipment to handle different form factors. For the second producer, build to print would require even further expenditure to put equivalent manufacturing processes in place, as well as mold existing manufacturing operations to the new product.

The lowest product recurring costs should be obtained under the box F^3 approach because the suppliers are given the most latitude to meet requirements. Both module F^3 and build to print restrict this flexibility.

In summary, just the costs of the different standardization levels do not clearly indicate which approach is the best. Historical data suggests that logistics cost are more significant than acquisition costs, making the build-to-print approach more attractive on a cost basis. However, in the future, technology trends show that reliability will continue to improve, resulting in reduced O&M/logistics costs.

7.1.2 OTHER CONCERNS REGARDING STANDARDIZATION LEVEL

Accountability is a critical factor. That is, if the computer does not work properly for some reason, who is at fault and who is responsible for correcting the problem? Under the box F^3 approach, the answer is comparatively simple, as only one supplier designed and built the box in question. For module F^3 and build to print, is it the specifier of the design or the manufacturer of the design? The problem lies in the difficulty of completely specifying design, processes, etc.

At the module F^3 level, the complete and unambiguous specification of complex logic functions can be quite difficult to meet. Typical modules can have hundreds of signals and test points that must be specified in terms of function and timing. The specification problem can be mitigated through the use of simple standard modules, but this may compromise design efficiency and performance.

Problems also arise at the build-to-print level. Prints often may not be complete enough to build a product that functions properly. The first manufacturer can point to their product, which works properly; the second manufacturer can point to their build-to-print product, which does not work properly. Resolution of these dilemmas can be difficult.

Another critical concern is the attractiveness to producers of participating at different levels. A significant proportion of DoD computers have been produced by companies that have assumed responsibility at all levels: initial specification, design, build, test, and product support. This is box level F^3. It could be expected that build-to-print business, which does not utilize the existing engineering expertise, would be unattractive to a "full-service" computer supplier and reduce "full support" to the Navy.

7.1.3 STANDARDIZATION LEVEL SUMMARY

There is no clear-cut best level at which to standardize. Nevertheless, a selection must be made. IBM recommends that the Navy standardize and procure at the box F^3 level because this will best encourage competition and will permit suppliers the maximum flexibility to meet the Navy's needs. The difficulty of specification can make module F^3 a highly risky approach. As computers become more reliable due to technology improvements, product costs will become more significant relative to logistics costs, and will reduce the logistics benefits of build to print.

7.2 ARCHITECTURE CERTIFICATION PROCESS

How does one test different computers from multiple vendors to verify that they conform to the standard ISA? The cost benefits available from architectural compatibility (i.e., common support software, transportability of application code, and programmer training) can only be captured if the machines precisely represent the architecture.

It is difficult to guarantee architectural compatibility. Architectural discrepancies can be very subtle in nature and result from such things as interactions between instructions, data sensitivities, and storage location sensitivities. It is not feasible to exhaustively test a machine to be sure that no architectural discrepancies remain. For example, just to check all possible pairs of instructions for each memory location with each data pattern would require more than 10 years for a typical machine. As a result, one must settle for reasonable testing.

IBM has recently completed an Air Force study contract on certification. The Air Force faces the same problem with multiple industry implementations of the MIL-STD-1750 architecture.

The 1750 certification study began with the identification of different techniques for performing architecture verification. Eight different techniques were identified. These were investigated by site visits to the locations where they were in use. These methods were evaluated on the basis of cost of implementation and its effectiveness at finding architectural discrepancies. The significant software effect associated with not finding architectural discrepancies at the time of certification lead to a recommendation of a two-phase test.

The first phase of testing relies on a "functional" type of test, which is comprised of a series of manually generated test cases. This method is summarized in Tables 7-1 and 7-2. The functional approach provides a predefined minimum level of testing. The second phase of testing is based on the "Random" approach. This test uses a random number generator to create instructions and data. These are executed in a sequence on both the machine under test and a simulator. The results are then compared. Table 7-3 and Figure 7-1 summarize this method.

The combined approach provided both a predefined minimum level of testing (from the functional test) and a high degree of quality (from the random test). The latter is due to the execution of both instruction sequences (to catch interactive effects) and a large number of instructions and data patterns.

The Navy should consider such a certification approach as part of the accreditation process.

7.3 COMMERCIAL DEVELOPMENTS

IBM examined the possibility of capturing the developments being made in the commercial computer environment and using them as building blocks for military computers. The motivation is quite clear if one

Table 7-1. Functional Type Test Overview

- Test approach
  - Apply a priori knowledge of computer testing to select test cases
  - Test boundary conditions
  - 5, 000 cases have historically been utilized
- Test case
  - Initialize registers and main storage
  - Execute one instruction
  - Compare to predetermined results
- Functional types differ significantly in their intended applications from engineering bring up through field testing
  - Some assume nothing works, and only a core set of instructions is available
  - Others assume everything works and all instructions are available
- Quality depends upon number and the amount of insight that was applied to selection of test cases
- Maturity can improve over time by addition of new, independent test cases
- Major cost expenditure element is the generation of test cases
- Cost is a direct function of the number of test cases

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considers the relative magnitudes of research and development funds available to commercial and the resulting technology breakthroughs that are being made versus that of the military computer communities.

IBM examined the price/performance index of its commercial computers. This index has price/performance improvement of approximately 15% per year, similar to the cost performance index for military computers. This would suggest that technology improvements have had similar effect on the two segments of the same company in spite of the differences in competitive environments and design objectives. It would appear that the infusion of technology is predictable.

A closer examination of technology infusion into military computers generally shows it to be limited to regular functions such as memory arrays, programmable logic arrays (PLAs), some microprocessor

Table 7-2. Functional Type Test

The following tests are performed:

- Test basic instruction
  - All formats
  - Function
  - Addressing
  - Correct status word alteration
  - Interrupts
- Tests memory
  - All 64K patterns in all locations
  - Protection
  - Priority
- Test registers
  - General registers all 64K patterns
  - Interrupt mask register, status register, fault register, CPU registers
- Miscellaneous tests
  - Timers
  - Discretes
  - Interrupts
  - DMA
  - Random instruction for illegal OP code

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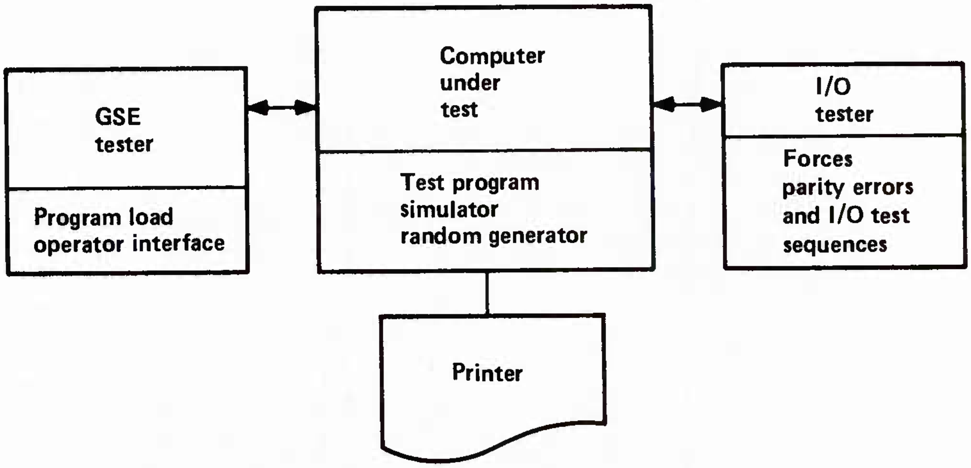
devices, etc. In fact, the average integration level of a modern military medium-class computer is about 1/10 of that of high function devices. The following are some considerations as to why this is occurring.

7.3.1 BUSINESS VOLUME

Currently, technology is being influenced by large-volume demands for two reasons. First, while device recurring costs are low, the technology development cost and the device personalization cost for custom function devices are very high. The use of LSI technology is economical only when these fixed costs can be borne by a large production base. This kind of production base is not generally found in the military market. Secondly, the rise in demand for commercial consumer products has strained the capacity of the device manufacturers, and they have turned their attention away from the less profitable markets.

Table 7-3. Random-Type Test Overview

- Test approach
  - Instructions and data automatically generated by random number generator
  - Boundary conditions not specifically tested
  - Errors due to interaction of instructions are captured
- Test block
  - Initialize registers and main storage
  - Execute sequence of randomly generated instructions (32-instruction block)
  - Compare to simulated results
- Quality can easily be increased by running longer
- Major cost expenditure element is for the "golden" simulator
- Cost is relatively independent of the number of test cases. This has potential for lowest cost per test case (because more cases are easily obtained by running longer).



Description

- o Computer under test is initialized to a known state
- o Variable length block of random instructions generated
- o Random block simulated under control of implementation table
- o Random block run on hardware
- o Results compared to simulated results
- o If comparison fails, replace last instruction with no-op until failing location found
- o Replace last instruction, run and print failure mechansim
- o When block analysis complete generate next test

Figure 7-1. Random-Type Test

7.3.2 FUNCTIONAL EQUIVALENCE

Military embedded computers have evolved with their own unique architectures, support software systems, and interfaces. As a result, the organizations and detailed logic designs of military computers are different from commercial. This limits the application of LSI devices developed for the commercial market.

7.3.3 PERFORMANCE CONSIDERATIONS

Transfusion of common function devices such as data flow, PLAs, etc., is also limited because most military computer designs are performance driven. Experience has shown that, in many instances, available high-function devices can only be used with some sacrifice in performance. Rather than compromise performance, the designer is forced to use more conventional logic. This is especially true in the medium- and large-class machines.

7.3.4 USE OF MICROPROCESSORS

Microprocessors are most likely to be found as controllers, embedded in I/O modules, or CPUs for small class computers. Again, the need for performance and special military specified functions has limited the application of microprocessors in medium- and large-class computers.

7.3.5 ENVIRONMENTAL FACTORS

The unique environmental requirements imposed on the military have also had an effect on the use of commercially developed devices. First, there are fundamental technology constraints at the device level, such as survivability in nuclear environments, which constrain the choice of technologies. In addition, environmental considerations require that special design constraints be placed on the device developers, especially in the area of packaging.

7.3.6 COMMERCIAL DEVELOPMENTS SUMMARY

In summary, military computer development trends are comparable with the commercial computer developments. There, the similarity ends. Variables such as MIL-SPEC environment, control of market offerings, business volume, DoD unique performance requirements, and world-wide military deployment logistics make the application of technology to computer development drastically different for both establishments. This is not likely to change. However, at each redevelopment cycle, commercial technology advances should be assessed and integrated where possible. Box F^3 helps support this goal.

- Sensitivity Analysis
  - Even if the full technology projections are not realized, the conclusions for redevelopment are still supported. Of course, total LCC savings are reduced, and the redevelopment interval moves out to the right.
  - For all the acquisition scenarios evaluated, multiple developers/single producer has a slight LCC advantage over other alternatives, but the final selection must consider qualitative factors such as operational readiness, single-source susceptibility, increased program management, etc.
  - Even with redevelopment, the production learning curve has an effect on hardware acquisition and spares cost, and any significant changes (e.g., dividing computer requirements between two producers, or not realizing total production, etc.) in the "defined market" will cause an increase in LCC.
  - Hardware competitive savings of anywhere from 10% to 20% support the need for multiple developers and can produce from 5% to 10% total Life Cycle Cost savings.
- Maintenance Considerations
  - The objective of mission maintenance-free computers is not realizable in the near term (next 10 years); aspects of redundancy, partitioning, and distributed systems with fault tolerance must be considered.
  - The maintenance/ILS concept of SRA discard is optimal for the large and medium computers; however, the cost penalties of WRA to depot may, in the future, be acceptable in light of other considerations; e.g., maintenance personnel.
  - The maintenance personnel problem (especially in the Data Specialist area) may be mitigated by the following considerations:
    - Mission maintenance-free computers
    - RIW/WRA to depot support concepts
    - Commonality between classes of processors to reduce multiple training aspects
    - Extensive self-diagnostics/BITE in computers, thereby reducing required skill levels.

8.3 PROFITABILITY ANALYSIS

The profitability analysis evaluated (from a seller's perspective) whether a reasonable and attractive business opportunity existed, based on market projection data provided by the Navy. It also attempted to answer two other questions: (1) Should the Government fund development?, and (2) Is "redevelopment" still profitable? The following conclusions resulted:

- With redevelopment (5-year production market assumed), a reasonable business opportunity existed for all three classes of computers; however, sufficient ROI seldom exists to make unfunded developments attractive.

- Risk to Government market stability further reduces the incentive to invest. This, coupled with ROI considerations, means that the Navy must provide development funds.
- Savings in production from competitive development can offset the Navy's cost for multiple developments.
- On a profitability basis, multiple producers further reduce revenue and ROI by reducing the production quantity for each producer. Hence, multiple developers/single producer seem optimal.

8.4 ACQUISITION CONSIDERATIONS

The primary objective of the Acquisition Framework Analysis Task was to

- Review current Navy computer acquisition policies
- Integrate the technology, LCC, and profitability and accreditation considerations
- Formulate a potential procurement framework.

This task was constructed from a procurement/contracts reference. The results of the Acquisition Framework Tasks are as follows:

- Establish a shipboard computer Central Acquisition Agency responsible for planning, requirements definition, coordinating user commitments, specification development, funding, procurement, and overall program management. Fund this agency on an independent basis to avoid conflicts.
- Production contract commitments should be considered on a multilayer funding basis or on a requirements basis; the former is more desirable.
- Manage with the goal of periodically redeveloping approximately every 5 years.
- To effectively manage redevevelopment to ensure timeliness and responsiveness to evolving Navy priorities, establish on-going studies within the Navy to measure and analyze trends, priorities, etc., for accreditation.
- The recommended acquisition scenario consists of
  - Dual development awards
  - Single production source
  - Multilayer funded production procurement
  - Redevelopment after approximately 5 years.

8.5 CONCLUSION

From the described study results, IBM concludes that the defined concept of accreditation is worth evaluating, appears to have a reasonable evolutionary basis for implementation, provides a meaningful benefit to the Navy, and should be implemented. Further studies are warranted to

Section 8
SUMMARY AND CONCLUSIONS

The accreditation framework proposed by IBM as a result of this study contract has as its basis five key premises:

- Periodic redevelopment should be implemented.
- Multiple competitive developments and a single production source is preferable.
- A reasonable business case must be constructed for industry, based on
  - Adequate market projections
  - Government funding for development.
- An acquisition policy, based on a commodity procurement agency, Box F^3, ISA certification for software portability, and production commitments is desirable.
- On-going concept formulation studies should be performed to adequately provide a foundation for decisions regarding accreditation.

The proposed accreditation framework is an evolutionary rather than a revolutionary one and is based on the assumption that drastic change could be chaotic and detrimental. The Navy's computer acquisition policies are continually changing (e.g., NECS/UYK-43) and Accreditation was defined by IBM as the next step beyond current policy to meet future needs and is consistent with evolving computer development trends.

As was described in the Study Methodology subsection, IBM chose to focus on four analysis areas:

- Technology trends and projections
- Life Cycle Cost (benefits to the buyer (Navy))
- Profitability (benefits to seller (Industry))
- Acquisition considerations.

The following is a summary of results of the Accreditation study and is organized by the four selected areas of study.

8.1 TECHNOLOGY TRENDS AND PROJECTIONS

IBM examined device as well as military computer trends, based on IBM FSD experiences of computer development and production. IBM found that

- Device level integration and performance increases (40%/year) exceeded that of computers at the box level (≈16%/year).
- Computer reliability is improving at approximately 14% year (again at the box level), but may be somewhat offset by more complex, higher function computers in the future.
- Computer price/performance is decreasing at approximately 16%/year.

In summary, based on past history, technology advances for the near future (next 10 years) are likely to continue, and its benefits suggest a policy of periodic technology infusion.

8.2 LIFE CYCLE COST

The Life Cycle Cost analysis focused on four areas of interest for accreditation:

- Effect of technology on LCC
- Optimizing development vs acquisition/logistics support costs
- Sensitivity analysis for
  - Acquisition scenarios
  - Rate of technology improvement
  - Production learning curve considerations
  - Competitive savings during the production acquisition
- Maintenance considerations
  - Logistics concepts (depot, SRA, vs. WRA repair)
  - Mission maintenance-free computers
  - Maintenance personnel impacts.

In examining all potential aspects of Accreditation which could provide cost improvement, IBM found that, in an estimated total computer program cost for the Navy of $2 billion, reductions of $0.5 to $0.6 billion could be achieved by periodic redevelopment.

The following is a summary of the Life Cycle Cost Analysis study task results:

- Technology Effect on LCC
  - Hardware cost/performance decreases substantially, reducing LCC in the areas of initial installed hardware and spares.
  - Improving computer reliability will reduce LCC in the areas of spares and recurring O&M.
  - For the assumptions baselined (fixed computer function, constant year dollars, and an established design in 1989), and for the technology projections estimated, LCC for 1989 computers will be nominally one-fifth of what it is today.
- Optimal Redevelopment
  - Based on the estimated technology projections and computer development and support costs, a periodic development approximately every 5 years appears reasonable.
  - Timely redevelopment provides the lowest total LCC; e.g., anywhere from 17% to 25% over no redevelopment.
  - Waiting too long, (>5 years) clearly costs more.

revalidate conclusions, properly integrate priorities, and define a detailed plan to make accreditation happen.

Accreditation as structured by this study appears reasonable. It has attractive features for industry and is responsive to the Navy's needs. IBM supports this progressive concept.

Section 9
RECOMMENDED FUTURE EFFORTS

Although this study has established a potential framework for Accreditation that appears to be a reasonable, evolutionary step in future Navy computer acquisition policy, further analysis and definition by the Navy of this concept is warranted prior to any policy implementation.

During the Navy review of IBM's Accreditation study results, some areas of further study were suggested, alternative acquisition policies considered, and revalidation of baseline data and assumptions discussed. The following summarizes additional study efforts which should be considered in future studies.

- Continuing Revalidation of baseline assumptions and data used in the three major analysis areas (LCC, profitability, acquisition policies)
- Further explore the aspects of computer maintenance personnel minimization, particularly in the areas of
  - More reliable, (mission maintenance free?) computers - system partitioning considerations, etc.
  - Trade off maintenance manpower problems (limited resources, training, system operation) against current ship logistics priorities
- Analyze an Accreditation concept where commonality exists between all three computer types (small, medium, and large): feasibility, LCC effect, acquisition policy, etc.
- Evaluate the effects of computer retrofit, based on periodic redevelopments
- Develop a strawman detailed implementation plan to define, step-by-step, a checklist of actions required to initiate policy for accreditation.
- Examine the policy of HOL standardization, which could potentially have an influence on computer hardware standardization and even on the concept of accreditation
- Re-evaluate the potential roles of the Accreditation principals (platform manager, development manager, etc.) to ensure consistency with Navy organizational policies.

IBM would welcome discussions on any of the preceding if further follow-on activity for Accreditation is contemplated.

Appendix A
ASSUMPTIONS FOR MODEL IN LCC ANALYSES

The Constituent elements and basic assumptions used in the Life Cycle Cost Analysis are defined and explained in this appendix.

A hardware baseline was required to provide some reasonable scenarios with which to extrapolate to future computer accreditation concepts. The Navy has two computers which are standards today - the AN/UYK-7 and the AN/UYK-20. Indications are that future weapons systems will require these two classes of computers as well as a small "under-the-covers" processor. Therefore, for this study three classes of future computers were considered, defined as small, medium, and large. The data required for each class of machine includes estimates of acquisition cost, quantities, reliability, development cost, and production nonrecurring start-up (NRSU).

A.1 CONSTITUENT ELEMENTS

The Life Cycle Cost model is composed of three constituent elements: development, investment, and support costs.

A.1.1 DEVELOPMENT COST

The development costs consist of contractor and Government cost. For this study, the development costs were estimated by a cost engineering group for each class of computers. The development was assumed to be a full-scale development engineering program for a form-fit-function computer which would then be followed by a full production phase.

It was realized that this would represent the lowest cost procurement approach as compared to build to print, module F^3, or variations of each. The development cost figure was maintained at a fixed sum independent of year of development. This figure was also used as a base for establishing Government development support costs, which were fixed at one-half of Contractor development costs. Table A-1 summarizes items related to development costs.

A.1.2 INVESTMENT COSTS

The investment cost is made up of four major elements: (1) acquisition of prime equipment hardware (2) nonrecurring start-up (NRSU) costs, (3) Government program management, and (4) acquisition of support equipment, training, supply support, and technical data. The unit hardware cost was established for each class of machine. The cost was modified during redevelopment cycles to reflect the technology and cost improvements projected during that time period.

Table A-1. Items Related to Development and Production NRSU for Navy Computer Accreditation Study

Development	Rate Related
Electrical Design	
Mechanical Design	
Environmental Engineering	
Systems Engineering	
Qualifications Testing	
Reliability Demonstration	
Manufacturing Support R/M, QE, CA, ME, PT	
Test and Support Software	
ILS	
IE	
Data Requirements	
Engineering Test Hardware	
Test/BI Equipment	

Production NRSU	Rate Related
Software Cleanup	
Other Design Changes	
Manufacturing Test/Env. Equipment	R
Tooling	R
Rearrangement Costs	R
R/M	
Engineering Support	
Data Requirements	

Prime hardware acquisition costs are the total costs to procure the quantity of computers required to equip all designated ships. It is the product of quantity required and the unit cost. It is expected that reasonable quantities for each class of machine could be based on the history of the AN/UYK-7 and AN/UYK-20. The Navy Embedded Computer Review Panel had gathered such data for their final report. An excerpt is presented here:

> ". . . the sponsors' data would yield a total through 1985 of $379M for UYK-7's @$250k each, and $126M for UYK-20's @$50k each. The commodity managers' forecasts similarly would yield $505M for UYK-7's, and $380M for UYK-20's . . ."

These volumes were predicated on a 10- to 15-year span of time. Because future computers are in increasing demand, it was decided that the estimates would more realistically be applicable to a 10-year period, and, therefore, the data was used as such. The small class of computers was generated from IBM FSD's Marketing Forecast group and was determined to be approximately 10,000 cards in a 10-year period. The quantities for the large and medium components were derived by dividing the business volume by the individual cost. (e.g., \$505M/\$205k = 2020 computers.) Because the technology trend charts pointed out relatively constant cost for increasing performance, the costs of the large and medium machines were assumed to be equal to that of the predecessor UYK-7 and UYK-20, that being \$250k and \$50k respectively. The small processor cost was estimated by IBM FSD as approximately \$5k (see Table A-2).

Table A-2. Acquisition Cost/Quantity Summary

Parameter	Class Small	 Medium	 Large
Acquisition Cost (\$K)	5	50	250
Reliability (MTBF) (h)	50,000	2,000	1,400
Total (\$M) Projected Quantities	50 (10,000)	380 (7,600)	505 (2,020)

NRSU costs were established for each class of computer and remained constant irrespective of year of procurement. Adjustments were made for a reduced production rate when the concept of multiple producers was considered.

The NRSU items which were considered for each class of computer are summarized in Table A-1. Those particular items most influenced by the rate of production are identified with an R. The production rate was assumed to be linear for a 10-year period. Table A-3 summarizes the costs. NRSU costs are illustrated for three production rates.

This study chose to use the commodity manager's forecasts vs. the sponsor's data forecast (Table A-2). It is expected that the true usage would likely fall between these two and that, due to future growths of computers, a proper estimate would be that of the sponsor's data forecast. It is worthy to note that although the costs as tabulated are precise, in reality, a range exists and that these values merely fall within the bounds. For example, see Figure A-1.

Government Program Management was maintained at a 60-person level of support effort for all three classes of machines. This figure as obtained from the Navy, based upon the present personnel level

Table A-3. Full-Scale Engineering Development and Production Nonrecurring Start-Up for Navy Computer Accreditation Study

Class	Development Contractor/Government ($M)		Production Rate ($M)		
			(100%)	(50%)	(30%)
Small	1.5	0.8	1.3 90/mo	1.2 45/mo	1.2 30/mo
Medium	10.0	5.0	15.0 60/mo	10.0 30/mo	8.5 20/mo
Large	30.0	15.0	18.0 20/mo	15.0 10/mo	13.5 6/mo

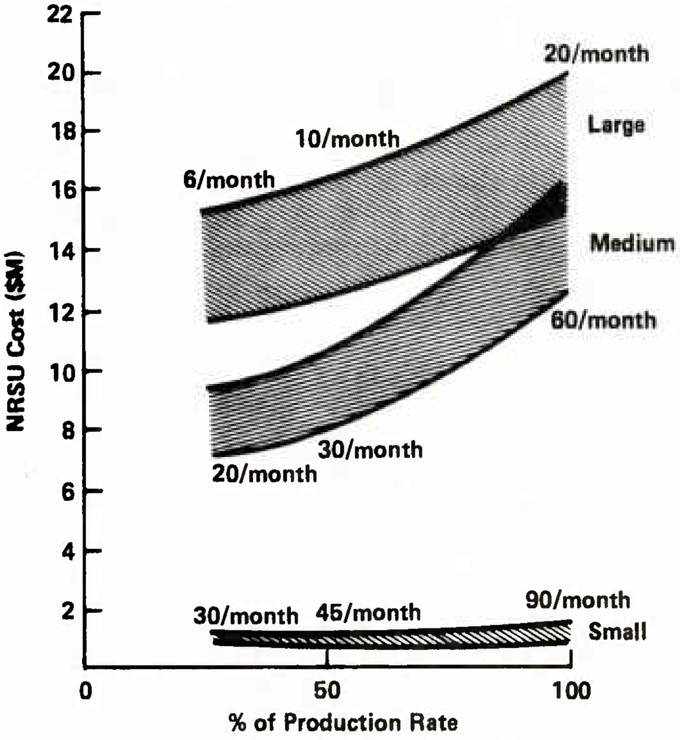


Figure A-1. Production NRSU

application to support the AN/UYK-7, AN/AYK-14, and AN/UYK-20. IBM assumed an allocation of this personnel level as a 25 man level of effort each for the large- and Medium class computers, and at a 10-person level of effort for the small class computer.

The support level established covered a single developer/single producer. The base personnel level of support was adjusted upward for multiple developments, suppliers, or reacquisitions. It was assumed that each development, new producer, or reacquisition introduced a new and different technology and therefore required multiple support personnel. The adjustment made considered utilizing existing personnel in common support areas and adding people to support unique areas.

Support equipment costs were considered for all three classes of computers. The current technology levels provide for extensive built-in test and fault isolation capabilities. This currently available capability eliminates the need for ship-level support equipment to facilitate the isolation of computer failures to the shop-replaceable unit (SRU) level.

The sets of support equipment required for the depot are calculated based on the projected usage of the item and the depot capability. For the large- and medium-class computers, the digital assemblies were assumed to be discard, so only the power supplies and memory assemblies required depot support equipment.

The initial training element includes all costs for training of the initial cadre of professional and maintenance personnel. For this study, it was assumed that the host system training would provide the necessary training to maintain the computer on a recurring basis.

Supply support includes the cost of all spare replaceable units for system support. This includes the spares necessary for ship support, depot, pipeline, and condemnation. The total spares cost for each replaceable unit is a function of the quantity of spares required and production unit cost. The quantity required is determined by the availability objective, which in this case was assumed to be 0.99. Spares were considered as being procured concurrent with production, and no cost factors were applied to the unit cost. The amount of spares in the inventory increased when different F^3 equipment was deployed.

A.1.3 SUPPORT COSTS

The support cost encompass five major areas: (1) corrective maintenance, (2) support equipment maintenance, (3) supply support, (4) data management, and (5) packaging and shipping. To compute these costs, a maintenance concept and operational criteria had to be defined as follows.

The recurring costs were computed for the discard and repair alternatives for the different classes of machines. The costs for the large- and medium-scale computers were based upon a cost-effective discard concept while the small-scale computer was repaired at depot.

Corrective maintenance includes the operational site or organizational repair level and depot level repair costs. The operational site level cost element includes labor and maintenance costs associated with verification and repair of the unit at the ship level. Depot level costs include the repair labor and materials costs associated with units repaired at depot. These costs include the test and repair of the power supplies and memory modules for the medium and large computer and all costs incurred for the one subassembly unit of the small computer.

Support equipment maintenance costs include the cost to operate and maintain the support equipment required at the depot level. This cost is based on a percentage of the initial acquisition cost of the support equipment.

The initial and recurring data management element includes the cost of reproduction, distribution, and file maintenance of technical data. It is a function of the number of pages of technical data and a cost factor for reproduction, distribution, and data management.

The packaging and shipping cost element applies to all units shipped between the ship and depot. It is a function of the expected number of failures resulting in a repair at depot and a standard cost factor for packaging and shipping.

A.2 RELIABILITY

The values of reliability for the three future classes of machines were again equated to the present values for the AN/UYK-7 and AN/UYK-20. Based upon communications with the Naval Underwater Systems Center, the data in Table A-4 was derived. The MTBF numbers used in the study for the medium- and large-class machines were obtained by factoring the observed AN/UYK-7 and AN/UYK-20 MTBF values for false removals and induced failures to account for maintenance actions and spares requirements.

Table A-4. Reliability Values

Class of Machine	Reliability Hours - MTBF
Large	1,400**
Medium	2,000
*Small	50,000

* The small processor card level class was estimated by IBM because no such class currently exists with which to compare.

** Averaged for Typical complexity.

A.3 LOGISTICS ESTIMATES

In addition to the assumptions associated with the input parameters, the following general assumptions for the logistics estimates were made. The computers would operate on an average of 720 hours per month, and the mission would last 90 days. The model provides for reliability growth, the computers are maintained as a fixed function, and there is box level F^3. Spares are procured coincident with production buys, and there is a fixed cost for recurring training. Operational and support software costs are not included in the overall system LCC. These assumptions and the model inputs are summarized in Table A-5.

The results of the model with these assumptions for the three classes of computers are summarized in Figures A-2, A-3 and A-4, where the Total Program Cost is shown as a function of the year of development start.

Table A-5. General Assumptions for LCC Analysis

- Built-in test/diagnostic capability held constant
  - Isolation to assembly w/o support equipment
- 15-year operation support period
- 720 hours/month operation
- Module spares on ship
  - 90-day consumption level
- Fixed function
- Fixed cost for recurring training
- Box level F^3
- Spares procured coincident with production buy
- Software costs excluded
- Development cost

		Production Volume		
	$M	Qty	U/C	Total Costs
- Small	1.5 MIL	10,000	5K	50 MILLION
- Medium	10.0 MIL	7,600	50K	380 MILLION
- Large	30.0 MIL	2,020	250K	505 MILLION

- Production rate vs nonrecurring start-up (NRSU) cost ($M)

Production rate:	100%	50%	33% - 25%
No. of Producers:	1	2	3 - 4
- Small	1.3	1.2	1.2
- Medium	15.0	10.0	8.5
- Large	18.0	15.0	13.5

- Competitive effects
  - Assumption for parametric analysis hardware and spares cost savings 10%, 20%

Government-Development Costs: One-half of contractor development costs

Government program Management: $50K per manyear

- 60-man level of effort support
  - 25 men (large computer)
  - 25 men (medium computer)
  - 10 men (small computer)

Government program manpower allocation

	One Producer		Addl/Producer	
	During Production	During O&S	During Production	During O&S
- Small	10 men	4	2	2
- Medium	25	10	8	4.5
- Large	25	10	8	4.5

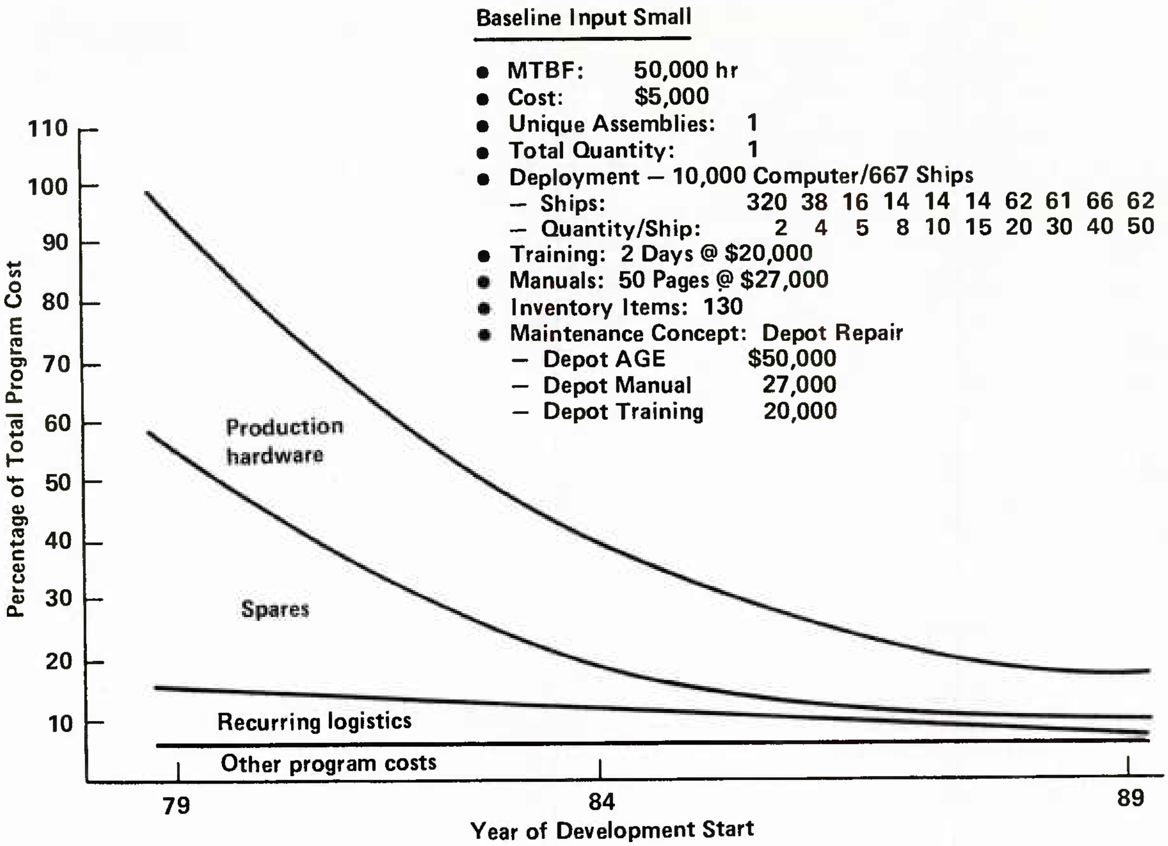


Figure A-2. Total Program Cost Components - Small Machine (Without Redevelopment)

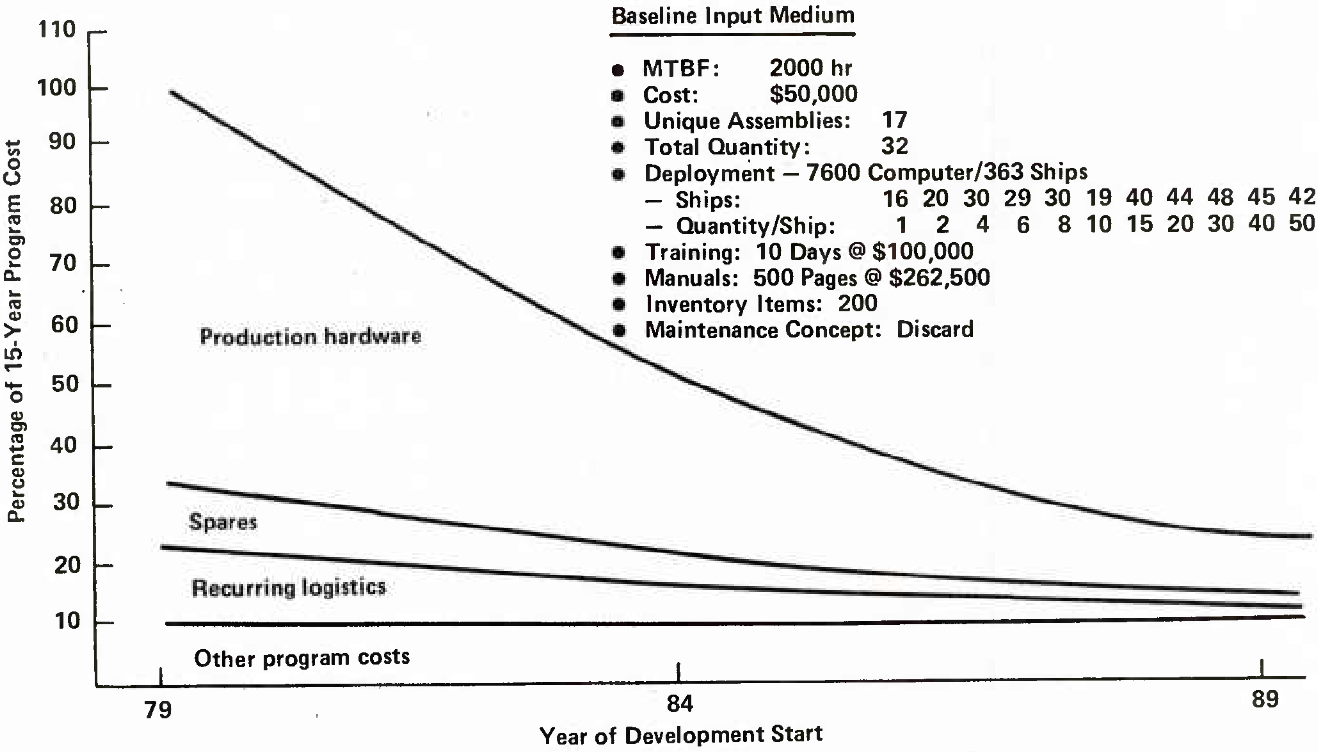


Figure A-3. Total Program Cost Components - Medium Machine (Without Redevelopment)

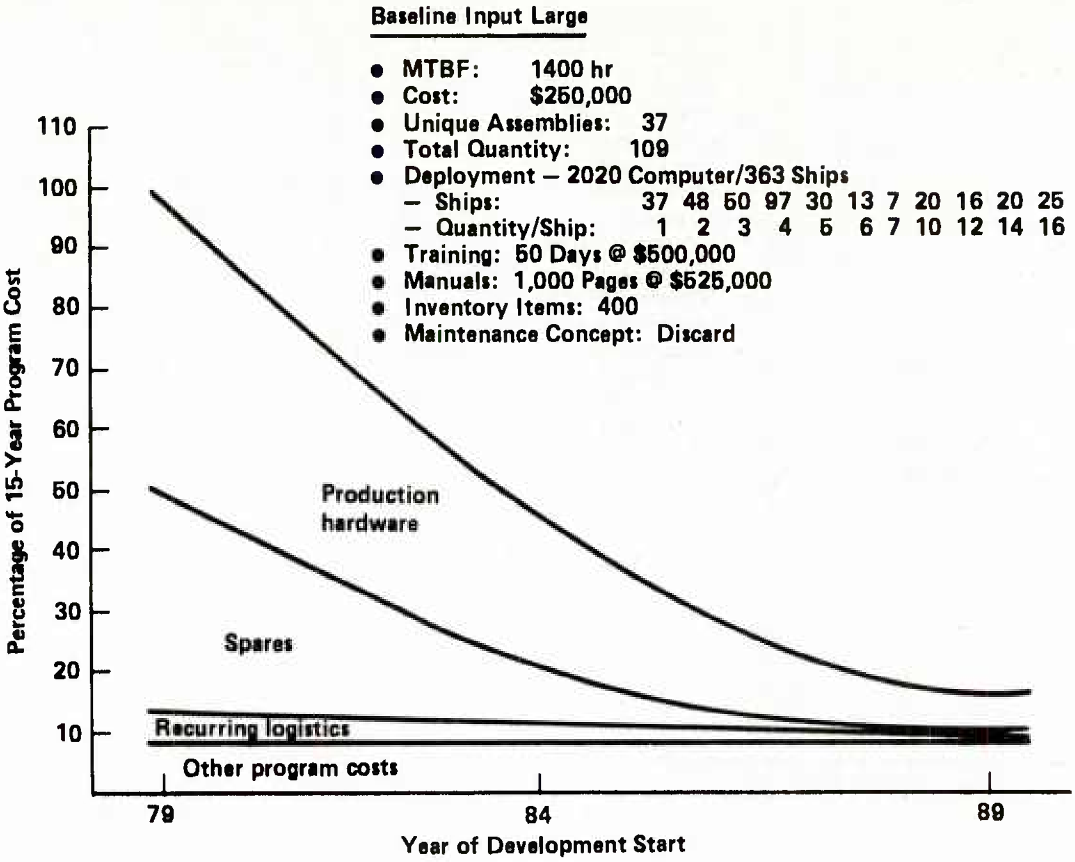


Figure A-4. Total Program Cost Components - Large Machine (Without Redevelopment)

Appendix B
MANPOWER PLANNING

As noted in Section 4, a shortage of skilled Data System Technicians presently exists in the fleet. This shortage is projected to continue into the next decade, unless action is taken to relieve the problem. As part of this study, information was received from Navy sources, analyzed against present hardware performance through the LCC model and summarized to compare against present planning figures. A dichotomy is found to exist in that the personnel-hour requirements projected from the LCC model analysis differ significantly from the personnel level assignments needed to satisfy demands from existing platforms, using the present standard computers.

B.1 NAVY PLANNING

Using information provided by Navy sources, projected costs were generated to cover hardware acquisition costs at the planned rate, consumption spares cost for a 15-year support period, and maintenance costs for the 15-year support period. The quantities for hardware acquisition are 1,000 AN/UYK-7s at a $275,000 unit price and 3,000 AN/UYK-20s at a unit price of $55,000. Average spares for the AN/UYK-7 cost approximately $15,000 per year and for the AN/UYK-20 cost approximately $5,500 per year. The cost to the Navy for operational and training costs for the 2000 Data System Technicians averages approximately $22,500 per computer per year. These costs are summarized in Table B-1.

Table B-1. Costs in Millions of Dollars

Item	AN/UYK-10	AN/UYK-7	TOTAL
Hardware Acquisition	165	275	440
Consumption Spares (15 years)	248	225	473
Maintenance (15 years)	720	480	1200
TOTAL	1133	980	2133

B.2 ANALYSIS

The Navy supplied MTBF and MTTR figures for the AN/UYK-20 standard computer are 6,132 hours MTBF and 15 minutes MTTR. Inserting these cost-driving parameters into the LCC model, we find the number of personnel-hours required to support the hardware failures expected during the operational period of 15 years may be calculated and translated in dollar costs. Significant differences exist in the costs projected from the present planning and those yielded from the LCC analysis. The results are shown in Table B-2.

Table B-2. Percentage Allocation of Costs for AN/UYK-20

Item	Navy Planning	LCC Analysis
Hardware Acquisition	15%	56%
Consumption Spares	22%	43%
Maintenance	63%	1%

The significant differences between the percentages of costs from two sources needs reconciling. Several possible areas for future investigation are suggested and listed:

- The Data System Technician is utilized not only to maintain computer hardware, but also to resolve any system discrepancies associated with computer or host system software.
- The requirement for one or more Data Systems Technicians to be included in the ship's company is driven by the host system and other peripheral equipment rather than computer maintenance only.
- The Navy planning figures may be influenced by significantly older vintage technology still in use in the fleet and have not been adjusted to take advantage of the improved performance of the later technology hardware.

It is thus recommended that a further study be conducted to resolve the issue of personnel hours vs personnel loading as the significant maintenance cost driver. This study should not be limited to the computer only but should include the number of deployed systems supported by the standard or embedded computer. The study should also consider other responsibilities that utilize the Data Systems Technician's time.

Appendix C
ARINC

Aeronautical Radio Incorporated (ARINC) is an airline-owned entity which has as one of its purposes the development of specifications for use in procuring avionic equipment. The procedures for developing the specifications and the procurement practices are of interest because it is generally accepted that ARINC is effective and because many of the problems faced by the airlines are shared by DoD. Through ARINC, the airlines have been able to buy avionic equipment of relatively high reliability and low cost. Development times are reasonable, and competition is maintained. Some of the relevant aspects of ARINC are discussed in this section.

Avionic requirements are defined through an open forum consisting of participants from potential vendors, the airline industry, and technical representatives. This open forum is known as Commercial Acquisition Methodology (CAM). The airlines make the requirement for new avionic equipment known for a 5-year period through the CAM. If there is sufficient interest expressed by the manufacturers in providing a given piece of equipment, ARINC generates a "characteristic", or specification, for the equipment. This precondition assures the existence of available competition.

The ARINC characteristic is a high-level specification for the equipment. The equipment is specified at the form-fit-function((F^3) level. Such things as form factor, weight, interconnections, and reliability, as well as functional performance, are specified. However, there are very few second-tier specifications imposed on the developer.

In most instances, manufacturers develop equipment independently and submit the equipment to the airlines for evaluation. All environmental testing and arrangements for FAA certifications are performed by the vendors prior to delivery to the airline. No procurement decision is made until the airlines have completed their evaluation.

A reliability improvement warranty is incorporated in the procurement contact. The manufacturer commits to maintain the equipment for a period of time at an agreed upon dollar value. This amount acts as an incentive to incorporate reliability improvements in the equipment. Fewer repairs means that the vendor effectively receives greater profit because the maintenance funds are not used up; conversely, excessive repairs reduce profits.

The successful vendor is given a favored vendor status, which is enjoyed as long as the equipment performance remains satisfactory. This is determined through a continuous monitoring process.

While there are some obvious differences between the needs of the airlines and the needs of the Shipboard Navy, there appears to be some elements of the ARINC procurement process that are worth considering:

- The use of a high-level specification, unencumbered by lower-tiered specifications, permits maximum supplier flexibility to meet the requirements of the job.
- RIW provides the incentive for the manufacturers to develop more reliable products and incorporate technology upgrades that improve reliability.
- The CAM provides long-term requirements information to the vendors, which reduces vendor investment risks.