AD-A094 693 INSTITUTE FOR DEFENSE ANALYSES ARLINGTON VA COST ANAL--ETC F/G 15/3
ON ESTIMATING THE COST GROWTH OF WEAPON SYSTEMS.(U)
JUN 80 N J ASHER, T F MAGGELET
UNCLASSIFIED IDA-P-1494 IDA/HQ-80-22466 NL

1 OF 1
AD-
A094693

END
DATE
FILMED
3-81
DTIC

AD-E500237
Copy 25 of 75 copies

LEVEL

(12)

AD A094693

IDA PAPER P-1494

ON ESTIMATING THE COST GROWTH OF WEAPON SYSTEMS

Norman J. Asher
Theodore F. Maggelet

June 1980

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

INSTITUTE FOR DEFENSE ANALYSES
COST ANALYSIS GROUP

IDA Log No. HQ 80-22466

The work reported in this document was conducted under IDA's Independent Research Program. Its publication does not imply endorsement by the Department of Defense or any other government agency, nor should the contents be construed as reflecting the official position of any government agency.

This document is unclassified and suitable for public release.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER

2. GOVT ACCESSION NO. AD-A094 693

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
On Estimating the Cost Growth of Weapon Systems

5. TYPE OF REPORT & PERIOD COVERED
FINAL
1 Nov 79 - 30 Jun 80

6. PERFORMING ORG. REPORT NUMBER
IDA Paper P-1494

7. AUTHOR(s)
Norman J. Asher
Theodore F. Maggelet

8. CONTRACT OR GRANT NUMBER(s)
IDA Independent Research Program

9. PERFORMING ORGANIZATION NAME AND ADDRESS
INSTITUTE FOR DEFENSE ANALYSES
400 Army-Navy Drive
Arlington, VA 22202

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS

11. CONTROLLING OFFICE NAME AND ADDRESS

12. REPORT DATE
June 1980

13. NUMBER OF PAGES
77

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)

15. SECURITY CLASS. (of this report)
UNCLASSIFIED

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

This document is unclassified and suitable for public release.

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

None

18. SUPPLEMENTARY NOTES

N/A

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

Weapon System Cost Growth, Selected Acquisition Report (SAR), Development Estimate, Defense Systems Acquisition Review Council (DSARC) Process, Cost Overrun, Development Cost, Procurement Unit Cost, Program Acquisition Cost

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

This paper documents schedule and cost growth in current major DoD weapon system acquisition programs that have attained Initial Operational Capability (IOC). Utilizing Selected Acquisition Report data, a methodology for projecting probable future growth in evolving systems that have not yet reached IOC was developed and described. Use of the growth projection methodology as an adjunct to future IDA weapon system analyses is recommended.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

IDA PAPER P-1494

ON ESTIMATING THE COST GROWTH OF WEAPON SYSTEMS

Norman J. Asher
Theodore F. Maggelet

June 1980

INSTITUTE FOR DEFENSE ANALYSES
COST ANALYSIS GROUP
400 Army-Navy Drive, Arlington, Virginia 22202

IDA Independent Research Program

PREFACE

Schedule and cost growth in DoD weapon system acquisition programs have been recognized as an economic fact of life. This growth has been the subject of many studies and analyses that have documented the phenomenon. A variety of causal factors have been identified, including:

- General economic inflation
- Supply/labor shortages
- Technological uncertainty
- Specification changes
- Changes in threat
- Budgetary constraints

While it may be interesting and informative to know why growth has occurred, senior decisionmakers need a realistic and simple-to-use method whereby they can project the probable cost of a system by the time it has matured enough to be placed in the hands of a using unit (i.e., by the time the system attains its initial operational capability).

This paper briefly outlines the weapon system acquisition cycle and the associated DoD management processes and tools. Its purpose is to develop a methodology for projecting future growth in individual programs. To this end, a total of thirty-four major weapon system programs were examined. The primary data source used in this effort was the Selected Acquisition Report--the official quarterly report used by the DoD to provide the Congress with updated cost, schedule, and performance data on new major acquisition programs.

Acquisition programs were split into four categories: aircraft, missiles, ships, and other systems. Within each category, individual weapon system schedule and cost growth was documented. Mean and median factors were derived for schedule, development cost and procurement unit cost growth. A schedule and cost growth projection methodology that relies on a simple charting technique was developed and then explained in a series of sketches and examples.

ABSTRACT

This paper documents schedule and cost growth in current major DoD weapon system acquisition programs that have attained Initial Operational Capability (IOC). Utilizing Selected Acquisition Report data, a methodology for projecting probable future growth in evolving systems that have not yet reached IOC was developed and described. Use of the growth projection methodology as an adjunct to future IDA weapon system analyses is recommended.

CONTENTS

FIGURES

TABLES

TABLES (Cont'd)

ABBREVIATIONS

CE	Current Estimate
DE	Development Estimate
DCP	Decision Coordinating Paper (formerly Development Concept Paper)
DSARC	Defense Systems Acquisition Review Council
DTC	Design-to-Cost
FYDP	Five-Year Defense Program
HARM	High-Speed Anti-Radiation Missile
IOC	Initial Operational Capability
LCCE	Life-Cycle Cost Estimate
MAA	Mission Area Analyses
MENS	Mission Element Need Statements
PDM	Program Decision Memorandum
PE	Planning Estimate
POM	Program Objective Memorandum
PPBS	Planning, Programming and Budgeting System
PUC	Procurement Unit Cost
RFP	Request for Proposal
SAR	Selected Acquisition Report
(S)SARC	(Service) Systems Acquisition Review Council
SDDM	Secretary of Defense Decision Memorandum
SOR	Stated Operational Requirement
SRAM	Short-Range Attack Missile

I. INTRODUCTION

The actual costs of weapon systems are virtually always much greater than estimates made during their planning and development phases. Accordingly, in studies involving the cost-effectiveness of weapon systems, current cost estimates of systems not yet deployed should be adjusted to reflect probable future cost growth. This adjustment is particularly important in studies involving the relative costs and effectiveness of weapon systems at different stages of their life cycle. Use of unadjusted costs would tend to favor unfairly those systems in earlier stages of development relative to those systems in later stages of development or deployment. This paper presents a methodology for making such adjustments to current estimates.

The IDA schedule and cost growth projection methodology uses the Selected Acquisition Report (SAR) as its data source. The SAR was chosen because it is an official report submitted by OSD to the Congress on the status of major acquisition programs. The SAR is a highly aggregated report which is focused on the "bottom-line" roll-up of a program's estimated acquisition costs. It is the one DoD document most often cited in Congressional and GAO reports dealing with cost growth.

This paper treats cost growth in weapon system acquisition programs as an economic fact of life. It does not address operating and support costs of a system once the system is fielded (deployed). The basic purpose of the paper is to provide a mechanism whereby the potential for growth in a program can be illuminated and quantified. The methodology is not a vehicle for explaining why growth occurred. The approach is straightforward and treats all programs on an "other things being equal" basis. As is the case with any estimating technique, the IDA growth projection methodology is not a panacea. Its use is most appropriate where data, existing cost estimating relationships, time or resources are not adequate or available to complete an independent cost analysis of a given program.

This study was performed under the IDA Independent Research program. Use of the proposed methodology in future weapon system studies and analyses is planned. Annual updates of this paper are anticipated.

II. PAST STUDIES OF COST GROWTH

A literature search provides many references to cost growth, a few of which are presented below.

A 1978 GAO Report (Ref.1) opened with the following:

> On March 27, 1794, the Congress authorized the building of six large frigates which were to form the backbone of the U.S. Navy. The then War Department was assigned the task of acquiring the ships. Nearly 17 months later the six keels were laid. Shortly thereafter, due to delays and cost overruns, the program was cut back to three frigates.
>
> Today, 184 years later, most Federal agencies are faced with the same problem--ultimate costs of major programs are often many times the estimated costs on which they were approved.

A 1965 Anser Memorandum (Ref.2) reported:

> The incongruity between estimated and actual costs of today's weapon systems indicates a need for cost estimates which more accurately predict the cost of future weapon systems. Estimates made near the beginning of a development program are particularly unreliable. For example, the cost of developing 11 existing weapon systems was as much as seven times the amount originally estimated. A study of the development and production costs of 33 weapon systems showed that the original cost estimates were 180 to 220 percent too low, on the average, even after price-level and cost-quantity adjustments were made.

A 1972 Rand Paper by Alvin J. Harman (Ref.3) indicated a continuation of cost growth:

> Improvement in the process of acquiring major weapon systems has been the subject of analyses and policy recommendations for several decades [see, for

example, Klein (1962)[1], Peck and Scherer (1962)[1], Marschak, et al. (1967)[1], Perry, et al. (1971)][1]. While system costs have increased as weapon systems have grown more complex, for programs of comparable duration and technical difficulty, the extent of cost growth over original estimates has not significantly improved [Harman (1970)][1].

A 1965 Rand Memorandum (Ref.4) noted that cost growth is also widely experienced in major civil projects.

Twenty-two chronologies of cost estimates of major articles of Air Force weapon systems constitute the basic data of this study. Even a cursory examination of the chronologies suggests that the estimates leave much to be desired. It should be recognized, however, that predicting how much something will cost that is to be produced a long time in the future is always a hazardous activity. The United States is studded with railroads, canals, tunnels, bridges, and highways that cost a great deal more than was originally expected. For example, the final cost of the Troy and Greenfield Railroad was more than ten times as much as the original estimate, principally because tunneling four miles through Hoosac Mountain turned out to be enormously more difficult than the railroad's geologists had predicted. The Welland Canal cost many times more than was expected because the height of a major cut, estimated at 30 feet, was actually 60 feet.

The Suez and Panama Canals tell much the same story. The earliest cost estimate for the Suez Canal, a half-century before it was finally built, was low by a factor of twenty; the year before digging actually began, the estimate was still low by a factor of three. The early abortive effort by the French to build a canal across the Isthmus of Panama was undertaken as a result of a substantial underestimate of the magnitude of the task. The total outlay on the project by the French and subsequently the United States was about twice what the French originally thought would be necessary. Even though the United States had the French experience to learn from, and a portion of the job was already done, the American outlay was 70 percent more than anticipated when the American work began.

---

[1] See Harman reference list, p. 74.

The nuclear power plants recently built offer another example. Almost without exception, the initial cost estimates for these plants were too low. Costs climbed from 50 percent to 100 percent, and in some cases are still climbing. It is instructive to examine the breakdown given by Consolidated Edison for the cost increases they experienced in their Indian Point plant. Though the total cost went up about 90 percent, expenditures on the strictly nuclear portion of the plant went up by a factor of three; the increase for the conventional elements, on the other hand, was only 37 percent. If one allows for general price-level increases and a slight change in gross capacity, the increase for the nuclear part of the plant still amounts to a factor of about two-and-a-half.

A 1972 Ph.D dissertation (Ref.5) included a review of the literature on cost growth of weapon systems.

The most sophisticated studies of actual cost performance on programs as compared to original cost estimates were the Merton J. Peck and Frederic M. Scherer studies[1] and several Rand Corporation studies.

Peck and Scherer analyzed twelve typical weapon systems programs of the 1950's. All twelve systems employed cost-plus-fixed-fee contracts. The average cost growth was found to be 220 percent beyond original target cost.[2]

Almost identical results came from a later study of 22 Air Force weapon systems programs involving 68 estimates. The study, entitled Strategy for R&D: Studies in the Microeconomics of Development, by Thomas Marschak, Thomas K. Glennan, Jr., and Robert Summers of Rand Corporation, showed an average cost growth of 226 percent beyond original estimated cost.[3] These programs also entailed primarily cost-plus-fixed-fee contracts of the late 1950's.

In the 1960's, incentive contracts, rather than cost-plus-fixed-fee contracts, were used for most engineering development efforts. One might therefore

[1] Merton J. Peck and Frederic M. Scherer, *The Weapons Acquisition Process--An Economic Analysis* (Boston: Graduate School of Business, Harvard University (1962).

[2] *Ibid.* p. 429.

[3] (New York: Springer-Verlag New York, Inc., 1967), p. 152.

expect actual program costs to be closer to original cost estimates. Two such studies of the 1960's were undertaken by Rand personnel.

Robert Perry et al. reported in a study of 21 Army, Navy and Air Force system acquisition programs that, "...[O]n average, cost estimates for the 1960's were about 25 percent less optimistic than those for programs for the 1950's. Thus, if reduction in bias (or reduced optimism) is a realistic index of "better" there is evidence of improvement in the acquisition process."[1] Even such a statement as this must be hedged considerably as Perry et al. were careful to do. "Still, the model has little explanatory power (in a statistical sense), and it does not indicate *why* improvements have occurred."[2]

In contrast, a more recent Rand follow-up study discounted any improvement in the 1960's over the 1950's noting that, "...[F]or programs comparable in length and difficulty, 1960's procurements would have resulted in actual costs exceeding estimates by roughly the same proportion as had 1950's procurements.[3]

A 1978 paper by Truman W. Howard (Ref.6) summarized the results of some other studies dealing with growth:

> Cost histories of 45 systems under development in June 1972 showed that estimates one year later exceeded development estimates by 20 percent ($19.1 Billion) [3].[4] Such widely publicized overruns have a severe impact on the credibility of both Government and industry management. One case, the C-5A airplane, nearly doubled its estimated unit cost from $28 to $55 million dollars over a five-year period [3].[4] Such cost growth experience is not new. Peck and Scherer [10][4] analyzed 12 weapon system development programs in the 1950's and found that development costs averaged 3.2 times the

---

[1] *System Acquisition Experience,* Memorandum RM-6072-PR, prepared for United States Air Force Project Rand (Santa Monica: The Rand Corporation, November 1969), p. 6.

[2] *Ibid.*

[3] Alvin J. Harman, *A Methodology for Cost Factor Comparison and Prediction,* Memorandum RM-6269-ARPA, prepared for Advanced Research Projects Agency (Santa Monica: The Rand Corporation, August 1970), p. 6.

[4] See Harman reference list, p. 74.

original estimate, and schedule slippage averaged 1.36 times the original estimate. Trainor [12][1] in a more recent study, analyzed nine major DoD and NASA development systems. Development costs averaged 1.31 times the original estimate, and schedule slippages averaged 1.6 times the original estimate.

A 1978 GAO Report (Ref.7) indicated pervasive cost growth for both military and civil major acquisitions:

> The estimated costs of major acquisitions have increased each year since June 30, 1975, when we issued our first combined military and civil major acquisitions status report on 585 projects estimated to cost $404 billion at completion. The estimated costs of 857 major acquisitions at September 30, 1978 have increased $49 billion over the past year to more than one-half trillion dollars.

A report of Congressional hearings on DoD cost estimates conducted in 1979 (Ref.8) concluded:

> The hearings focused on the validity and overall value of Department of Defense cost estimates given Congress at two critical stages in weapon systems procurement--(1) at the initial, conceptual stage when a Planning Estimate (PE) is made and Congress has to authorize and appropriate the money for a new weapon system, and (2) at the time full-scale production [sic][2] funds are requested, when a baseline Development Estimate (DE) is given. The Planning Estimate and the Development Estimate were then compared to the Current Estimate (CE) that is reported in the quarterly SAR.
>
> Since 1969 the initial (planning) estimate has turned out to be approximately 100 percent below the actual costs of major systems. The later, more refined development cost estimate given Congress prior to full-scale development has proven to be approximately 50 percent below actual procurement costs.
>
> The review by the Subcommittee failed to find one example where the Department of Defense accurately estimated or overestimated the cost of any major weapon system.

---

[1] See Harman reference list, p. 74.

[2] "Production" used incorrectly; should have been "development."

These excerpts reveal a consistent and continuing pattern over many years of cost growth on both military and civil major acquisitions. Additional references are included in the list of references.

Much has also been written on the causes of cost growth. Some of the more frequently cited causes are:

"Force Majeure"

- Natural disaster
- Civil disorder
- Labor strike
- Fire

General Economic Inflation

Cost estimates based on previous similar system (each succeeding generation tends to cost more than last generation).

Supply shortages

Labor shortages

Poor management

Technological uncertainty

- Unknowns
- Unknown unknowns

Environmental laws/regulations

Specification changes

Quantity changes

Reliability problems

Concurrency (trying to produce too fast).

Tight budgets

Competitive environment

- within branch of service
- within service
- among services
- DoD vs. other federal agencies
- Executive branch vs. Congress

- among contractors
- among individuals

While the above list may not be exhaustive, we believe that two causes must be singled out because of their impact. First of all, we believe that the competitive environment in which weapon systems are developed is the major factor leading to cost growth. All weapon systems must compete for funds at many levels within the federal government. This competition involves both implicit and explicit rankings of competing systems on a cost-effectiveness basis. Effectiveness usually involves intangible factors as well as characteristics that can be measured quantitatively. However, cost is only expressed in quantitative terms. There is an obvious incentive for the proponents of a system to underestimate its cost in order to increase its probability of acceptance.

Secondly, tight budgets are an often-overlooked cause of cost growth. There is a management school of thought which holds that overly-generous budgets lead to unnecessary costs. This basic idea was popularized as one of Professor Parkinson's laws (Ref.9).

> Work expands so as to fill the time available for its completion.

In order to avoid this pitfall, tight budgets (and schedules) are established and so contribute to later cost growth. This same idea was discussed in a paper by Wayne Allen (Ref.10).

> As dollars are the most widely used control mechanism, a practice of minimizing estimates of future costs has evolved as a management technique for attempting to impress contractors with the continuing need to produce more for less and in a shorter period of time.

And, in a Rand report (Ref.11):

> The conventional view is that a contractor is more motivated to economize and to attempt to find ways to reduce cost if a development contract is negotiated for the lowest possible amount and if the

planning estimate for production items is also low. Cost growth may occur, but it is assumed that final cost would have been even higher had the contractor not been constrained by the low early estimates.

Although writers have different opinions of the relative importance of various causes of cost growth, there is general agreement that there are a number of contributing factors, and program results almost invariably exhibit resulting cost growth. Accordingly, in Chapter V we present a method by which cost estimates of weapon systems in development can be adjusted upward in order to predict more accurately their probable future costs regardless of cause.

III. DoD WEAPON SYSTEMS ACQUISITION MANAGEMENT AND THE SELECTED ACQUISITION REPORTS (SARs)

The continued schedule and cost growth experienced in major weapon systems acquisition programs is frequently cited by critics of the Defense establishment as an indicator of poor management practices. While this statement is an over-simplification of an extremely complex problem, given the various reasons for schedule and cost growth enumerated in the previous chapter, it may be helpful to review briefly the process whereby the DoD manages the acquisition of new major weapon systems and the reporting procedures which allow the Congress to exercise its responsibilities for oversight. A familiarity with the management process and reporting procedures is a prerequisite to an understanding of the growth projection methodology proposed in Chapter V. Accordingly, the focus of this chapter will be on the Defense Systems Acquisition Review Council (DSARC) process and the Selected Acquisition Reports. The latter are the official means employed by the Department of Defense to provide Congress with updated cost, schedule, and performance data on major weapon systems, while the former (the DSARC process) provides the base for the data contained in the SARs.

A. THE MAJOR SYSTEM ACQUISITION PROCESS[1]

The current major system acquisition process was established in 1968 to provide a means for better managing the acquisition of major systems (a major system is any development

[1]This section has been excerpted (and modified) from Chapter 4, Assistant Secretary of the Army (IL and FM) *Report to the Army Acquisition Management Task Force*, 28 November 1979.

effort so designated by the SECDEF. Usually, those programs whose RDT&E costs are projected to exceed $100 million or procurement costs are projected to exceed $500 million in FY 80 dollars are designated major programs). DoD Directive 5000.1 and DoD Instruction 5000.2[1] govern this process, which is now made up of four phases, through which a program normally proceeds before a system is actually fielded. Decision points (or milestones) mark the entry into each succeeding phase of the process.

At each key decision point, top management of the sponsoring Service will gather together in a series of meetings culminating in a (Service) Systems Acquisition Review Council (S)SARC meeting to review all aspects of a particular program and its alternatives. Recommendations of the (S)SARC are reviewed and approved by the Service Secretary prior to forwarding his decision on the program to OSD for review. OSD will then convene a Defense Systems Acquisition Review Council (DSARC) which is chaired by the Defense Acquisition Executive who currently is the Under Secretary of Defense for Research and Engineering. The DSARC conducts an independent review of the program and makes its recommendations to the Secretary of Defense. SECDEF approval is announced in a Secretary of Defense Decision Memorandum (SDDM) that signals successful completion of a milestone and is authorization to proceed into the next phase of the acquisition cycle.

The materiel acquisition process complements the DoD requirements definition process. Statements of weapon system requirements result from continuing evaluations of existing technology, threat, doctrine, organizations, and material systems (i.e., technical and operational suitability, system

---

[1]DoDD 5000.1, "Major System Acquisitions," March 19, 1980.
DoDI 5000.2, "Major System Acquisition Procedures," March 19, 1980.

assessments, logistic assessments, and readiness reviews). These evaluations are known as mission area analyses (MAA). MAA needs also arise from Program 6.1 "technology base" efforts. MAA deficiencies or needs are translated into mission element need statements (MENS) and forwarded to the Secretary of Defense for approval.

MILESTONE 0 (ZERO)--CONCEPT EXPLORATION PHASE

Approval of the Mission Element Need Statement by SECDEF constitutes the first decision point of the acquisition process. (This decision milestone was added in 1977). A Secretary of Defense Decision Memorandum is issued to the Service(s) to explore and develop alternative system concepts to satisfy the approved need. A major part of this phase is the development of program estimates for each of the conceptual system alternatives. These estimates are not considered firm since systems are not clearly defined and the values for system parameters are uncertain.

MILESTONE 1--DEMONSTRATION AND VALIDATION PHASE

The second decision point is reached at the end of the Concept Exploration Phase. The program life-cycle cost estimates (LCCE) that address the estimated acquisition (development and procurement) and ownership (operating and support) costs of all the alternatives to be considered at this decision point are incorporated into a document called the Decision Coordinating Paper (DCP). The DCP provides the primary documentation (acquisition strategy, alternatives, and issues) for use by the DSARC in arriving at its milestone recommendation. One or more systems are nominated by the DSARC to proceed through the next phase of the acquisition process. For very select high-interest programs, the acquisition portion of the LCCE is incorporated into a program monitorship report. This report, established in 1968, is called the Selected Acquisition

Report (SAR).[1] It serves as the baseline for monitoring future program performance. At this point, the SAR program estimate is referred to as the "planning estimate." The planning estimate is also used in the Planning-Programming-Budgeting System (PPBS) to plan for the financing of the program.

During this phase, prototype systems may be developed and tested to prove that hardware can be built to meet the requirement of the conceptual system. The program selected at Milestone I may not call for total development of a new system. The selected program may only involve modifying an existing system to a configuration that meets the required need. In such cases, prototype systems are not built. At the end of this phase, an analysis is conducted to prepare for the next decision point. This analysis involves reconfirmation or rejustification of the requirement against the latest threat assessment, and the preparation of updated program estimates. These estimates make use of new information acquired during the developmental and testing efforts. These are the first estimates based on information gained from actual development and testing of system hardware.

MILESTONE II--FULL-SCALE DEVELOPMENT PHASE

The third decision point of the acquisition process occurs at the end of the demonstration and validation phase. The program estimates of all the alternatives are again recorded in the DCP. The estimate of the program alternative selected by the (S)SARC and DSARC becomes the new *baseline* for the program. Management thresholds are established about this new program estimate. These thresholds serve as a means for controlling the program within prescribed levels of allowable changes that may subsequently occur. Concurrently, the acquisition portion

[1]DoDI 7000.3, "Selected Acquisition Report," April 4, 1979.

of the program estimate is substituted in the SAR for the planning estimate, and becomes the new baseline for monitoring program performance. In the SAR this revised baseline is referred to as the "development estimate." This estimate is also used for programming and budgeting purposes. It must be noted that for most systems, SAR submissions begin after a Milestone II decision has been made.

Prototype systems are also built during this phase of the program. In the demonstration and validation phase, prototypes were built to demonstrate the ability to build a weapon system possessing the capabilities required to respond to the need. Having proven this capability, the prototypes in full-scale development are built to demonstrate the ability of the system to perform successfully in the field and to demonstrate the adequacy of the system's design for eventual quantity production. Upon completion of this phase, another analysis is conducted in preparation for the final program decision. This analysis again involves reconfirmation or rejustification of the requirement against the latest threat assessment and the preparation of updated program estimates.

MILESTONE III--PRODUCTION AND DEPLOYMENT PHASE

The procedures associated with the fourth and final decision of the acquisition process are quite similar to the Milestone II procedures. The program estimate of the alternative selected becomes the new baseline in the DCP. Thresholds are also revised and a new SDDM issued. The cost estimate becomes the current estimate in the SAR. The development estimate established at the time the program entered full-scale development continues as the SAR baseline.

With the Milestone III decision made, the program proceeds into production. Unless problems occur during this phase that cause a DCP threshold to be exceeded, the program never returns to the (S)SARC or DSARC for another decision. However, progress of the program continues to be monitored by review of the SAR until ninety percent of the production program is completed. At that time, the SAR is terminated.

B. VARIATIONS IN THE PROCESS

The acquisition managers may determine that a specific system program need not pass sequentially through all the phases of the process. Programs may also require major restructuring before a particular phase of the acquisition process is completed. Variations from the normal acquisition process are determined on a case-by-case basis.

C. THE A-X AS AN EXAMPLE OF DEFENSE SYSTEM ACQUISITION

No major weapon system has passed through all milestones of Defense acquisition review since Milestone 0 was added to the previous milestones. Thus, no program can be cited as a perfect example of compliance with the current process. The A-X (now A-10) Program does, however, exemplify the process with the exception of Milestone 0, and the events leading to its initiation are described herein for comparison with current Milestone 0 requirements.

CONCEPT EXPLORATION (NOW MILESTONE 0)

In December 1966, the Tactical Air Command forwarded a "Stated Operational Requirement" (SOR) for an aircraft to be designed for highly-survivable, heavily-armed, Close Air Support (CAS) of front-line troops.[1] This would lead to the first aircraft so specifically designed for the U.S. Air Force. (Today the Air Force would be required to submit a Mission Element Need Statement (MENS) to document the need for the mission. Approval

---

[1]Defense Marketing Service, *Military Aircraft*, 1979.

of the MENS at Milestone 0 signifies that the Secretary of Defense (SECDEF) intends to satisfy the need identified.)[1]

In the case of the A-X, the Request for Proposal (RFP) for design studies of CAS aircraft was circulated in March 1967. Following completion of the design studies, the RFP for prototyping went to twelve aircraft companies (in May 1970). Boeing, Cessna, Fairchild, General Dynamics, Lockheed and Northrop responded. In December, the Air Force tentatively selected Northrop to prototype two YA-9As, and Fairchild two YA-10As.

MILESTONE I--DEMONSTRATION AND VALIDATION

The Defense Systems Acquisition Review Council (DSARC) met on December 17, 1970 and approved the A-X Program for prototyping. (Note: the initial SAR was submitted as of 30 June 1971). A competitive fly-off of the Northrop and Fairchild demonstration vehicles was completed in December 1972.

MILESTONE II--FULL-SCALE DEVELOPMENT (FSD)

On January 17, 1973, the DSARC met to consider the Air Force selection of the Fairchild YA-10A as the winner and to approve the program for FSD. A Design-to-Cost (DTC) goal of $1,532,000 average unit flyaway cost (FY 1970 Constant Dollars), for 600 aircraft at a peak rate of 20 per month was also established. Formal SECDEF approval of the A-10 for FSD, including six pre-production aircraft, occurred January 18, 1973. The Development Estimate at the DSARC II became the baseline for the program.

MILESTONE III--PRODUCTION AND DEPLOYMENT

The Air Force returned to the DSARC on July 9, 1974 for approval of the A-10 for initial production. Long-lead procurement items were authorized on July 31, and after another

[1]DoDD 5000.1, Sec. D, paragraph 3a, p. 4.

DSARC meeting on November 19, 1974, SECDEF approved the first 22 production A-10As on December 19, 1974. The Air Force gave Fairchild a contract for this quantity on December 20. (Normally, a DSARC IIIB is held to go to rate production. In the case of the A-10 Program, a Development Concept Paper (DCP 23)[1] was signed in lieu of DSARC IIIB on February 10, 1976).

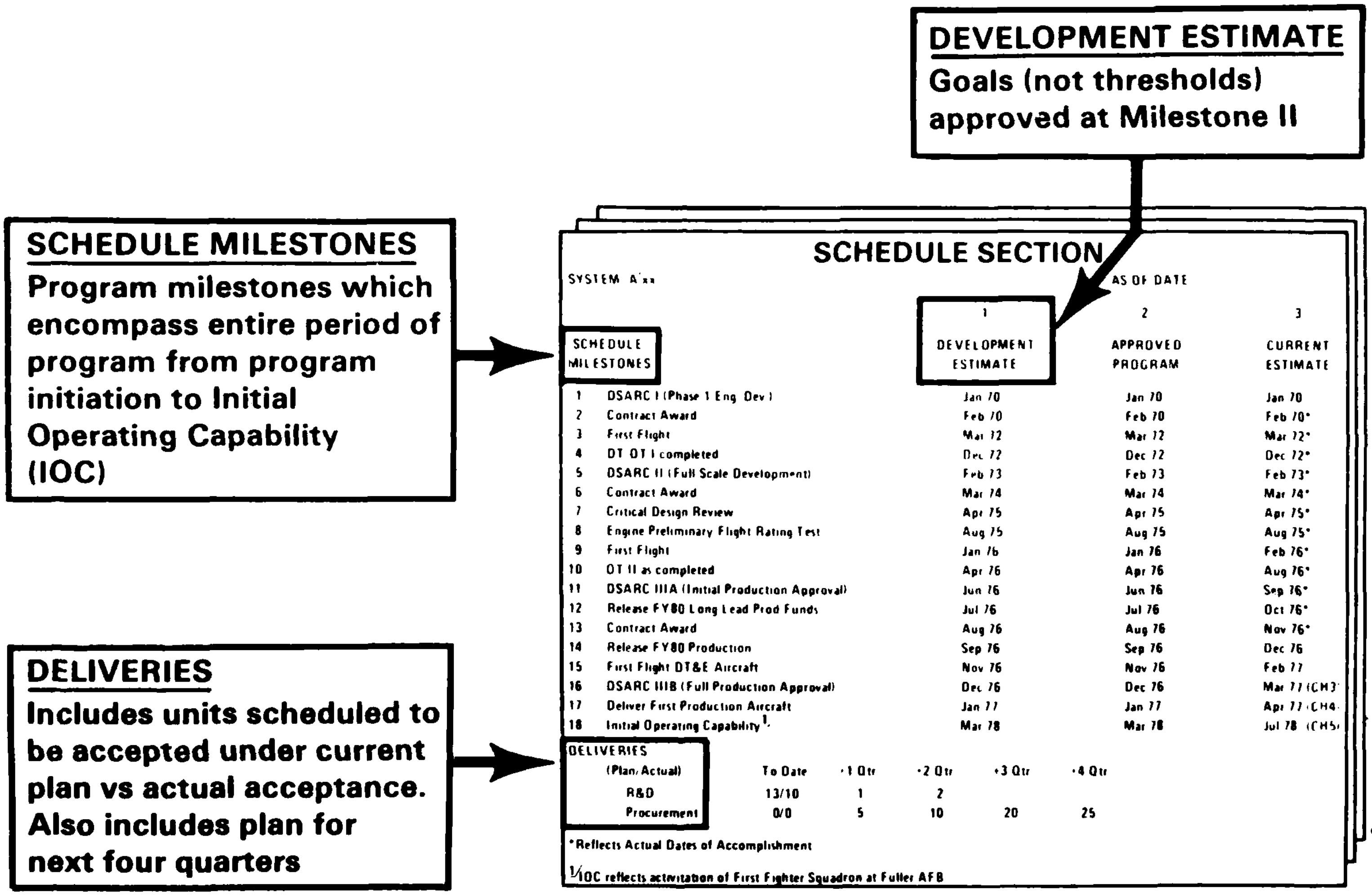
D. USE OF SELECTED ACQUISITION REPORT (SAR) DATA

The SAR is an official DoD quarterly report that is closely linked to the major weapon system acquisition and DSARC milestone processes. As such, the SAR provides a definitive and standardized source of data that has proved to be invaluable in developing our proposed methodology for predicting probable schedule and cost growth during a major weapon system's acquisition cycle. The Program Manager prepares and the Services submit reports as of 31 March, 30 June, 30 September, and 31 December. The reports are forwarded through appropriate channels to the Assistant Secretary of Defense (Comptroller) for submission to the Congress. The 31 December report is important because it coincides with the Presidential budget submission to the Congress. Thus, the Services and OSD must take care to ensure that the SAR data contained in the *Current Estimate (CE)* match budget items and the January Five-Year Defense Program (FYDP). The CE is the Service's latest forecast of the operational/technical characteristics, schedule, and program acquisition cost to acquire stated quantities. Since the March, June, and September SAR submissions go to Congress while that body is debating authorizations and appropriations for those weapon systems, program changes to these reports are usually limited to those resulting from a Congressional action or DSARC decision. Otherwise, SARs support documentation and testimony

[1]The "Development Concept Paper" is now called the Decision Coordinating Paper.

already before the Congress. Inasmuch as the final budget is usually not voted in time to be incorporated in the 30 September SARs, thorough SAR updates normally occur annually only in December.

Meanwhile, the internal DoD processes--e.g., the POM, PDM, October Budget Estimates Submission--may have substantially changed a particular SAR program, and/or the costs associated therewith. For the reasons cited above, the December SAR is likely to be the only quarterly submission that is a timely "snap-shot" of a program's status. Hence, our study effort focused on the data contained in the 31 December reports. Figure 1 is an example of a SAR Milestone Schedule and Figure 2 is an example of a SAR Annex, detailing a program's acquisition cost. A perusal of Figure 2 will quickly pinpoint one limitation of the SAR: the cost data presented in the report are highly aggregated. Admittedly, we would prefer a data source with much more detail available. We evaluated the potential of other documents such as the Decision Coordinating Paper and the Integrated Program Summary. We opted to use the SAR because of its visibility at decisionmaking levels and because it has a prescribed format common to all Services, which allows year-to-year comparisons to be made.



SCHEDULE MILESTONES	1 DEVELOPMENT ESTIMATE	2 APPROVED PROGRAM	3 CURRENT ESTIMATE
1 DSARC I (Phase 1 Eng Dev)	Jan 70	Jan 70	Jan 70
2 Contract Award	Feb 70	Feb 70	Feb 70*
3 First Flight	Mar 72	Mar 72	Mar 72*
4 DT OT I completed	Dec 72	Dec 72	Dec 72*
5 DSARC II (Full Scale Development)	Feb 73	Feb 73	Feb 73*
6 Contract Award	Mar 74	Mar 74	Mar 74*
7 Critical Design Review	Apr 75	Apr 75	Apr 75*
8 Engine Preliminary Flight Rating Test	Aug 75	Aug 75	Aug 75*
9 First Flight	Jan 76	Jan 76	Feb 76*
10 OT II as completed	Apr 76	Apr 76	Aug 76*
11 DSARC IIIA (Initial Production Approval)	Jun 76	Jun 76	Sep 76*
12 Release FY80 Long Lead Prod Funds	Jul 76	Jul 76	Oct 76*
13 Contract Award	Aug 76	Aug 76	Nov 76*
14 Release FY80 Production	Sep 76	Sep 76	Dec 76
15 First Flight DT&E Aircraft	Nov 76	Nov 76	Feb 77
16 DSARC IIIB (Full Production Approval)	Dec 76	Dec 76	Mar 77 (CH3)
17 Deliver First Production Aircraft	Jan 77	Jan 77	Apr 77 (CH4)
18 Initial Operating Capability[1]	Mar 78	Mar 78	Jul 78 (CH5)

DELIVERIES (Plan/Actual)	To Date	+1 Qtr	+2 Qtr	+3 Qtr	+4 Qtr
R&D	13/10	1	2		
Procurement	0/0	5	10	20	25

*Reflects Actual Dates of Accomplishment

1/ IOC reflects activation of First Fighter Squadron at Fuller AFB

FIGURE 1. Selected Acquisition Report Format D--Schedule Milestones

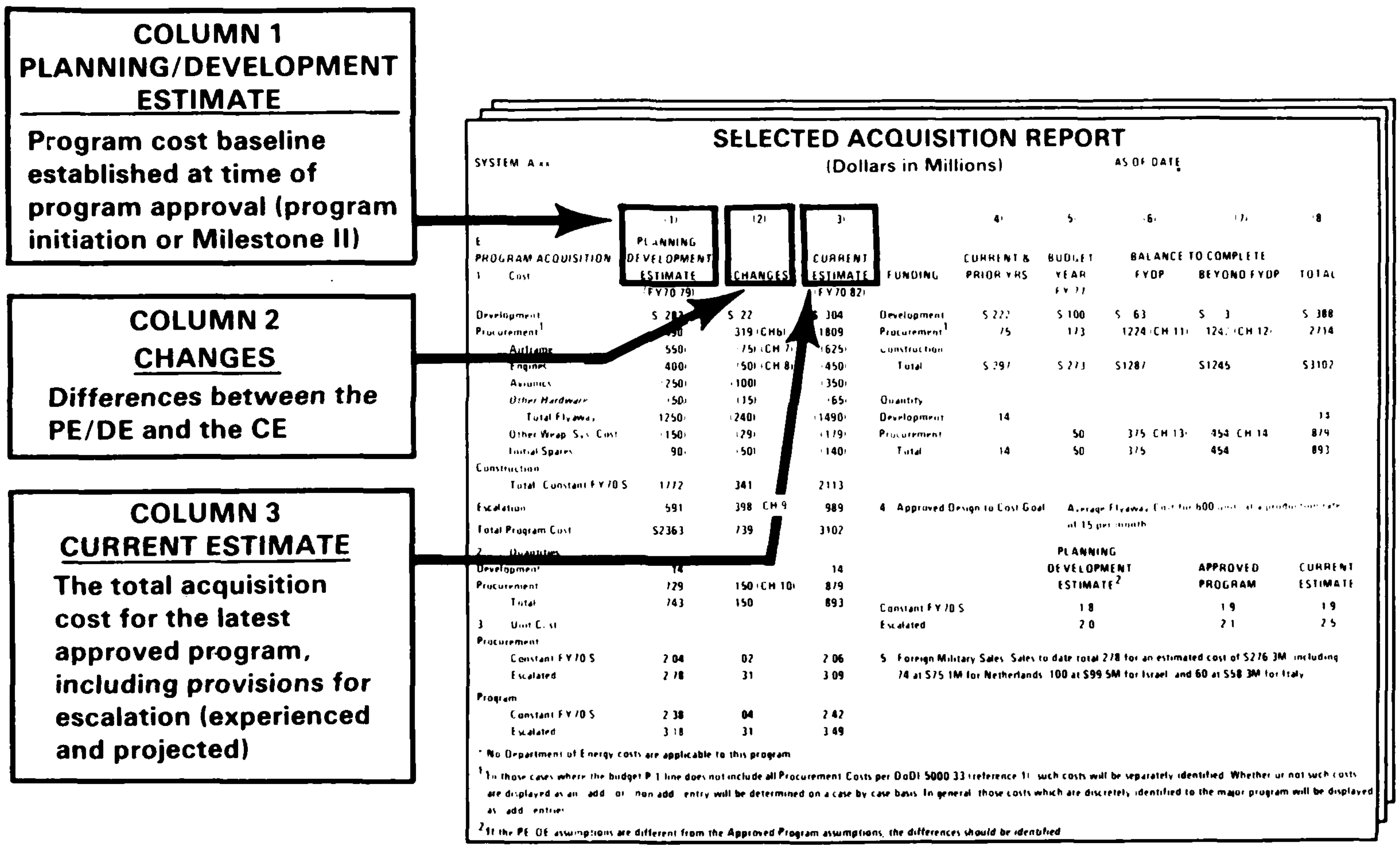


FIGURE 2. Selected Acquisition Report Format E--Program Acquisition Cost

IV. SELECTED ACQUISITION REPORT (SAR) DATA

A. INTRODUCTION

During the research phase of this study, schedule and cost data on weapon systems were extracted from the SARs, separated into four weapon system categories (missiles, aircraft, ships, other) and subsequently analyzed. Our initial analysis of the data revealed that the SAR reporting process, while evolving over time, took on an added dimension in calendar year 1975. Prior to that, cost estimates were only expressed in current or "then year" dollars, with no common basis for year-to-year comparison. Commencing with the December 31, 1975 SAR and all subsequent submissions, program cost estimates are presented in both current and constant-year dollars, thus providing the requisite measure of comparability as well as a means to quickly assess the effects of inflation on a particular program. Constant dollar values will be used throughout this report. In those circumstances where data were extracted from pre-1975 SARs, the current dollar figures were escalated/de-escalated, as appropriate, to a given base-year constant dollar figure (i.e., the constant-year dollar base cited in 1975 and later SARS).

B. ISOLATING THE IMPACT OF INFLATION

Individual SARs reflect the estimated program costs in both constant and current dollars, the latter value being derived by adding actual and anticipated inflation costs to the constant dollar value of the estimate. Nowadays, it is not uncommon to discover that the original (base-year constant dollar) estimate of a program's cost has more than doubled when examined in terms of today's value of the dollar (i.e., current dollar value). Although in this report we express cost values only in terms of constant dollars, we do, nevertheless, recognize and acknowledge that public pronouncements on cost growth in weapon system acquisition programs are usually made without adjusting for inflation (i.e., in current dollars). Given the normal development cycle for a new weapon system (ten or more years seems representative), the impact of inflation in a program can be severe. We would observe that since the DoD in and of itself cannot control inflation or its effects, it is more useful to focus on constant dollar growth as a more meaningful measure of management effectiveness in a particular program.

To maintain uniformity in the DoD budget process, the OSD Comptroller periodically updates escalation indices associated with a particular appropriation (RDT&E, MILCON, etc.). The indices are published several times during the fiscal year based on guidance received from the Office of Management and Budget (OMB) so that the stated budget requirements for a commodity or system will accurately reflect the current buying power of the dollar. A program manager normally maintains an audit trail of his program on a constant dollar basis; thus, in preparing a quarterly SAR submission he would use the indices to "inflate" his program's Current Estimate constant dollar costs to the corresponding current dollar value. The process whereby inflation indices are updated is the end product of a comprehensive effort to collect data from a myriad of sources within both the public (including each military service) and private sectors of the economy. One word of caution: The historical inflation experienced by one Service in a particular appropriation (e.g., aircraft procurement) may differ from that experienced by another Service.

C. DATA COLLECTION CHARTS

As an aid to more rigorous analysis, a simple graphing technique was employed to portray the schedule and cost growth during both the development and the procurement phases of a particular acquisition program. The development chart displayed the changes in the estimate of when the system would attain its Initial Operational Capability (IOC) and the growth, over time, in estimated development costs (RDT&E). See Fig. 3 for a sample development chart. The procurement chart captured the changes in the Procurement Unit Cost (PUC) and procurement quantities of the system as measured from the date of the Development Estimate (i.e., completion of MILESTONE II) through the IOC date and up to the present (or whenever the SAR reporting requirement for a particular system ceased). The Procurement Unit Cost is derived by dividing the total procurement costs (i.e., flyaway, other weapon system, and initial spares) by the quantity of systems to be procured. See Fig. 4 for a sample procurement chart. Although a majority of earlier studies of cost growth opted to analyze growth on a "Program Acquisition Cost" basis, this study has elected to examine the program in more detail by segregating the development cost from the procurement cost growth patterns. It should be understood, however, that the Program Acquisition Cost is simply the sum of the development, procurement and military construction costs.

During the course of our investigations, a total of 67 SAR systems were examined; of that total, 34 systems which had achieved IOC were selected for detailed analysis. Each system was assigned to one of four material categories: missiles, aircraft, ships, and other. We anticipate that in future updates of this paper, when additional systems currently under development reach IOC, the category "other" will be replaced by two new categories: command, control, communications and intelligence (C^3I) and tracked vehicles and other weapons.

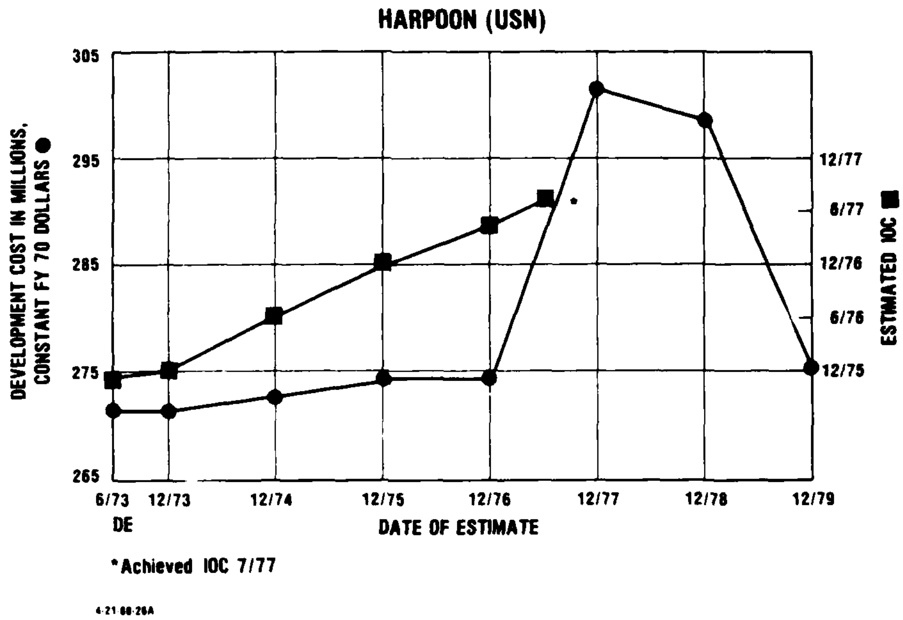


FIGURE 3. Sample Development Cost Chart

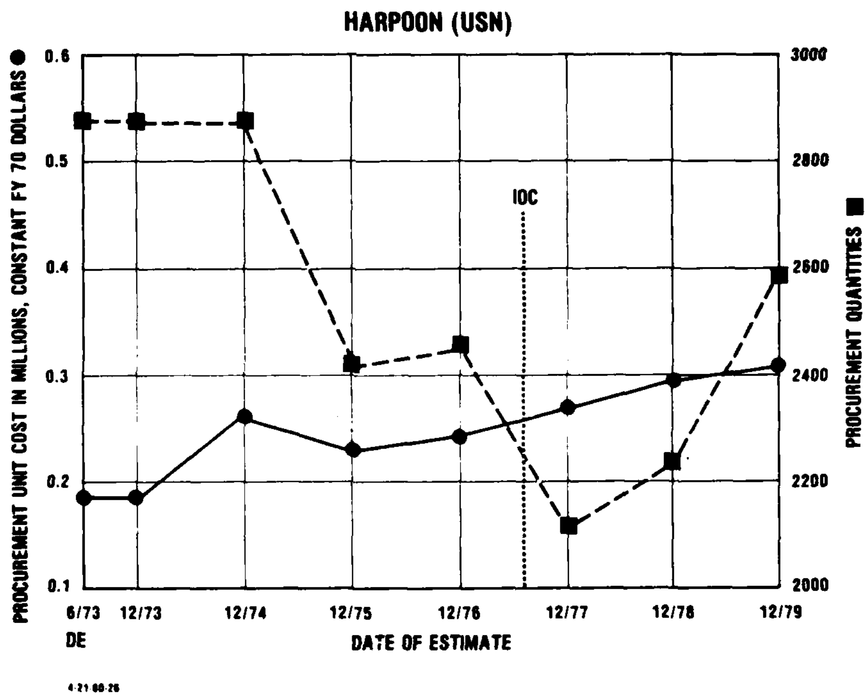


FIGURE 4. Sample Procurement Unit Cost Chart

For purposes of exposition, primary focus was placed on the missile systems. The charts that had been developed earlier (Figs. 3 and 4) were then re-checked to see if any apparent anomalies existed in the data that might prejudice use of the data as a predictor of future growth. For example, in the area of procurement unit costs one would intuitively expect that the PUC would increase significantly if the procurement quantities were cut. Likewise, one would anticipate that a significant increase in quantity would reduce the PUC, or at least hold the cost constant from one year to the next. In the case of the U.S. Air Force Short-Range Attack Missile (SRAM), the latter expectation did not hold--at one point prior to IOC the procurement quantities increased by a factor of 2.7 and the procurement unit costs increased by a factor of 4.3. Unfortunately, the SRAM was an early program that reached IOC in August 1972. The data and analyses presented in the SRAM SAR were quite sketchy. A massive cost increase (by a factor of 7.6 times the Development Estimate of procurement costs) was attributed to an "Estimating Change." Unable to isolate the actual factors involved in the SRAM developmental history, we elected to exclude SRAM data from any further consideration. It must be reiterated, however, that the basic aim of this paper is to develop schedule and cost growth factors, and not to delve into the reasons for growth. We must also point out that the estimated cost data contained in SAR reports is *not* normalized (i.e., adjusted for quantity changes). Given this fact and recognizing the virtual impossibility of accurately predicting probable future quantity changes in a given weapon system procurement program, we elected to pursue the development of our methodology without relying on normalized cost/quantity data. This decision was reinforced by our initial findings, which are discussed in the following section.

D. INITIAL FINDINGS

After the development and procurement charts were completed, they were reviewed to determine if any trends could be discerned. This initial inspection of the charts led to two findings:

1. Achievement of IOC marks the end of significant cost growth for most systems. (Note: the IOC date is usually the last schedule milestone subject to a DCP threshold restriction).

2. Procurement quantities are as likely to increase as they are to decrease. For 35 programs at or beyond IOC, procurement quantities increased from the development estimate in 14 cases, decreased in 16 cases, and remained unchanged in five cases (see Table 1). This finding is at variance with the commonly held belief that as the acquisition cycle evolves, smaller quantities of systems are procured than planned earlier because of the effects of schedule/cost growth and constrained budgets. However, it should be noted that in most cases the Army procured fewer quantities than planned, the Air Force procured more, while the Navy had roughly equal numbers of cases where more and fewer quantities were procured. The same procurement quantity growth factors, grouped by type of system, are:

PROCUREMENT QUANTITY GROWTH FACTORS

	<1.0	1.0	>1.0
Aircraft	2	2	4
Missiles	8	2	7
Ships	2	1	4
Other	2	0	1
Total	14	5	16

The procurement quantity growth factors by type of system do not show any strong biases toward factors greater than one or less than one.

TABLE 1. PROCUREMENT QUANTITY GROWTH FACTORS--SYSTEMS AT OR BEYOND IOC (AS OF DECEMBER 1979)

		PROCUREMENT QUANTITY GROWTH FACTORS			
SERVICE	SYSTEM	PLANNING ESTIMATE	DEVELOPMENT ESTIMATE	IOC	LATEST SAR
ARMY	DRAGON	-	1.00	0.35	0.27
	I-HAWK	1.01	1.00	0.61	0.86
	LANCE	-	1.00	1.00	2.00
	M-198	-	1.00	0.96	0.96
	TACFIRE	-	1.00	1.02	0.39
	TOW	-	1.00	0.48	0.59
	UH-60	-	1.00	1.00	1.00
AIR FORCE	A-10	1.00	1.00	1.01	1.13
	E-3A	-	1.00	0.74	0.74
	E-4	-	1.00	0.83	0.83
	F-15	-	1.00	1.00	1.00
	MAVERICK A/B	-	1.00	1.29	1.18
	MINUTEMAN III	-	1.00	0.95	1.13
	SIDEWINDER[1]	-	1.00	1.89	1.64
	SPARROW III[1]	-	1.00	1.86	1.72
	SRAM	-	1.00	2.14	2.14
NAVY[2]	CAPTOR	-	1.00	0.15	0.15
	CVAN-68	-	1.00	1.00	1.00
	DD-963	-	1.00	1.03	1.03
	DLGN-38	1.33	1.00	1.33	1.33
	E-2C	-	1.00	1.68	3.39
	FFG-7	-	1.00	1.10	1.10
	F-14	-	1.00	0.70	1.04
	HARPOON	1.46	1.00	0.73	0.90
	LHA	-	1.00	0.56	0.56
	MK-48	-	1.00	1.00	0.68
	NATO-PHM	-	1.00	0.18	0.18
	PHALANX	-	1.00	1.26	1.26
	PHOENIX	-	1.00	1.07	1.20
	POSEIDON	-	1.00	1.01	0.95
	P-3C	-	1.00	1.85	2.64
	SIDEWINDER	-	1.00	1.18	1.14
	SPARROW	-	1.00	0.63	0.90
	SSN-688	-	1.00	1.22	1.19
	TRIDENT MISSILE	-	1.00	0.94	0.94

[1] System developed by U.S. Navy. USAF has separate procurement program.

[2] AEGIS Program not listed since procurement is included in individual shipbuilding programs.

E. SCHEDULE GROWTH

Schedule growth during development of a new weapon system is normally measured by the amount of slippage experienced in a program between a fixed base date (e.g., the approval date of either the Planning Estimate or the Development Estimate) and the attainment of the system's Initial Operational Capability. To avoid confusion, schedule growth discussed in this report will use the IOC date established at the time of Development Estimate approval as the base date. All systems in each of the four weapon system categories were analyzed individually. After the necessary data were collected, the cumulative total growth factor and cumulative average schedule growth rates were computed using the following formulas:

$$\text{Cumulative total growth factor} = \frac{\text{Actual time (in years) from DE approval to IOC}}{\text{Initial estimated time (in years) from DE approval to IOC}}$$

and,

$$\text{Cumulative average} = \sqrt[n]{\text{Cumulative total growth factor}}$$

where n = Time interval in years from date of Development Estimate approval to actual IOC Date.

As can be seen from the equation immediately above, the "cumulative average" figure is the compound annual rate of growth over the time period from DE to IOC. Table 2 displays schedule growth, by category, for the systems analyzed. This table also includes the average elapsed time in years required for the "typical" system in a particular category to attain IOC. Mean and median values for the various categories are also summarized. We recommend more weight be given to median values than to mean values in our cost growth methodology. As can be seen in Table 2 (Aircraft), a single program (the E-4) can have an undue effect on mean values.

TABLE 2. SYSTEM SCHEDULE GROWTH

AIRCRAFT

System	TIME					GROWTH FACTORS	
	Date of Development Estimate	Initial Estimate IOC Date	Actual IOC Date	Years--Dev. Estimate To Est. IOC	Years--Dev. Estimate To Actual IOC	Cumulative Total	Cumulative Average
A-10	5/71	6/77	10/77	6.1	6.4	1.05	1.01
E-2C	4/68	11/73	2/74	5.6	5.8	1.04	1.01
E-3A	6/71	3/77	4/78	5.8	6.8	1.18	1.03
E-4	1/73	6/74	4/75	1.4	2.3	1.64	1.24
F-14	1/69	4/73	12/73	4.3	4.9	1.14	1.03
F-15	1/70	7/75	9/75	5.5	5.7	1.04	1.01
P-3C	6/67	3/70	7/70	2.8	3.1	1.13	1.04
UH-60	6/71	6/79	11/79	8.0	8.4	1.05	1.01
MEDIAN				5.6	5.8	1.09	1.02
MEAN				4.9	5.4	1.16	1.05

MISSILES

System	Date of Development Estimate	Initial Estimate IOC Date	Actual IOC Date	Years--Dev. Estimate To Est. IOC	Years--Dev. Estimate To Actual IOC	Cumulative Total	Cumulative Average
CAPTOR	6/71	9/76	7/79	5.3	8.1	1.54	1.05
DRAGON	7/65	5/70	9/74	4.8	9.2	1.92	1.07
HARPOON	6/73	11/75	7/77	2.4	4.1	1.71	1.14
I-HAWK	12/68	4/71	11/72	2.4	3.9	1.63	1.13
LANCE	6/67	6/70	6/72	3.0	5.0	1.67	1.11
MK-48	6/71	2/72	2/72	0.7	0.7	1.00	1.00
MAVERICK (A/B)	7/68	12/71	2/73	3.4	4.6	1.35	1.07
MINUTEMAN III	3/68	6/70	6/70	2.3	2.3	1.00	1.00
PHOENIX	12/62	4/73	12/73	10.3	11.0	1.07	1.01
POSEIDON	11/66	11/70	3/71	4.0	4.3	1.08	1.02
SIDEWINDER (N)	1/71	3/74	5/78	3.2	7.3	2.28	1.12
SPARROW (N)*	6/68	1/69	4/76	0.6	7.6	13.00	1.39
SRAM	12/66	2/70	8/72	3.2	5.7	1.78	1.11
TOW	5/66	8/68	9/70	2.3	4.3	1.87	1.17
TRIDENT I	10/73	10/78	10/79	5.0	6.0	1.20	1.03
MEDIAN				3.2	5.0	1.63	1.07
MEAN				3.7	5.5	1.51	1.07

*Values not used to calculate the Mean.

SHIPS

System	Date of Development Estimate	Initial Estimate IOC Date	Actual IOC Date	Years--Dev. Estimate To Est. IOC	Years--Dev. Estimate To Actual IOC	Cumulative Total	Cumulative Average
CVAN 68	12/67	3/73	3/76	5.3	8.3	1.57	1.06
DD 963	6/70	6/75	6/77	5.0	7.0	1.40	1.05
CGN 38	12/71	12/75	9/77	4.0	5.8	1.44	1.07
FFG 7	10/72	5/78	3/79	5.6	6.4	1.14	1.02
LHA	12/68	2/74	5/77	5.2	8.4	1.62	1.06
NATO PHM	9/72	3/76	5/78	3.5	5.7	1.63	1.09
SSN 688	1/71	9/74	11/76	3.7	5.8	1.57	1.08
MEDIAN				5.0	6.4	1.57	1.06
MEAN				4.6	6.8	1.48	1.06

OTHER

System	Date of Development Estimate	Initial Estimate IOC Date	Actual IOC Date	Years--Dev. Estimate To Est. IOC	Years--Dev. Estimate To Actual IOC	Cumulative Total	Cumulative Average
AEGIS	12/69	5/75	12/79	5.4	10.0	1.85	10.6
M-198	12/71	5/77	4/79	5.4	7.3	1.35	1.04
TACFIRE	12/67	7/74	4/79	6.6	11.3	1.71	1.05
PHALANX	1/73	1/77	8/79	4.0	6.6	1.65	1.08
MEDIAN				5.4	8.7	1.68	1.06
MEAN				5.4	5.8	1.64	1.06

As an example, within the missile category, the schedule growth ranged from zero growth in the MINUTEMAN III and Mk-48 Torpedo programs to an additional 7-1/4 years above the initial estimate of the time interval between the date of Development Estimate approval and the initially estimated date of IOC attainment for the SPARROW III program. The actual time required to attain IOC, as measured from the date of DE approval, ranged from 2-1/4 years to 11 years. The mean and median figures for this time interval were 5.5 and 5.0, respectively. The computations yielded a median cumulative average growth rate for missile systems of 1.07 over a developmental period of approximately five years. The median cumulative total schedule growth amounted to 1.63 times the initial estimate of the time interval between approval of the DE and the anticipated IOC date.

Rounding out our analysis of schedule growth, we developed composite graphs that plotted the changes in the estimated IOC dates of individual systems over time--extending from date of DE approval until actual date of IOC achievement (see Figs. 5 through 8). We examined the actual shape of the schedule growth curves to determine if there were any specific types of curves associated with a particular weapon system category. We posited three types of growth curves and their properties:

- Concave: Early program slippage, with growth leveling off prior to IOC.
- Straight Line: Relatively uniform growth throughout the program.
- Convex: Little if any growth early in the program, preponderance of growth later in program up to and including IOC attainment.

While this proved to be an interesting effort, we found that the missile curves were the only category to demonstrate a dominant trend (i.e., toward concavity). After much deliberation--and

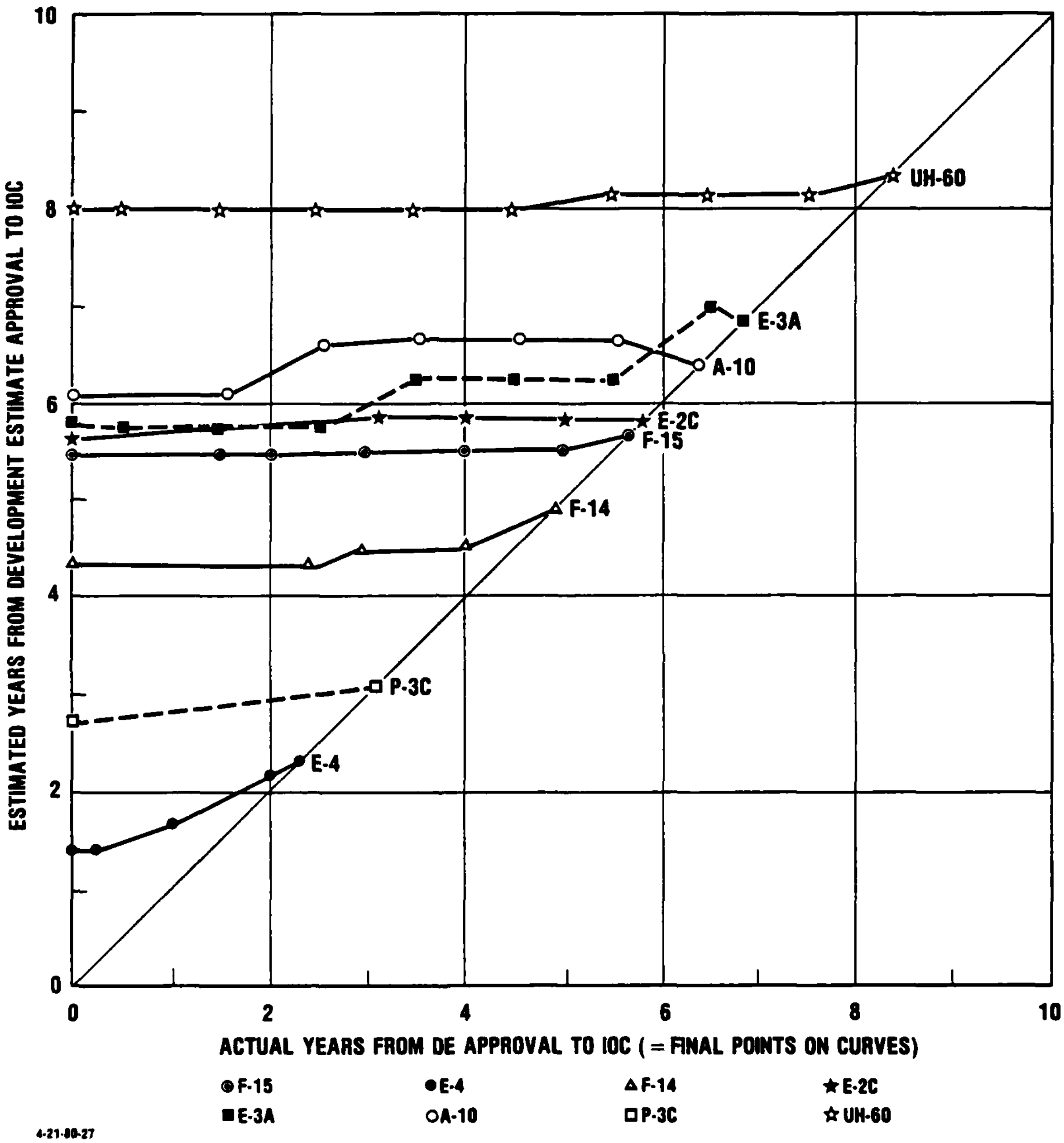


FIGURE 5. Schedule Growth, Aircraft

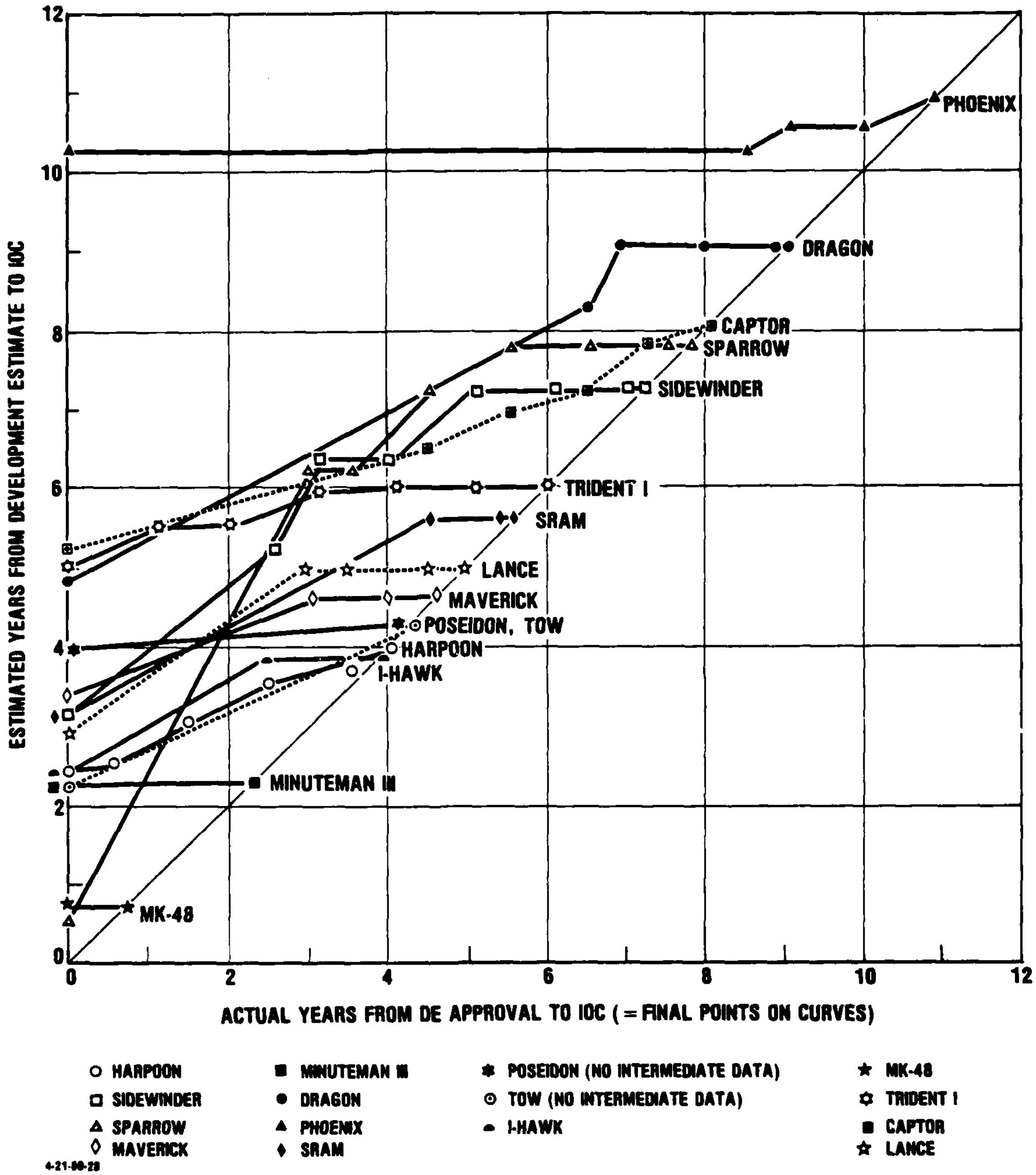
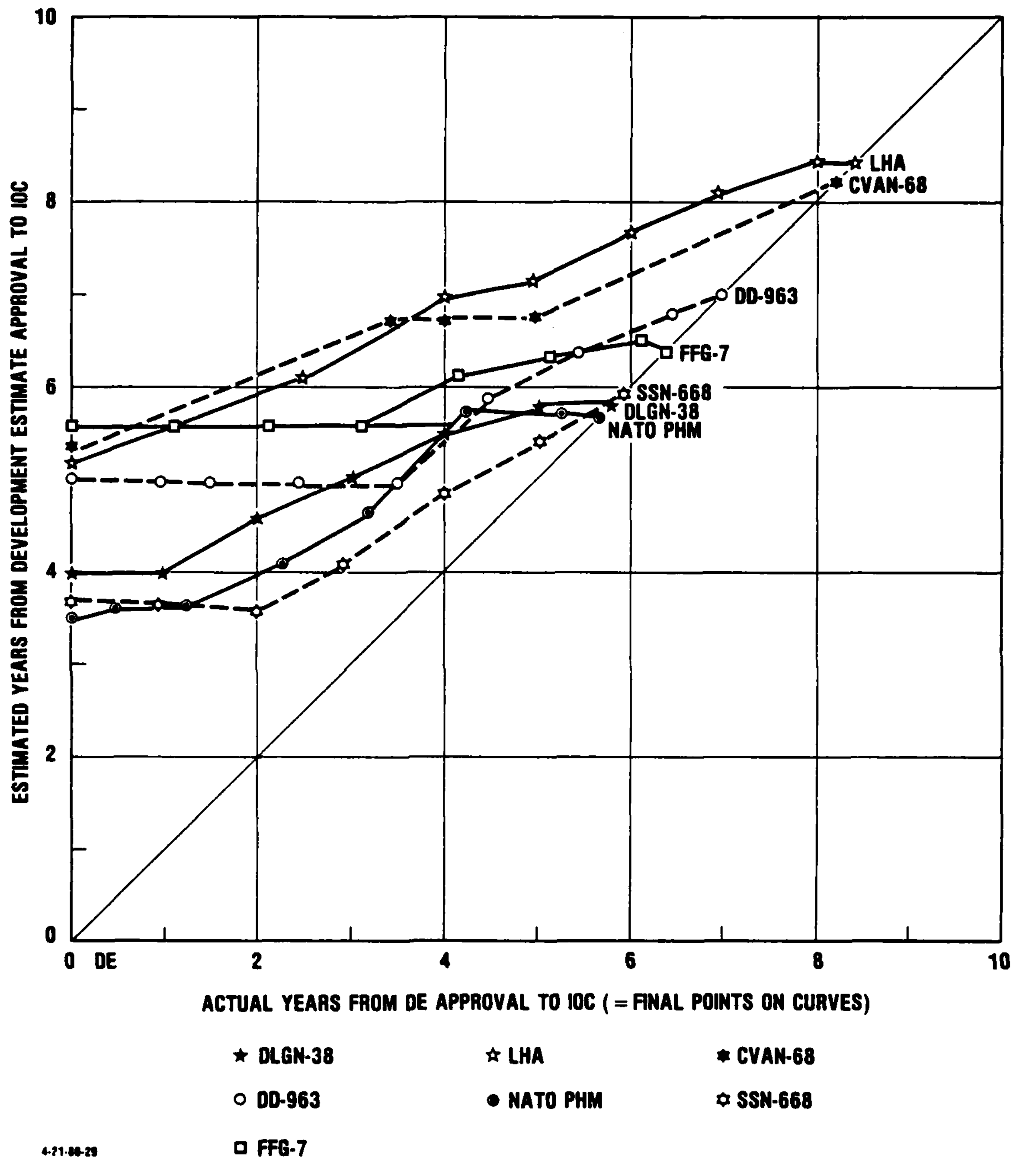


FIGURE 6. Schedule Growth, Missiles



4-21-86-29

FIGURE 7. Schedule Growth, Ships

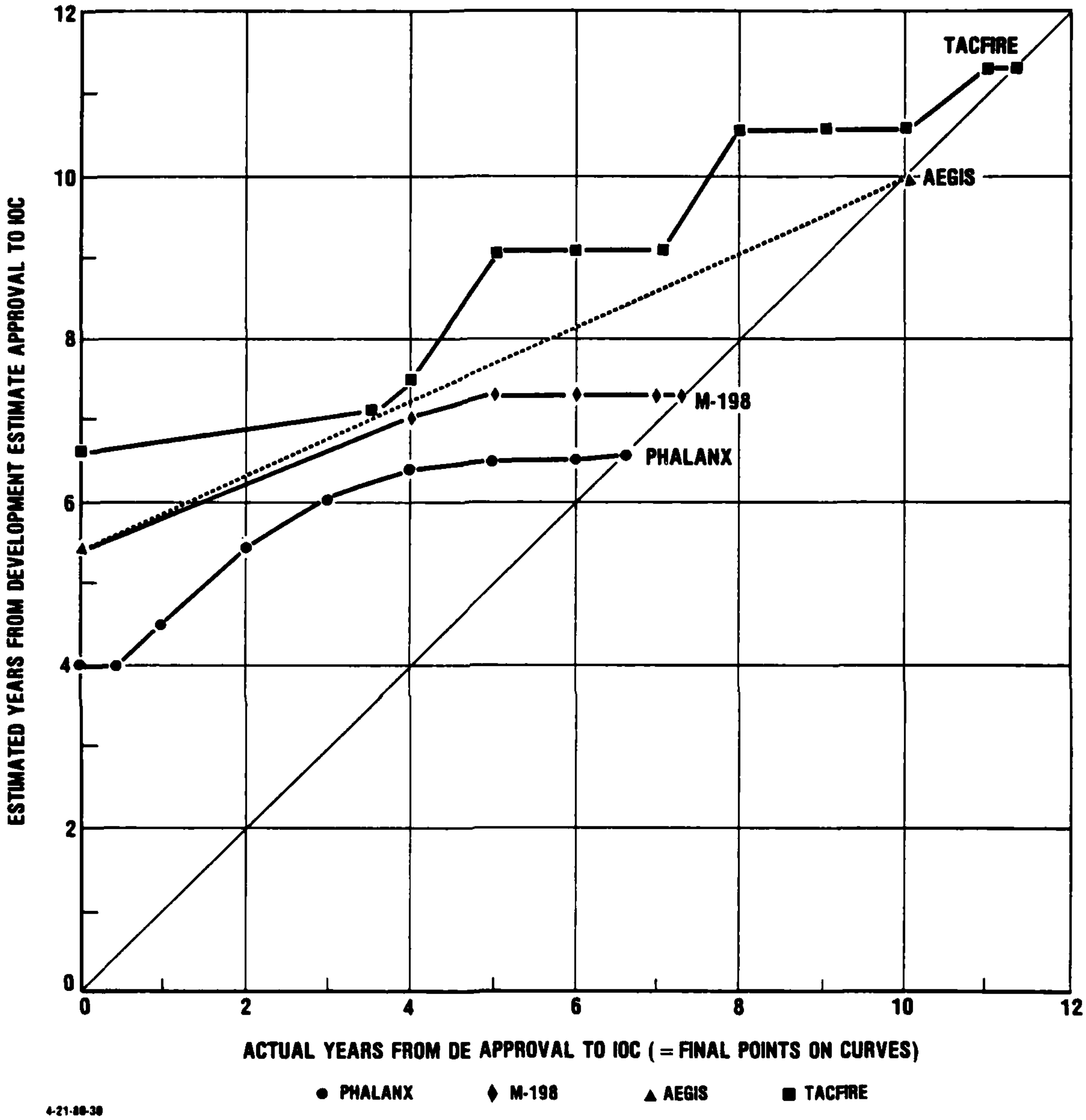


FIGURE 8. Schedule Growth, Other

considering the degree of uncertainty normally associated with the estimation process--we decided that it would be feasible to develop a schedule growth projection methodology based on the median cumulative total growth rate experienced in each weapon system category. Thus, with the exception of mature missile programs, we feel that a straight-line projection will adequately approximate the growth a specific program will experience. The details of the methodology will be discussed in Chapter V.

F. COST GROWTH

The techniques applied in our analysis of weapon system cost growth are quite similar to those used in our investigation of schedule growth. Cumulative total and cumulative average development cost and procurement unit cost growth factors were computed for each of the four weapon system categories using the following formulas:

$$\text{Cumulative total} = \frac{\text{Estimated (x or y) at IOC date}}{\text{Estimated (x or y) at DE approval date}}$$

$$\text{Cumulative average} = \sqrt[n]{\text{Cumulative total growth factor}}$$

where x = Development Cost
y = Procurement Unit Cost
n = Time interval (in years) from date of Development Estimate approval to actual IOC date.

To test the validity of our earlier finding that IOC marks the end of significant cost growth for a weapon system acquisition program, the cumulative total and the cumulative average growth patterns of those SAR systems that had achieved IOC were examined. The growth rates were computed using the formulas:

$$\text{Cumulative total} = \frac{\text{Estimated (x or y) in latest SAR}}{\text{Estimated (x or y) at IOC date}}$$

$$\text{Cumulative average} = \sqrt[t]{\text{Cumulative total growth factor}}$$

where x = Development Cost
y = Procurement Unit Cost
t = Time interval (in years) from IOC date to latest SAR estimate.

Table 3 (Development Cost) and Table 4 (Procurement Unit Cost) display the cumulative total and cumulative average cost growth factors for those systems in the four weapon categories that have attained IOC. These tables confirm that cost growth after IOC is much lower than prior to IOC. In our cost growth methodology we ignore post-IOC cost growth.

Our next step involved the plotting of the cumulative average growth factors in order to provide a visual display of the data and emerging trends (if any). Growth to IOC was analyzed (see Figs. 9 through 16). Note that all systems initially have zero growth (a factor of 1.00) at the time of DE approval. One finding that can be derived from these charts is that time moderates the cumulative rate of annual cost growth.

TABLE 3. DEVELOPMENT COST GROWTH FOR SYSTEMS ANALYZED

AIRCRAFT

System	Base Year	Estimated Development Costs (Millions of Base Year Constant $) At Development Estimate Approval Date	At IOC	Latest SAR	GROWTH FACTORS: Development Estimate Approval Date to IOC Date — Cumulative Total	Cumulative Average	IOC Date to Latest SAR — Cumulative Total	Cumulative Average
A-10	1970	281.9	335.0	343.0	1.188	1.027	1.024	1.011
E-2C	1968	129.3	196.4	215.8	1.519	1.074	1.099	1.016
E-3A	1970	761.0	1178.8	1187.3	1.549	1.058	1.007	1.004
E-4	1974	158.8	293.5	294.7	1.848	1.306	1.004	1.001
F-14	1969	899.5	1367.5	1392.1	1.520	1.089	1.018	1.003
F-15	1970	1654.9	1869.7	1921.2	1.130	1.021	1.028	1.006
P-3C	1968	203.0	210.4	248.0	1.036	1.012	1.179	1.018
UH-60	1971	357.3	365.8	365.8	1.024	1.003	1.000	1.000
MEDIAN					1.354	1.043	1.021	1.005
MEAN					1.352	1.074	1.045	1.007

MISSILES

System	Base Year	At Development Estimate Approval Date	At IOC	Latest SAR	Dev. Cumulative Total	Dev. Cumulative Average	IOC Cumulative Total	IOC Cumulative Average
CAPTOR	1971	85.5	100.3	100.3	1.173	1.020	1.000	1.000
DRAGON	1966	61.7	116.9	116.3	1.895	1.072	0.995	0.998
HARPOON	1970	272.0	301.7	275.3	1.109	1.026	0.913	0.964
I-HAWK	1969	95.5	106.6	145.5	1.116	1.029	1.365	1.064
LANCE	1970	349.0	356.1	349.0	1.020	1.004	0.980	0.992
MK-48	1972	150.4	155.8	275.9	1.036	1.052	1.771	1.078
MAVERICK (A/B)	1968	115.7	124.9	120.7	1.079	1.017	0.966	0.991
MINUTEMAN III	1967	1835.4	1846.4	1800.0	1.006	1.003	0.975	0.997
PHOENIX	1963	94.0	144.3	194.8	1.535	1.040	1.350	1.051
POSEIDON	CURRENT $	1222.1	1303.8	1300.2	1.067	1.015	0.997	0.999
SIDEWINDER (N)	1971	6.6	44.8	44.6	6.788	1.300	0.996	0.997
SPARROW (N)	1968	24.9	80.2	91.4	3.221	1.162	1.140	1.037
SRAM	CURRENT $	167.6	464.5	453.8	2.771	1.196	0.979	0.988
TOW	1966	97.9	101.9	117.7	1.041	1.009	1.155	1.024
TRIDENT I	1974	2794.1	2935.4	2935.4	1.051	1.008	1.000	1.000
MEDIAN					1.109	1.026	0.997	0.999
MEAN					1.794	1.064	1.105	1.012

SHIPS

System	Base Year	At Development Estimate Approval Date	At IOC	Latest SAR	Dev. Cumulative Total	Dev. Cumulative Average	IOC Cumulative Total	IOC Cumulative Average
CVAN 68	1967	No Development Funds						
DD 963	1970	36.0	37.6	38.3	1.044	1.008	1.019	1.008
DLGN 38	1970	21.2	21.2	21.2	1.000	1.000	1.000	1.000
FFG 7	1973	14.1	20.1	20.1	1.426	1.056	1.000	1.000
LHA	1969	22.3	22.2	22.2	0.996	0.999	1.000	1.000
NATO PHM	1973	70.5	82.7	82.7	1.173	1.028	1.000	1.000
SSN 688	1971	0.0	4.8	18.8	--	--	3.917	1.576
MEDIAN					1.044	1.008	1.000	1.000
MEAN					1.128	1.018	1.489	1.098

OTHER

System	Base Year	At Development Estimate Approval Date	At IOC	Latest SAR	Dev. Cumulative Total	Dev. Cumulative Average	IOC Cumulative Total	IOC Cumulative Average
AEGIS	1970	394.2	504.0	504.0	1.279	1.025	1.000	1.000
M-198	1972	30.9	41.7	41.7	1.350	1.042	1.000	1.000
PHALANX	1972	38.8	113.4	113.4	2.923	1.174	1.000	1.000
TACFIRE	1968	50.8	77.0	77.0	1.516	1.037	1.000	1.000
MEDIAN					1.433	1.040	1.000	1.000
MEAN					1.767	1.070	1.000	1.000

TABLE 4. PROCUREMENT UNIT COST GROWTH FOR SYSTEMS ANALYZED

AIRCRAFT

System	Base Year	Estimated Procurement Unit Costs (Millions of Base Year Constant $) At Development Estimate Approval Date	At IOC	Latest SAR	GROWTH FACTORS Development Estimate Approval Date to IOC Date Cumulative Total	Cumulative Average	IOC Date to Latest SAR Cumulative Total	Cumulative Average
A-10	1970	2.04	2.60	2.67	1.275	1.039	1.027	1.012
E-2C	1968	14.36	19.74	15.41	1.375	1.055	0.781	0.958
E-3A	1970	33.1	43.9	43.5	1.326	1.042	0.991	0.995
E-4	1974	42.5	47.9	77.3	1.127	1.053	1.614	1.110
F-14	1969	9.7	12.3	13.83	1.268	1.050	1.124	1.020
F-15	1970	5.94	7.29	7.71	1.227	1.037	1.058	1.013
P-3C	1968	10.49	11.14	9.89	1.062	1.020	0.888	0.987
UH-60	1971	1.43	1.55	1.55	1.084	1.010	1.000	1.000
MEDIAN					1.251	1.041	1.014	1.006
MEAN					1.221	1.038	1.060	1.012

MISSILES

CAPTOR	1971	0.036	0.184	0.184	5.111	1.226	1.000	1.000
DRAGON	1966	0.00113	0.003	0.00298	2.666	1.112	0.992	0.998
HARPOON	1970	0.182	0.269	0.303	1.478	1.100	1.126	1.049
I-HAWK	1969	0.0459	0.0736	0.071	1.603	1.129	0.965	0.993
LANCE	1970	0.105	0.122	0.126	1.162	1.031	1.033	1.006
MK-48	1972	0.372	0.368	0.367	0.989	0.985	0.997	1.000
MAVERICK (A/B)	1968	0.0126	0.0151	0.0124	1.198	1.040	0.821	0.932
MINUTEMAN III	1967	3.95	5.96	4.05	1.509	1.201	0.680	0.950
PHOENIX	1963	0.189	0.335	0.272	1.772	1.053	0.812	0.966
POSEIDON	CURRENT $	3.425	4.183	4.177	1.221	1.048	0.999	1.000
SIDEWINDER (N)	1971	0.023	0.038	0.045	1.652	1.071	1.184	1.119
SPARROW (N)	1968	0.04	0.066	0.061	1.650	1.066	0.924	0.978
SRAM[1]	CURRENT $	0.09	0.441	0.427	4.900	1.322	0.968	0.985
TOW	1966	0.00197	0.00385	0.003025	1.954	1.169	0.787	0.962
TRIDENT I	1974	6.20	5.59	5.59	0.902	0.983	1.000	1.000
MEDIAN					1.556	1.069	0.995	0.999
MEAN					1.776	1.087	0.951	0.997

[1]Data not used to compute Median/Mean.

SHIPS

CVAN 68	1967	504.9	584.1	590.6	1.160	1.018	1.011	1.003
CVAN 69	1967	475.8	607.6	604.9	1.277	1.022	0.996	0.997
DD 963	1970	78.62	83.0	85.48	1.060	1.008	1.030	1.013
DLGN 38	1973	215.1	235.45	238.5	1.095	1.016	1.013	1.006
FFG 7	1973	52.13	89.15	89.15	1.710	1.086	1.000	1.000
LHA	1969	141.0	222.8	242.94	1.580	1.056	1.090	1.038
NATO PHM	1973	20.5	39.8	39.8	1.941	1.123	1.000	1.000
SSN 688	1971	160.2	SAR	DATA	INCOMPLETE			
MEDIAN					1.277	1.022	1.011	1.003
MEAN					1.403	1.047	1.020	1.008

OTHER

AEGIS	1970	Procurement Integrated with Shipbuilding Costs						
M-198	1972	0.123	0.150	0.150	1.219	1.028	1.000	1.000
PHALANX	1972	1.185	1.645	1.645	1.388	1.050	1.000	1.000
TACFIRE	1968	0.695	1.436	2.045	2.066	1.066	1.424	1.657
MEDIAN					1.388	1.050	1.000	1.000
MEAN					1.558	1.048	1.141	1.219

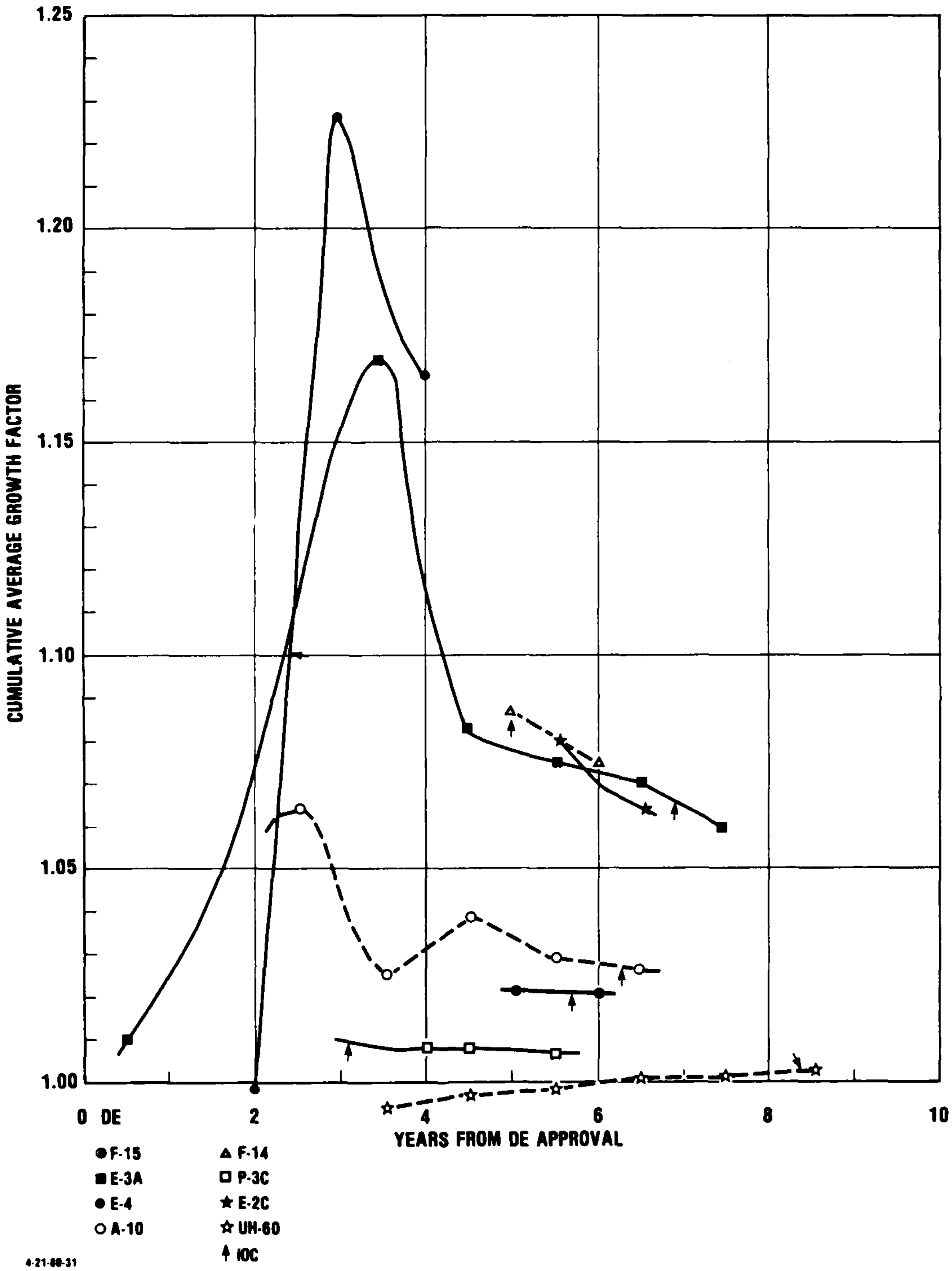


FIGURE 9. Development Cost Growth, Aircraft

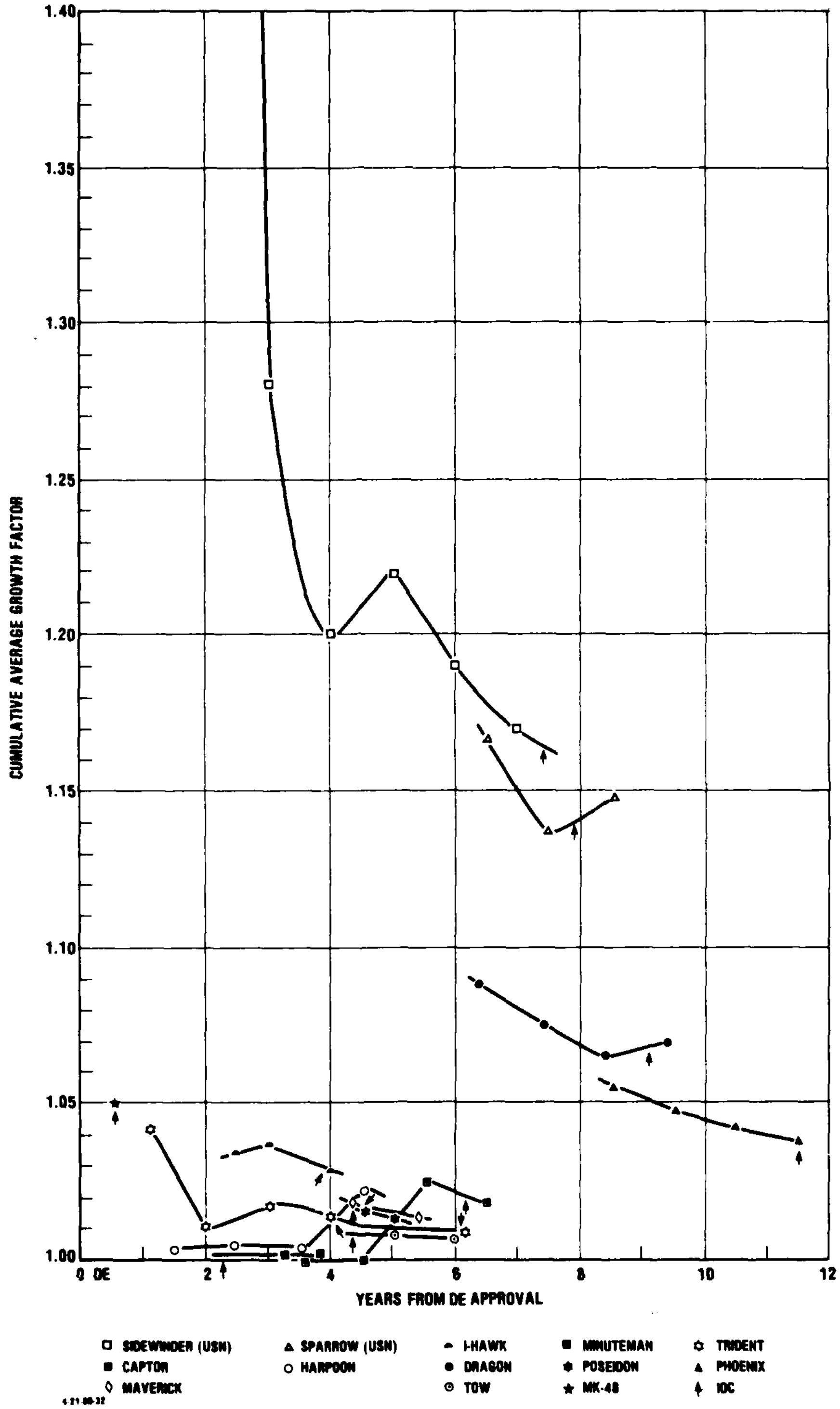


FIGURE 10. Development Cost Growth, Missiles

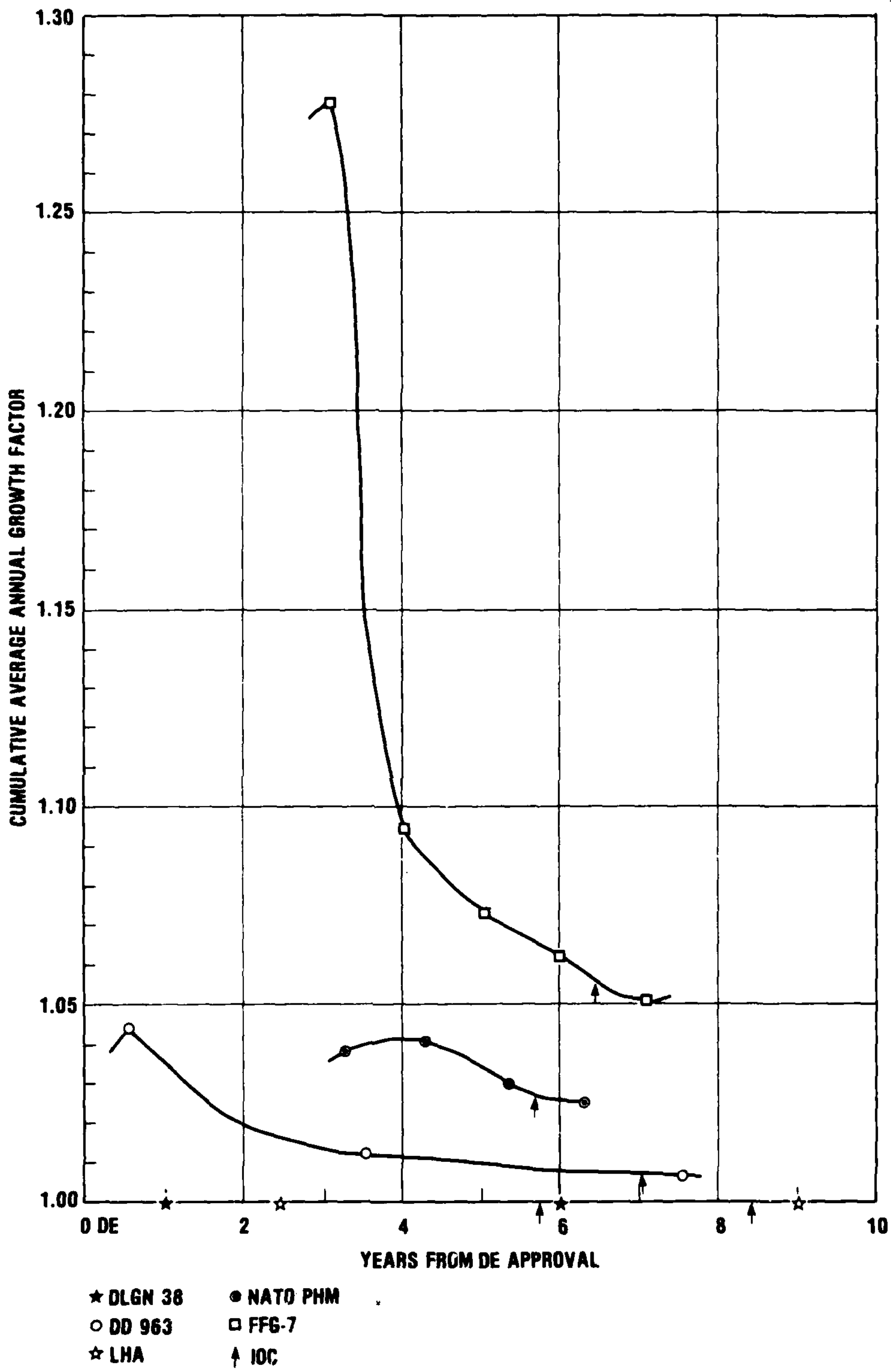


FIGURE 11. Development Cost Growth, Ships

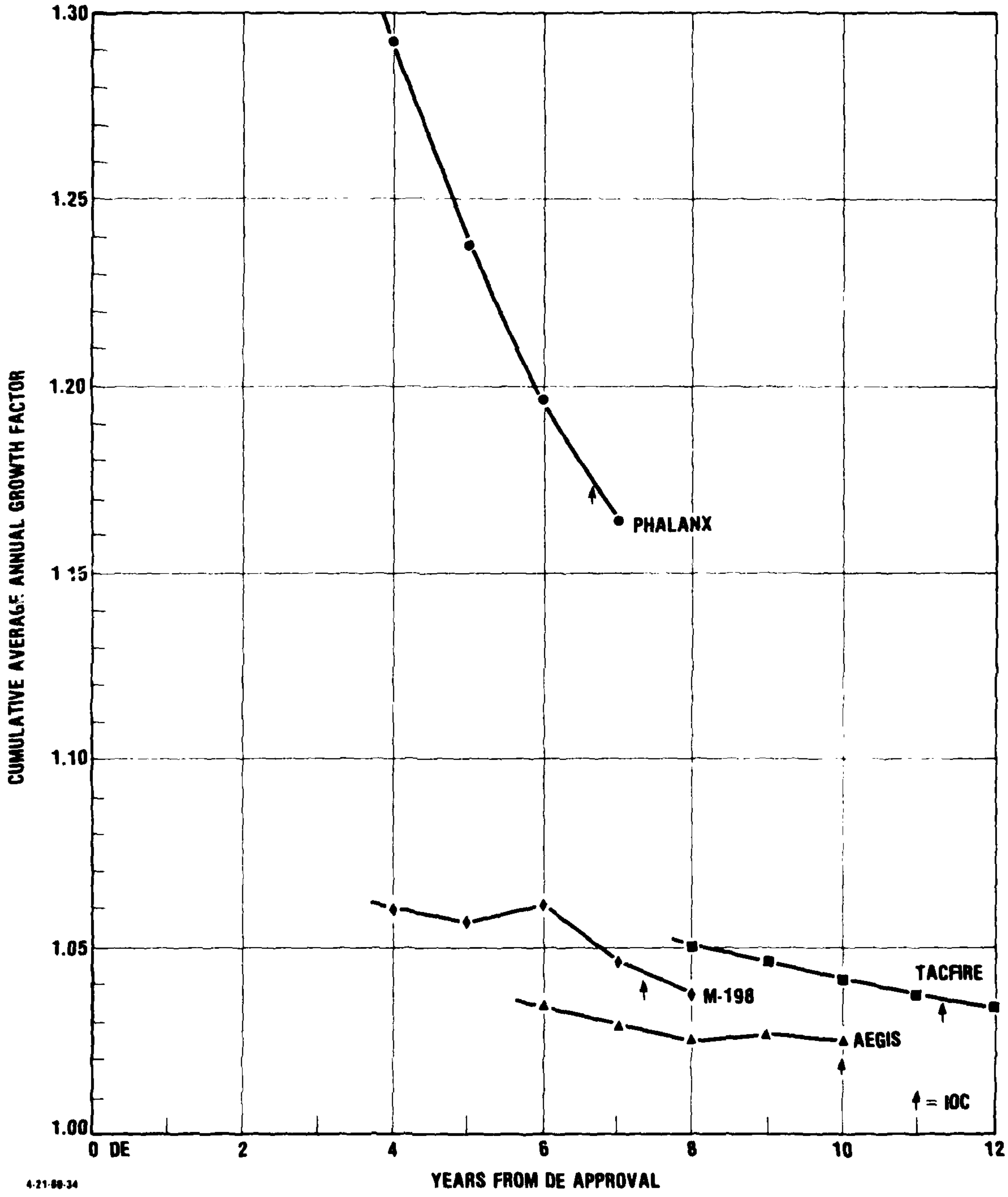


FIGURE 12. Development Cost Growth, Other

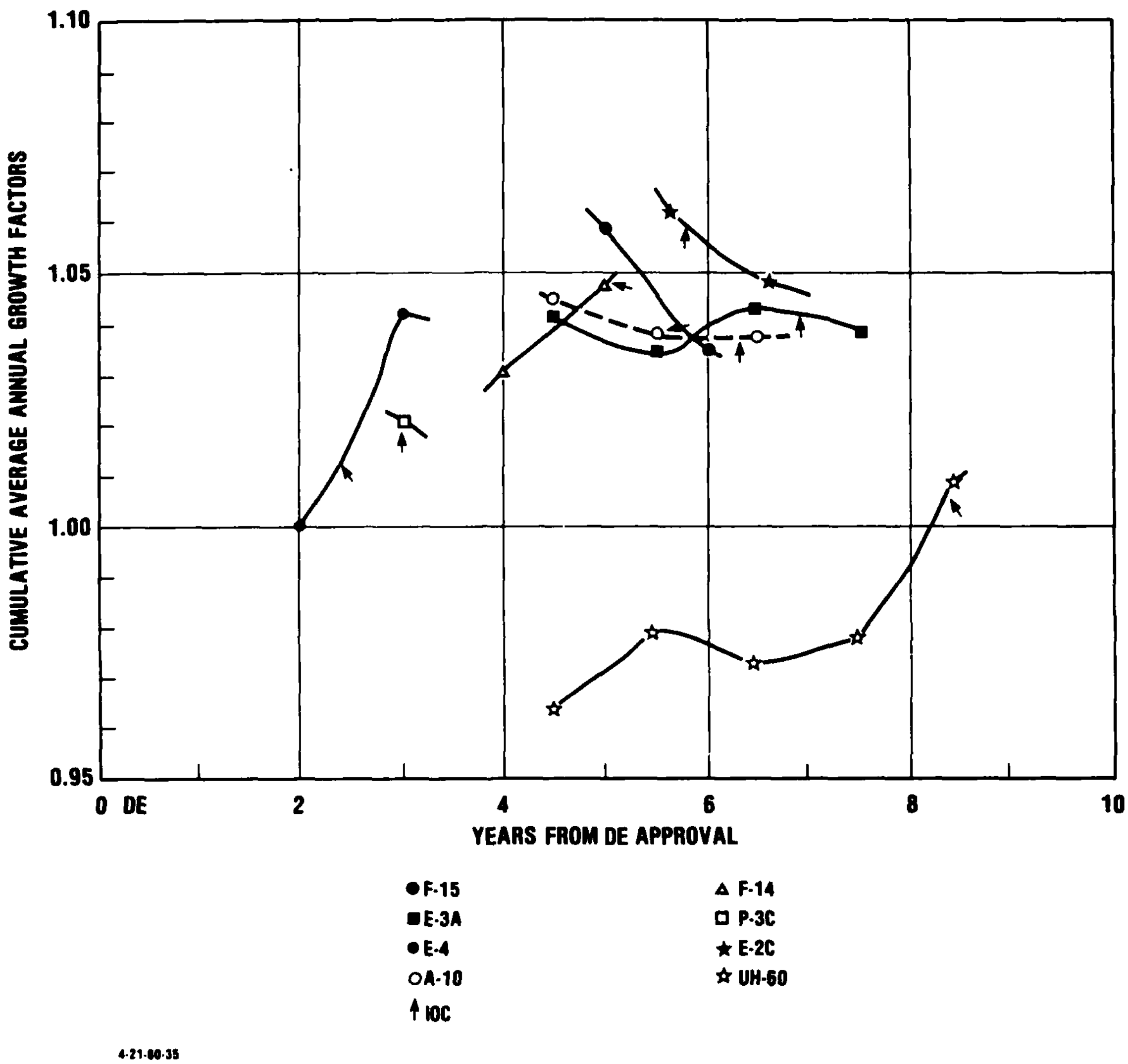


FIGURE 13. Procurement Unit Cost Growth, Aircraft

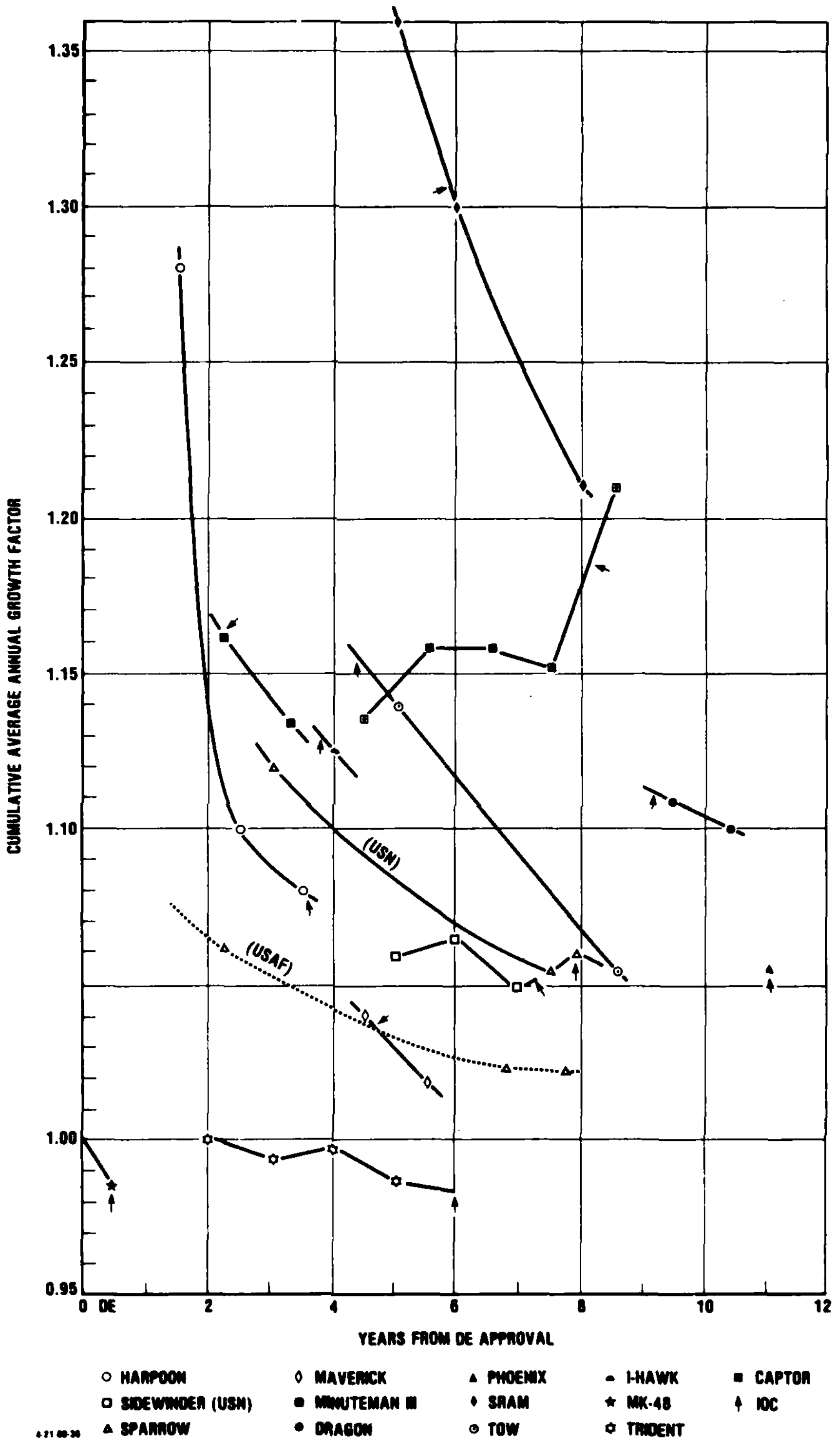


FIGURE 14. Procurement Unit Cost Growth, Missiles

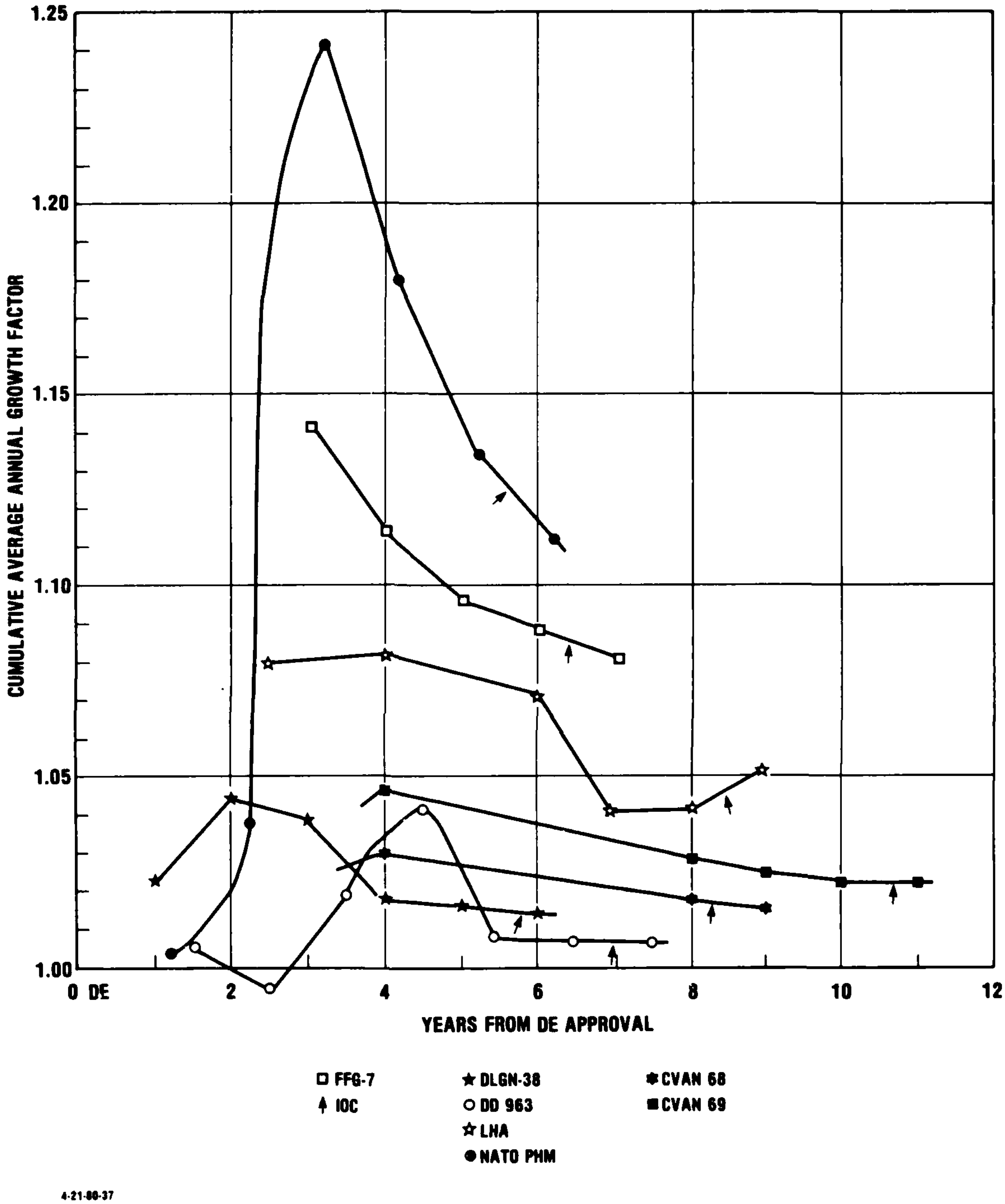


FIGURE 15. Procurement Unit Cost Growth, Ships

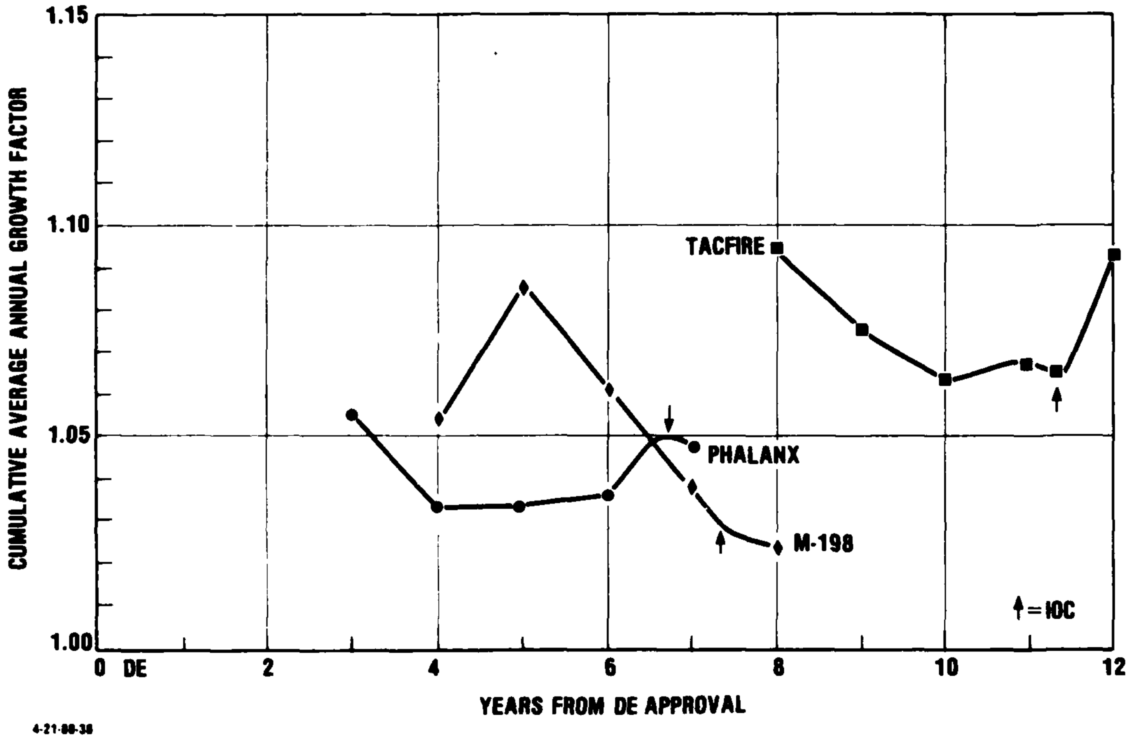


FIGURE 16. Procurement Unit Cost Growth, Other

V. A METHODOLOGY FOR PROJECTING SCHEDULE AND COST GROWTH

A. INTRODUCTION

An analyst's capability to project probable growth in weapon systems baseline estimates is a function of the current stage of system development and information available (e.g., Baseline Cost Estimate, Independent Cost Assessment, Decision Coordinating Paper, Integrated Program Summary, SAR, etc.). As a system matures, information and data become more specific and trends more visible; hence more refined growth projection techniques can be used over time, and hopefully result in more accurate schedule and cost estimates. Use of a specific technique by an analyst must be tempered by a subjective evaluation of all available information. To facilitate understanding the methodology, let us expand upon the information contained in Chapter III of this report, and assume that Fig. 17 represents the typical acquisition cycle time line applicable to any weapon system development program. For convenience, we have partitioned the time line into specific time segments. The breakpoint between segments was nominally established as the date of the Milestone decision meeting. In actuality, the time segment will begin several months prior to one Milestone and end several months prior to the next Milestone. This offset occurs because of the time required to develop, refine, coordinate, staff and obtain Service and OSD approval of the schedule and cost estimates used at the DSARC decision meetings.

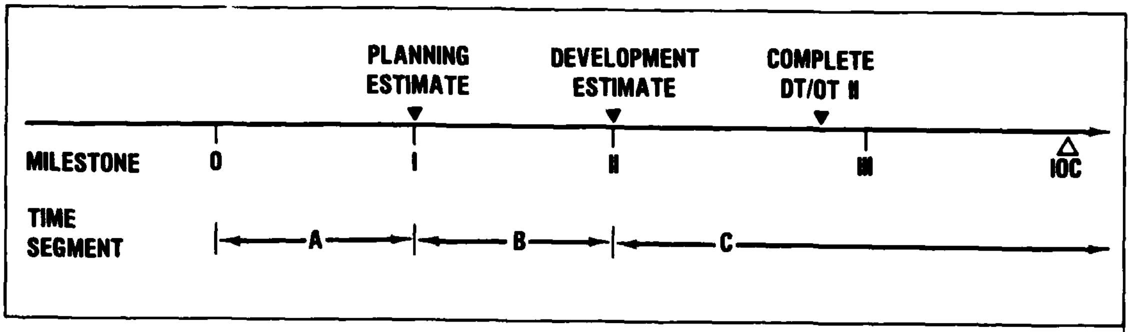


FIGURE 17. Acquisition Cycle Time Line

TIME SEGMENT A

During this period, a Mission Element Need Statement (MENS) will have been approved by OSD. As part of that approval process, the DoD Component(s) identified the general magnitude of acquisition resources they would be willing to invest to correct the deficiency. No engineering cost estimate has been prepared because a candidate system has not been defined. Lacking adequate system definition, the schedule and cost growth methodology proposed in this paper is not applicable to any program whose stage of development would lie within Time Segment A.

TIME SEGMENT B

This period extends from the initial preparation of the Planning Estimate (PE), which is presented to DSARC principals at decision Milestone I, to the point in time when the preparation of the Development Estimate (DE) is initiated. Unfortunately, schedule and cost data on systems which have progressed through Time Segment B and have attained IOC are quite limited. It should be noted that at present, only one pre-Milestone II system is being reported upon via the SAR. Usually, the PE is a rough estimate based, in part, on parametric costing techniques. An earlier OSD study[1] provided *current dollar* cost data on 36 programs which were in production (i.e., had passed Milestone III but not IOC). Although its objective was to document the reasons for cost growth, the OSD study did, in fact, report that the estimated program acquisition costs (development, procurement and MILCON) for the 36 systems grew by a factor of 2.3 during the period between Milestone I and Milestone III. A caveat: no suggestion was made or inferred in the OSD study to the effect that the factor (2.3) could or should be used to project future costs of analogous developmental programs. Using data contained in post-1975 SAR submissions and appropriate OSD inflation indices, we converted the current dollar Planning Estimate costs for 16 of the 36 systems to a constant dollar base. That data, together with data on 6 additional systems, are presented in Table 5 simply to demonstrate that program growth does occur between Milestone I and Milestone II.

For systems in Time Segment B, the IDA projection methodology assumes that only the Planning Estimate schedule and cost data are available (i.e., no subsequent SARs are available). In those circumstances where updated data are available, follow the procedures for Time Segment C. In applying the Segment B methodology, one must first calculate the probable schedule growth:

[1]Memorandum for Distribution, "System Acquisition Cost Growth Study," Office of the Director of Defense Program Analysis and Evaluation, November 12, 1973.

TABLE 5. PROGRAM ACQUISITION COST GROWTH, PE TO DE

System	Base Year	Estimated Program Acquisition Costs (Millions of Base Year Constant Dollars): At Planning Est. Approval Date	Estimated Program Acquisition Costs (Millions of Base Year Constant Dollars): At Development Est. Approval Date	Cumulative Total Growth Factor PE to DE
AIRCRAFT				
A-10[1]	1970	1,768	1,768	1.00
E-2C	1968	411	531	1.29
F-14[1]	1969	5,391	5,391	1.00
F-15	1970	4,675	5,988	1.28
P-3C	1968	814	1,294	1.59
UH-60[1]	1971	1,942	1,942	1.00
MEDIAN				1.14
MEAN				1.19
MISSILES				
DRAGON[2]	1966	383	404	1.05
HARPOON	1970	804	795	0.99
I-HAWK	1969	336	588	1.75
MK-48	1972	609	1,672	2.75
MAVERICK (A/B)	1968	224	332	1.48
MINUTEMAN III[2]	1967	2,695	4,674	1.73
PHOENIX[2]	1963	371	536	1.44
SIDEWINDER[1]	1971	87	87	1.00
SPARROW	1968	140	454	3.24
TOW	1966	410	727	1.77
MEDIAN				1.61
MEAN				1.72
SHIPS				
CVAN 68 / CVAN 69	1967	863	981	1.14
DD 963	1970	1,504	2,395	1.59
DLGN 38	1970	675	722	1.07
LHA	1969	580	1,291	2.23
MEDIAN				1.37
MEAN				1.51
OTHER				
AEGIS	1970	388	394	1.02
COMPOSITE				
MEDIAN				1.29
MEAN				1.48

[1] PE = DE (Per notation in SAR).

[2] SAR indicates no escalation in original estimates, PE and DE.

Step 1. Using the program milestone schedule approved at DSARC I, determine the estimated time (in years) from DSARC I to IOC.

Step 2. Select the appropriate weapon system category median cumulative total schedule growth factor from Table 2 (e.g., aircraft = 1.09).

Step 3. Multiply the time span (in years) by the schedule growth factor, then increase the product by 20 percent.[1]

Step 4. Convert the resultant time span to years and months; add this figure to the date of the planning estimate to obtain the probable date of IOC attainment.

Once the adjusted time span between the PE approval date and the revised IOC date has been determined, a projection of the development cost and procurement unit cost (at IOC) can quickly be calculated using the following formula:

$$C_{IOC_{(x \text{ or } y)}} = (GF)^{s}_{(x \text{ or } y)} \times C_{PE_{(x \text{ or } y)}}$$

where

C_{IOC} = Probable cost at projected IOC date

x = Development cost

y = Procurement unit cost

GF = Median cumulative average growth factor from Tables 3 or 4, as appropriate

s = Time span in years, PE to projected IOC date

C_{PE} = Estimated cost at date of planning estimate approval (Milestone I).

[1] This factor was developed based on a limited sample of seven systems for which we were able to obtain PE, DE, and actual IOC data.

To illustrate how the methodology is applied, assume that a new aircraft program is being evaluated and the following schedule and cost data have been extracted from the DCP and IPS.

Schedule	
Milestone I	- June 1980
Milestone II	- June 1982
Milestone III	- December 1985
IOC	- June 1987
Estimated Costs (FY 81 Constant $ in millions)	
Development	- $2,250
Procurement unit	- $12.5

Projected IOC

1. Time span Milestone I to IOC = June 1987-June 1980 = 7 years.
2. Median cumulative total growth factor, aircraft = 1.09.
3. Adjusted time span = 7 x 1.09 x 1.2 = 9.16 = 9 years, 2 months.
4. Projected IOC = June 1980 plus 9 years and 2 months = August 1989.

Projected Development Cost at IOC

$C_{IOC_x} = (1.043)^{9.2} \times \$2,250 = \$3,314.3$ million.

Projected Procurement Unit Cost at IOC

$C_{IOC_y} = (1.041)^{9.2} \times \$12.5 = \$18.1$ million.

TIME SEGMENT C

This segment begins with the initial Service "approval" of the Development Estimate prior to the DSARC II meeting and extends through the IOC date. The key event during this segment (with respect to our proposed schedule and cost projection methodology) is the successful completion of development testing and operational testing, referred to as DT/OT II, TECHEVAL/OPEVAL, or DTE depending upon the Service involved. It is almost axiomatic that the degree of success achieved in a testing program will determine how much additional schedule and cost growth a program will experience prior to IOC. As might be expected, our historical data indicate that there is a high probability of schedule slippage associated with completion of DT/OT II.

In Time Segment C, when only the Development Estimate schedule and cost data are available (i.e., no subsequent SARs are available), we recommend the following procedure for predicting probable schedule and cost growth. In this circumstance, one would first select the appropriate category median cumulative total schedule growth factor from Table 2 and then multiply the estimated time interval from the DE approval date to the expected IOC date (in years) times the schedule growth factor. Convert the resultant to years and months and add it to the date of DE approval, thus yielding the probable IOC date. In similar fashion, select the appropriate development cost and procurement unit cost median cumulative average growth factors from Tables 3 and 4, then multiply the cost values contained in the DE by the cumulative average growth factors compounded over the time span in years from the DE approval to the adjusted IOC date to obtain the probable cost values at IOC. This procedure should only be used when current data are not available; it should *not* be used once the first updated December SAR is available. In the latter circumstance, the procedures discussed in the following sections should be used.

B. DATA COLLECTION

Assuming that updated SARs are available, the analyst must initially collect all available data and reduce it to a usable form. This type of activity would include the computation of the various growth factors mentioned in this paper (viz., cumulative total and cumulative average development cost and procurement unit cost growth factors). In all probability, the system will not, as yet, have achieved IOC; therefore, the cost growth formulas described in Section F, Chapter IV, should be modified as follows:

$$\text{Cumulative total} = \frac{\text{Estimated (x or y) per latest SAR}}{\text{Estimated (x or y) at DE approval date}}$$

$$\text{Cumulative average} = \sqrt[z]{\text{Cumulative total growth factor}}$$

where x = Development Cost
y = Procurement Unit Cost
z = Time in years from DE Approval Date to Current Estimate Date

C. SCHEDULE GROWTH PROJECTION METHODOLOGY

The proposed methodology for projecting schedule growth in all weapon system acquisition programs (with the sole exception of "mature" missile programs which are addressed later) involves a simple two-step process. The first step requires the analyst to graph the annual schedule growth to date using the technique discussed in Section E, Chapter IV. The second step generates a straight-line projection from the Current Estimate plot to the IOC diagonal on the schedule growth graph. The projected IOC date is computed by using the formula:

$$P_{IOC} = GF_{CAT} \times (CE_{IOC} - ET) + ET$$

where

P_{IOC} = Projected IOC date

GF_{CAT} = Weapon System Category median cumulative total schedule growth factor (Table 2)

CE_{IOC} = Current Estimate (in years) from Development Estimate approval to IOC date

ET = Elapsed Time (in years) from Development Estimate approval to current SAR data.

When analyzing a mature (i.e., more than three years have elapsed since Development Estimate approval) missile program with adequate information and data available, we recommend a five-step process that adjusts for the seemingly concave nature of missile schedule growth curves:

Step 1. Plot the schedule growth to date.

Step 2. Review the shape of analogous schedule growth curves.

Step 3. Establish upper and lower bounds for the projected IOC date.

Step 4. Subjectively evaluate all available information.

Step 5. Extend a curvilinear projection from the Current Estimate plot to a point on the IOC diagonal that lies between the bounds established in Step 3.

In Step 3, the upper bound is established by using the straight-line projection technique discussed in the preceding paragraph (i.e., Step 2 for all categories). The lower bound is established by simply assuming no further schedule growth in the program and accepting the currently estimated IOC date. The following example will demonstrate how this special application of the schedule growth methodology is used. We must point out that the schedule and cost data of most weapon system programs currently in the Full-Scale Development phase of the acquisition cycle are classified. We have, therefore, opted to use a hypothetical system in order to permit more widespread distribution of this paper. The example is augmented by a series of sketches (Fig. 18) to demonstrate the technique.

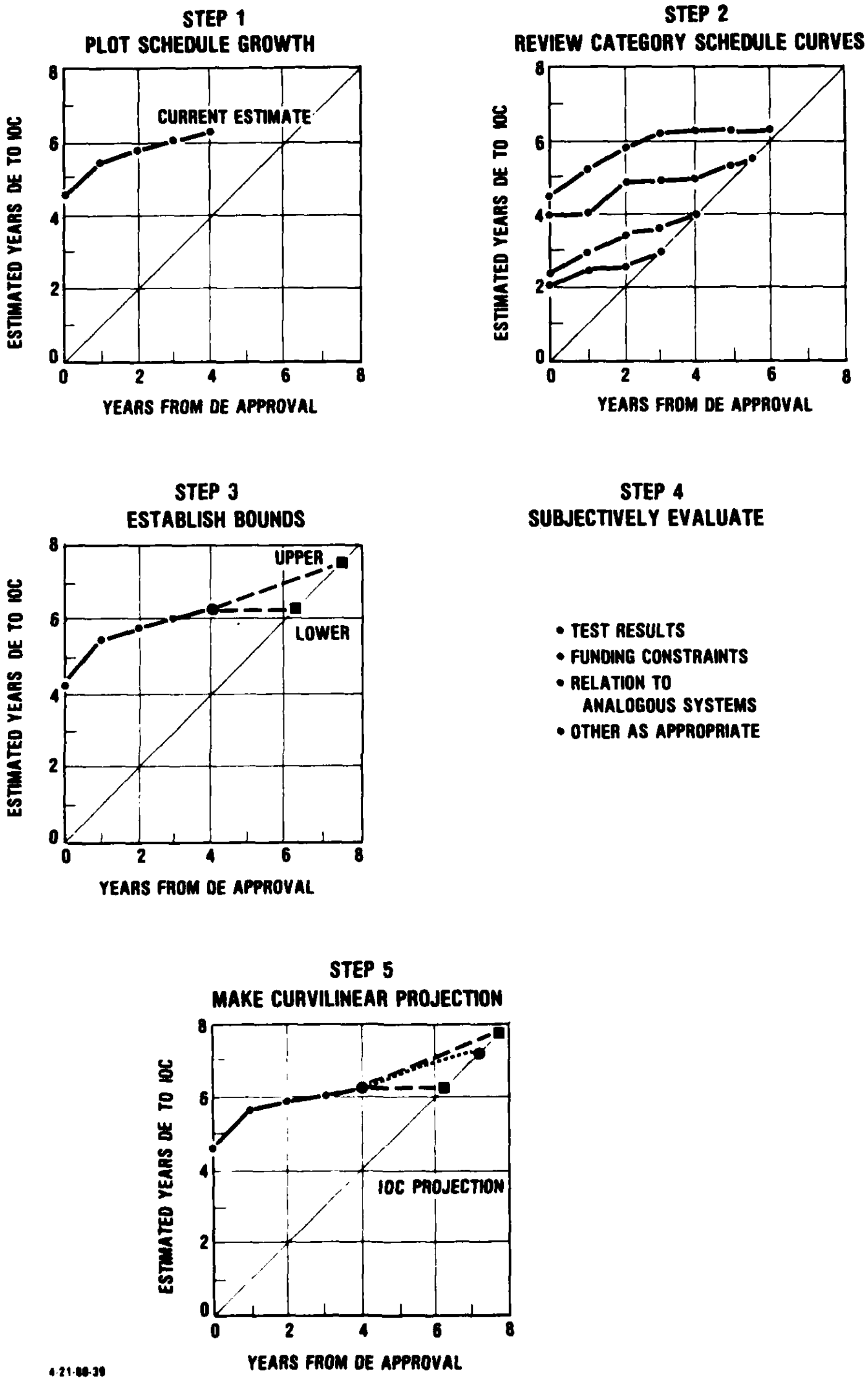


FIGURE 18. Schedule Growth Methodology Example

EXAMPLE: Assume that we are analyzing a missile program which successfully completed a DSARC II four years ago. DT II has commenced, operational testing has not. Let us further assume that the Development Estimate originally postulated an IOC date in 4-1/2 years and that in the four years since the DE was approved, a total of twenty-one months have been added to the expected IOC date (i.e., after one year of program development, IOC was estimated to occur in 5-1/2 years; after two years, 5-3/4 years; after three years, it was 6 years, and now after four years, the current estimate is that IOC will be attained 6-1/4 years from the DE approval date per information extracted from the latest SAR). Our first step will be to plot these data. At Step 2 we note that the schedule growth graph appears to follow the generally concave shape typical of analogous missile programs. At Step 3, we compute the upper bound on projected schedule growth as follows:

```
 2.25 Years (6.25 years, Current Estimate
            DE to IOC, minus 4.00 years,
            elapsed time in program)
x1.63 Growth Factor, Missile Median Cumulative Total
 3.67 Years
+4.00 Years elapsed to date
 7.67 Years = 7 years and 8 months
```

The lower bound is again established by simply assuming no further schedule growth. Our subjective evaluation of the program at Step 4 would heavily weight the facts that the program is mature and operational testing has not been completed. With regard to the latter, during the research phase of this study we examined the impact of early and successful completion of Development Test II/Operational Test II (DT/OT II) on missile system development programs. Table 6 provides an indication of how nine missile systems were affected by the outcome of DT/OT II. We note, however, that sufficient information was not available on aircraft, ship and "other" weapon system categories to allow us to report a specific finding. Finally, our decision at Step 5 would be to extend a concave projection from the current estimate plot to the IOC diagonal. Our estimate would be that the program will achieve IOC 7-1/4 years after DE approval, one year later than the Current Estimate.

TABLE 6. SCHEDULE GROWTH SUBSEQUENT TO DT/OT II (MISSILE SYSTEMS)

System	Date DT/OT II Completed	Estimated IOC Prior To Testing	Actual IOC Date	Schedule Growth (in years)
CAPTOR	Jan 75	Jan 78	Jul 79	1.5
DRAGON	Nov 72	Oct 73	Sep 74	0.9
HARPOON	Mar 77	Jun 76	Jul 77	1.1
I-HAWK	Nov 71	Oct 72	Nov 72	0.1
MAVERICK (A/B)	Nov 71	Feb 73	Feb 73	0.0
PHOENIX	Sep 72[1]	Apr 73	Dec 73	0.7
SIDEWINDER	Jan 76	May 77	May 78	1.0
SPARROW	Sep 74	Sep 74	Apr 76	1.6
TRIDENT I	Jan 77	Sep 79	Oct 79	0.1
MEDIAN				0.9
MEAN				0.8

[1]Start date, completion date not indicated in SAR.

D. COST GROWTH PROJECTION METHODOLOGY

The probable acquisition cost of a weapon system at IOC can also be projected from current SAR data using a relatively simple six-step methodology. The methodology can be applied to project both development phase cost growth (i.e., requirements for RDT&E funding) and investment phase cost growth (i.e., procurement funds). We retain the same four weapon system categories; however, different median cost growth factors must be used (see Tables 3 and 4), depending upon which phase of the acquisition cycle is being evaluated. Collection of current SAR data and computation of cumulative total and cumulative average growth factors for development costs and procurement unit costs in accordance with the procedures described in Chapter IV must be completed prior to applying the methodology. The analyst will then be required to work through the following steps twice; the first time to develop a projection of probable development cost growth and the second time to derive the procurement unit cost projection:

Step 1. Plot the cumulative average cost growth to date.

Step 2. Add a vertical line to the chart that depicts the projected IOC date developed in accordance with the methodology described in Section C.

Step 3. Review the cost curves of analogous weapon systems.

Step 4. Establish upper and lower cumulative average growth factor bounds at the projected IOC date.

Step 5. Subjectively evaluate all pertinent data.

Setp 6. Extend a curvilinear projection from the Current Estimate plot (Step 1) to the projected IOC date line.

Step 4 is the first step which may cause some difficulty for the analyst who is employing the methodology, since a measure of subjectivity is involved. Initially, establish the upper bound by assuming that the current growth rate will also be experienced at the projected IOC date. For the lower bound, take the Current Estimate cost data, assume no further cost growth will occur in the program and use the following formula to calculate the cumulative average growth factor at the projected IOC date:

$$\text{CUM AVG} = \sqrt[t]{\frac{\text{Current Estimate (x or y)}}{\text{Development Estimate (x or y)}}}$$

where x = Development Cost

y = Procurement Unit Cost

t = Time (in years) from DE approval date to the projected IOC date.

This technique should be appropriate for use with a "normal" system (i.e., a system whose curves follow the pattern of most analogous systems and whose cost growth factors tend toward the median of its category). Recognizing that not all systems are "normal," it may also prove helpful to plot the category median and mean cumulative average growth factors on the projected IOC date line. Four reference points on the projected IOC date line will thus be available to the analyst for detailed evaluation and subsequent selection of upper and lower bounds deemed most appropriate to the system being analyzed. Step 5 is where the analyst earns his money--a subjective evaluation of all available data must be made. Depending upon how one evaluates the program, make a curvilinear projection (Step 6) from the Current Estimate plot to the projected IOC date. The final step will be to read the "final" cum avg factor at the projected IOC date and compute the cost at IOC using the formula:

$$C_{IOC} = \begin{pmatrix} \text{final} \\ \text{cum avg} \\ \text{cost factor} \end{pmatrix}^{t} \times \begin{pmatrix} \text{Initial} \\ \text{DE Cost} \end{pmatrix}$$

where t = Time (in years) from DE approval date to the projected IOC date.

Let us now return to our missile system example to see how the methodology works. For simplicity, we will limit our description to the procedures that would be used to project the Procurement Unit Cost at the projected IOC date. Figure 19 contains a series of sketches which summarize the steps we would take.

> <u>EXAMPLE</u> (continued): Assume that the Procurement Unit Cost has been increasing over time with costs estimated as follows: \$.15M in FY-77 constant dollars at the time of DE approval, \$.165M after one year, \$.176M after two, \$.185M after three and \$.19M after four years (the current estimate). The cumulative

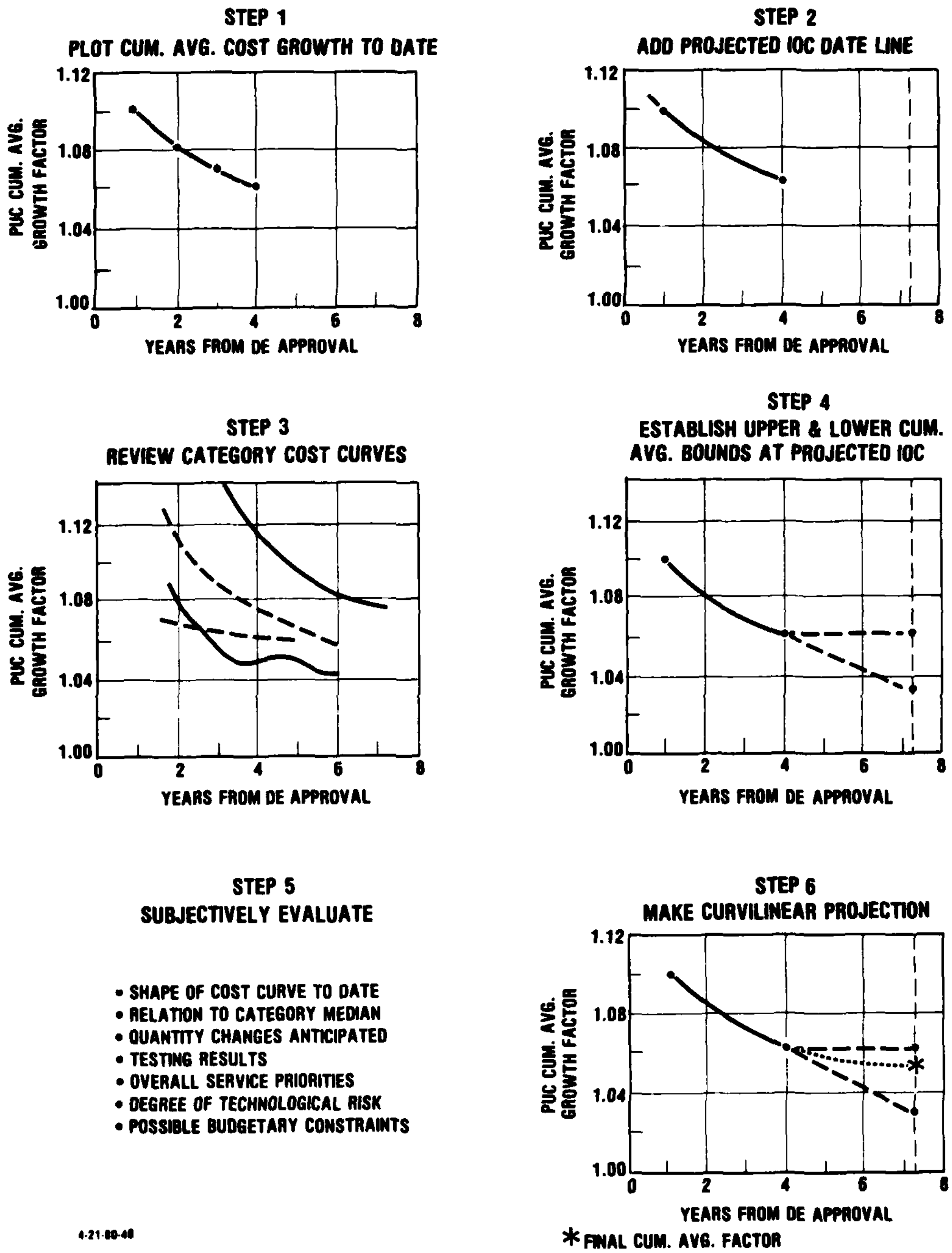


FIGURE 19. Cost Projection Methodology Example--Procurement Unit Cost

average growth rates are then computed from the above data and plotted on the cumulative average Procurement Unit Cost (PUC) growth chart (Step 1).

We add the projected IOC date line derived earlier to the chart at Step 2. The PUC growth curves of other missile programs (Fig. 14) are then reviewed (Step 3). Since the PUC growth curve of our example appears to be "normal," we follow the standard procedures for establishing upper and lower bounds at Step 4. The lower bound is computed by solving:

$$LB = \sqrt[7.25]{\frac{.19}{.15}} = 1.033$$

At Step 5 we subjectively evaluate all available data. Based on that evaluation we make a curvilinear projection from the current estimate plot to the IOC date line and read the "final" cumulative average PUC growth factor (1.058) at the most probable IOC date.

After completing the necessary computations, our methodology would project a PUC of $.23M at IOC, seven and one-quarter years from the date of DE approval compared to the currently estimated PUC of $.19M with IOC six and one-quarter years from DE. The IDA cost projection represents a compound annual growth rate of 5.8 percent. The reader will note that in this example cost growth is less than the median and the mean for the fifteen missile systems that formed the base for our study (Table 4).

E. SUMMARY

Cost growth in major (and non-major) weapon system acquisition programs continues to be of vital concern to the Congress and key decisionmakers within the Department of Defense. The capability of projecting probable future growth in a specific program is a necessary tool for effective acquisition management. This paper describes the development of a relatively simple methodology for projecting schedule and cost growth in a weapon system program and its application to a hypothetical weapon system. The schedule and cost growth projection methodology outlined in this paper is recommended for use in IDA evaluations of weapon system development programs. It could also be of value to other agencies/elements of the DoD cost analysis community and is, therefore, similarly recommended.

CITED REFERENCES

1. *A Range of Cost Measuring Risk and Uncertainty in Major Programs--An Aid to Decisionmaking.* Report to the Congress by the Comptroller General of the United States, February 2, 1978.

2. Analytic Services, Inc., *A Survey of Techniques for Improving Cost Estimates of Future Weapon Systems,* ANSER Memorandum AM-65-2, R. D. Carter, March 1965.

3. The Rand Corporation, *Choice Among Strategies for System Acquisition,* Rand Corporation, P-4794, A. J. Harman, March 1972.

4. The Rand Corporation, *Cost Estimates as Predictors of Actual Weapons Costs: A Study of Major Hardware Articles,* Rand Memorandum RM-3061-PR (Abridged), Robert Summers, March 1965.

5. Nelson, B.B., *Improving Cost Estimating and Analysis In DOD and NASA,* The George Washington University, D.P.A., 1972.

6. Howard, Truman W. III, *Methodology for Developing Total Risk Assessing Cost Estimates (TRACE),* U. S. Army Missile Research and Development Command, Redstone Arsenal, Alabama, 1978.

7. *Financial Status of Major Federal Acquisitions,* Report to the Congress by The Comptroller General of the United States, September 30, 1978.

8. *Inaccuracy of Department of Defense Weapons Acquisition Cost Estimates,* Ninth Report by the Committee on Government Operations, November 16, 1979.

9. Parkinson, C. Northcote, *Parkinson's Law and Other Studies in Administration,* Houghton Mifflin Company, Boston, 1957.

10. Allen, Wayne M., *Should Cost/Will Cost/Must Cost--A Theory on the Cause of Cost Growth.* U. S. Army Safeguard System Office, Arlington, Virginia, June 1972.

11. The Rand Corporation, *Bias in Initial Cost Estimates: How Low Estimates Can Increase the Cost of Acquiring Weapon Systems*. Rand Report R-1467-PA&E, Joseph P. Large, July 1974.

UNCITED REFERENCES

A Cost Performance Forecasting Concept and Model, Cost Research Report No. 117, Cost Analysis Division, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, November 1974.

A Production Study Sequel to the Cost Performance Forecasting Concept and Model, Cost Research Report No. 132, Directorate of Cost Analysis, Aeronautical Systems Division, Wright-Patterson AFB, Ohio, August 1976.

Automated Financial Analysis Program, A User's Guide, Cost Analysis Division, Electronic Systems Division, Hanscom AFB, Bedford, MA, November 1976.

Babiarz, A.S. and P.W. Giedras, *A Model to Predict Final Cost Growth in a Weapon System Development Program,* Air Force Institute of Technology, August 1975.

Buckelew, W.F., *Economic Escalation and the Military Program Manager,* Defense Systems Management School, Ft. Belvoir, VA, November 1975.

Computer Program Input Instructions for Cost Performance Forecasting Model, Cost Research Report No. 117-A, Cost Analysis Division, Aeronautical Systems Division, Wright Patterson AFB, Ohio, February 1975.

Cost Growth in Major Weapon Systems, Comptroller General of the United States, March 26, 1973.

Cost Performance Forecasting Study, Cost Analysis Division, Space and Missile Systems Organization, Los Angeles, CA, June 1977.

Cummins, J.M., *Cost Overruns in Defense Procurement: A Problem of Entreprenurial Choice Under Uncertainty,* Dissertation, Northwestern University, 1973.

Dienemann, Paul F., Memorandum, *Study of Weapon System Cost Growth,* OSD, Office of the Director, Planning and Evaluation, Washington, D. C., August 9, 1976.

Glover, W.L. and J.C. Lenz, *A Cost Growth Model for Weapon System Development Programs*, Air Force Institute of Technology, 14 August 1974.

Henry, D.D., *Statistical Analysis of the Effectiveness of Program Initial Conditions as Predictors of Weapon System Acquisition Program Success*, Naval Postgraduate School, Monterey, California, December 1976.

Launer, R.L., H.F. Candy, and S.H. Carter, *Cost Growth Effects of Contract Size, Duration, Inflation, and Technology*, Procurement Research Office, USALMC, Ft. Lee, VA, May 1972.

Lewis, Edwin M. and Eugene D. Pearson, *The Air Force Cost Estimating Process: The Agencies Involved and Estimating Techniques Used*, Air Force Institute of Technology, June 1977.

Management Consulting and Research, Inc., *Cost Growth in Navy Selected Acquisition Reports (SARS)*, TR-7817-1, Clifton N. Horton, et al., 25 July 1979.

Martin, M.D., *A Conceptual Cost Model for Uncertainty Parameters Affecting Negotiated, Sole-Source Development Contracts*, Dissertation, The University of Oklahoma Graduate College, 1971.

The Rand Corporation, *System Acquisition Strategies*, Rand Corp., R-733-PR/ARPA, R. Perry et al., June 1971.

The Rand Corporation, *An Overview of Acquisition Policy Effectiveness in the 1970s*, Rand/WN-10435-DR&E, G.K. Smith, February 1979.

Schow II, H., *Macrobehavior of Development Costs and Estimates (STEC Plots)*, Systems and Cost Analysis Division, U. S. Army Materiel Command, Washington, D. C. Technical Report 68-2, September 1968.

The Army Cost Estimating and Monitorship Subcommittee, *Report to The Army Acquisition Management Task Force*, Department of the Army, Office of the Assistant Secretary, 28 November 1979.

Trainor, Richard James, *Study of Factors Leading to Changes in Cost Estimates on Selected Major Department of Defense and National Aeronautics and Space Administration Development Systems*, Ph.D. Dissertation, The George Washington University, 1977.

Webb, Donald E., *The Study of Cost Growth of a Major Weapon System,* Naval Postgraduate School, Monterey, California, December 1974.

Weida, Major William J., *A General Technique for R&D Cost Forecasting,* USAF Academy, Colorado, September 1977.

Weida, Lt. Col. William J., *Forecasting Expenditures for Weapons,* U.S. Air Force Academy, Colorado, July 1979.

Weida, Lt. Col. William J., 2Lt. Steven D. Clark, and 2Lt. James E. Rowland, *Determining Government Disbursements from Normalized Spending Patterns,* USAFA-TR-79-4, U.S. Air Force Academy, Colorado, May 1979.

REFERENCES FROM ALVIN J. HARMAN PAPER

[1] Klein, B.H., "The Decision-Making Problem in Development," in R.R. Nelson (ed.), *The Rate and Direction of Inventive Activity*, Princeton University Press, Princeton, 1962.

[2] Peck, M.J. and F.M. Scherer, *The Weapons Acquisition Process: An Economic Analysis*, Graduate School of Business Administration, Harvard University, 1962.

[3] Marschak, T.A., T.K. Glennan, Jr., and R. Summers, *Strategy for R&D: Studies in the Microeconomics of Development*, Springer-Verlag, New York, 1967.

[4] Perry, R., G.K. Smith, A.J. Harman, and S. Henrichsen, *System Acquisition Strategies*, R-733-PR/ARPA, The Rand Corporation, June 1971.

[5] Harman, A.J. (assisted by S. Henrichsen), *A Methodology for Cost Factor Comparison and Prediction*, RM-6269-ARPA, The Rand Corporation, August 1970.

REFERENCES FROM TRUMAN W. HOWARD PAPER

[3] Comptroller General of the United States. *Cost Growth in Major Weapon Systems*. Report to the Committee on Armed Services, House of Representatives. Washington, D.C.: Government Printing Office, 1973.

[10] Peck, M.J. and Scherer, F.M. *The Weapons Acquisition Process: An Economic Analysis*. Boston: Harvard University, 1962.

[12] Trainor, R.J. *Study of Factors Leading to Changes in Cost Estimates on Selected Major DOD and NASA Development Systems*. Doctoral Dissertation, George Washington University, Washington, D.C., May 1977.

DATE
ILMED
- 8