PRE-PLANNED PRODUCT IMPROVEMENT: BETTER WAY OF WEAPON SYSTEM ACQUISITION?

Philip T. Mackey, Captain, USAF

LSSR 64-[illegible]

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

85

PRE-PLANNED PRODUCT IMPROVEMENT
A BETTER WAY O WEAPON SYSTEM ACQUISITION?

Philip T. Mackey, Captain, USAF

LSSR 64-83

The contents of the document are technically accurate, and no sensitive items, detrimental ideas, or deleterious information are contained therein. Furthermore, the views expressed in the document are those of the author(s) and do not necessarily reflect the views of the School of Systems and Logistics, the Air University, the United States Air Force, or the Department of Defense.

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER LSSR 64-83	2. GOVT ACCESSION NO. AD-A153 802	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) PRE-PLANNED PRODUCT IMPROVEMENT: A BETTER WAY OF WEAPON SYSTEM ACQUISITION?		5. TYPE OF REPORT & PERIOD COVERED Master's Thesis
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Philip T. Mackey, Captain, USAF		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS School of Systems and Logistics Air Force Institute of Technology, WPAFB OH		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS Department of Communication AFIT/LSH, WPAFB OH 45433		12. REPORT DATE February 1984
		13. NUMBER OF PAGES 81
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

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

18. SUPPLEMENTARY NOTES

Approved for public release: IAW AFR 190-17.
LYNN E. WOLAVER
Dean for Research and Professional Development
Air Force Institute of Technology (ATC)
Wright-Patterson AFB OH 45433
17 March 84

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

Product Improvement
Aquisition
Modification
Cost
Procurement

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

Thesis Chairman: Ronald G. Blackledge, Lt Col, USAF

DD FORM 1473

The object of this thesis was to evaluate the acquisition approach called pre-planned product improvement or P3I and the benefits it offers. First a comparison of P3I and a similiar concept called Evolutionary Acquisition or EA, was made to improve understamding of P3I and how it relates to EA. It was concluded that EA, as defined, is a Command and Control (C2) specific P3I application. Then, to see if the theorized benefits of P3I actually come about, the cost and schedule performance of a P3I program was compared to that of non-P3I programs. Acquisition lengths were also compared. This comparison found that P3I may indeed lessen acquisition times and enhance cost and schedule performance.

LSSR 64-83

PRE-PLANNED PRODUCT IMPROVEMENT
A BETTER WAY OF WEAPON SYSTEM ACQUISITION ?

A Thesis

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology
Air University

In Partial Fulfillment of the Requirement for the
Degree of Master of Science in Logistics Management

By

Philip T. Mackey, MS
Captain, USAF

February 1984

This thesis, written by

Captain Philip T. Mackey

has been accepted by the undersigned on behalf of the faculty of the School of Systems and Logistics in partial fullfillment of the requirements for the degree of

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

DATE: 16 February 1984

Ronald G. Blackledge
COMMITTEE CHAIRMAN

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

INTRODUCTION

For the past decade, the United States has relied on the qualitative superiority of its weapons to offset the quantitative advantage of its principle opponent, the Soviet Union.

> This preference for high value, multipurpose weapons and the desire to substitute technology for manpower can be called an American 'doctrine of quality'.[13:550]

In recent years, the Soviets have eroded the U.S.'s once sizable qualitative edge. Their present generation of military aircraft, the MIG-23/27 Flogger, the SU-19 Fencer, and the TU-22M Backfire, all possess far greater performance than their predecessors (23). The Soviets are presently diligently working on another generation of advanced aircraft. The MIG-29 Fulcrum, the SU-27 Flanker, and the TU-122 Blackjack are said to be equivalent to or better than the U.S.'s F-15, F-16, and B-1 aircraft (23:73,83,84;24). In his recent testimony to Congress, the Under Secretary of Defense for Research and Engineering (USDRE), Dr. Richard D. DeLauer, stated that "our combat forces face superior quantities of increasingly capable Soviet equipment in almost every mission area (9:I-4)."

This impressive growth in the Soviet combat potential is due, in part, to their massive commitment to military research and development (R&D). As shown in Figure One, the USSR has outspent the US by a wide margin in research, development, test, and evaluation (RDT&E) in the last decade (9:I-10). This sustained RDT&E effort has enabled the Soviets to "close the technology gap (9:I-9)." They have gained ground in six vital basic technology areas (Figure Two). This trend is also evident in deployed weapons systems, where the Soviets have eroded US superiority in seven areas (Figure Three).

Because of the inherent stability in Soviet weapon system development and procurement (1:8,22:3), it is obvious that they will continue to improve their weapon's technology. The threat to the US and its allies, whose technological lead has been a vital factor in the military balance is clear (9:I-6).

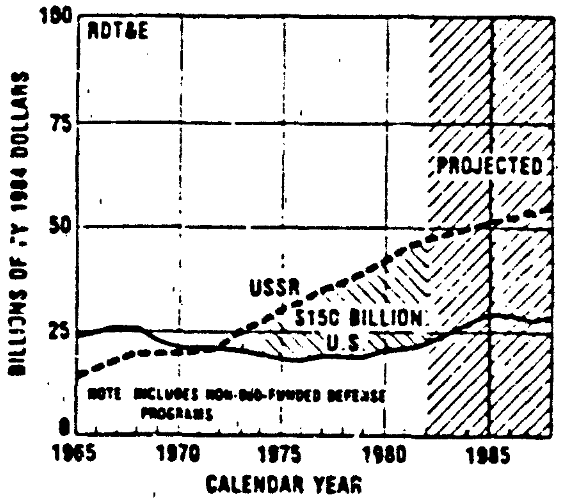

Figure 1

US/USSR Military RDT&E Expenditures
(DeLauer,1983:Fig.I-6)

BASIC TECHNOLOGIES	U.S SUPERIOR	U.S /USSR EQUAL	USSR SUPERIOR
1 Aerodynamics/Fluid Dynamics		X	
2 Automated Control	X		
3. Conventional Warhead (including Chemical Explosives)			X
4 Computer	X		
5 Directed Energy		X	
6 Electro-Optical Sensor (including IR)	X →		
7 Guidance & Navigation	X →		
8 Microelectronic Materials & Integrated Circuit Manufacture	X		
9 Nuclear Warhead		X	
10 Optics	X →		
11. Power Sources (Mobile)		X	
12 Production/Manufacturing	X		
13 Propulsion (Aerospace)	X		
14 Radar Sensor	X →		
15 Signal Processing	X		
16 Software	X		
17. Stealth (Signature Reduction Technology)	X		
18 Structural Materials (lightweight, high strength)	X →		
19 Submarine Detection (including Silencing)	X →		
20 Telecommunications	X		

Figure 2

Relative US/USSR Standing in the 20 Most Important Basic Technology Areas (DeLauer,1983:Fig.II-4)

DEPLOYED SYSTEM	U.S SUPERIOR	U.S./USSR EQUAL	USSR SUPERIOR
STRATEGIC			
ICBM		X →	
SSBN		← X	
SLBM	X →		
Bomber	X		
SAMs			X
Ballistic Missile Defense			X
Anti-Satellite			X
Cruise Missile	X		
TACTICAL			
Land Forces			
SAMS (Including Naval)		X	
Tanks		X	
Artillery		X	
Infantry Combat Vehicles		X	
Anti-Tank Guided Missiles		X	
Attack Helicopters		X	
Chemical Warfare			X
Theater Ballistic Missiles			X
Air Forces			
Fighter-Attack Aircraft	X →		
Air-to-Air Missiles	X		
PGM	X →		
Air Lift	X		
Naval Forces			
SSNs		X	
Anti-Submarine Warfare	X →		
Sea-Based Air	X		
Surface Combatants	X →		
Cruise Missile		X	
Mine Warfare		X	
Amphibious Warfare	X		
C^3I			
Communications	X →		
Command & Control		X	
Electronic Countermeasures/ECCM		X	
Surveillance and Reconnaissance	X →		
Early Warning	X		

Figure 3

Relative US/USSR Technology Level
in Deployed Military Systems
(DeLauer,1983:Fig.II-4)

CHAPTER II

PROBLEM STATEMENT

Background

The critical question, how to maintain the military balance between the United States and the Soviet Union, has generated much furor and controversy. Some feel that our reliance on high technology, the American 'doctrine of quality', is, in itself, faulty. They believe that simpler, less costly weapons are what is needed.

> The current weapons, they argue, are too expensive, have a poor operationally ready (OR) rate due to their complexity and would, after all, be defeated by a greater number of cheaper, simpler weapons. [17:53]

The reformers feel that simpler weapons will have inherently better OR rates and, because of lower acquisition costs, more of them can be bought; leading to a more useful and less vulnerable force (17:53). Unfortunately there are several weaknesses in this reasoning.

Soviet Experience

One is the automatic assumption that simple weapons have inherently better OR rates than high technology ones. The Soviet experience in this area is enlightening. "The general trend in Soviet weapons is for relatively simple designs (2:14)." Simple designs are easier and cheaper to mass produce. They are also easier to operate and maintain, thus requiring less training of personnel (22:14). However, the simple Soviet equipment is not necessarily reliable. The Soviet's main tank engine, for example, requires an overhaul every 250 hours (versus 500 hours for any maintenance on the US M-60 tank engine). The US Army's OpFors (Opposing Forces) units, which operates and maintains captured Soviet equipment, feel that it is "simple, even crude, in design but very unreliable (8:141)." Soviet aircraft have had similar problems. The MIG-21's engine is overhauled every 300 hours (versus 800 hours for typical US fighter engines)(8:177). Some MIG-21 components, such as the aircraft's brakes, are replaced after only two or three flights (8:169). Fortunately, due to its simple design, the MIG-21 is relatively easy to repair. The low reliability of individual Soviet weapons may be one reason they produce and field so many of them (8:188). The Soviet's emphasis on mass, along with their rigorous, effective preventative maintenance practices, may insure that the unreliability of the individual weapon does not detract from their overall force reliability.

F-15 Experience

Another assumption is that high technology weapons have low OR rates. However these low OR rates may not be inherent in the weapon itself (17:55). It may be caused by improper or inadequate logistical support. The F-15 aircraft provides a good illustration of this. Numerous problems suffered by the F-15 could be traced to a lack of needed spare parts, both for the aircraft and for its essential support equipment, such as the Avionics Intermediate Shop (AIS) test set. This deficiency resulted, in part, from a decision to cut back on the spare parts buy in order to preserve the number of F-15s procured (14:30). When sufficent spares are available, the F-15 has had an impressive sortie rate (14:26). One must evaluate the entire problem before concluding that high technology is the cause of a low OR rate (17:55).

Use of High Technology

In fact, high technology, if properly used, can lead to more reliable, less expensive systems (17:54). Commercial products such as televisions, calculators, and computers are good examples of this. Solid state electronics have lead to more durable, reliable systems with easier diagnosis and repair when failures do arise (17:54). Unfortunately, in the military, advanced technology has been commonly used to increase performance at the expense of reliability (7:16). "Military preferences for high performance....[have] dominated the US [acquisition] process (13:548)." This preference has resulted in many weapons systems with outrageous cost growth (the C-5A, the F-111, and the B-1A for example). When fielded these systems often can not achieve their high performance potential because of maintainability and reliability problems. Yet high technology, if properly applied, can improve reliability, lessen maintenance, and lower costs. Some reformers, in their quest for simple weapons, may have overlooked this fact.

US Comparative Advantage

The main weakness in the case for simple weapons is that it is in high technology that the US still enjoys a comparative advantage (17:55). Although the USSR has closed the gap in recent years, they are still behind in many technological areas. Their ongoing efforts to steal US technology is ample proof of this. However the USSR has a substantial advantage over the US in manpower. They insure full use of this advantage through their policy of universal military conscription. As General George S. Patton once said:

> [The Russians]...have a very large manpower which they are willing to expend recklessly. It therefore behooves us to devise military formations which will exploit our natural aptitude for machines and at the same time save our somewhat limited and very valuable manpower. [17:56]

As former Secretary of Defense Harold Brown states:

> The United States has no real choice but to adopt high technology for its weapon systems, given the relative advantage it can provide over potential adversaries... [7:16]

To fail to make use of this advantage may be throwing away a major equalizing factor (7:20).

Resource Requirements

More capable, higher technology weapons can not only offset numerical superiority, but also allow one to accomplish the same mission with fewer resources (17:56). Greater numbers of simpler weapons would require more resources. A much larger standing army would be needed (17:56). The increased personnel costs alone would significantly reduce the savings from lower acquisition costs (17:56). The higher logistical costs of maintaining such a force are also not addressed by the reformers. Simple weapons may not require the expensive support equipment and highly trained technicians that high technology weapons sometimes do, but they still need fuel, spare parts, maintainers, and facilities. If more simple weapons are bought, more support is required.

It is questionable if the American public will accept such a sizable increase in our Armed Forces. The present US force levels are, historically, the highest ever maintained in peacetime. It is doubtful if an increased volunteer force, with its associated increased expense, is politically or even economically viable. Reinstitution of the draft may be required--a very controversial option with many difficulties (17:56).

The United States may not be able to abandon, in total, its "doctrine of quality" (7). To do so would be to abandon our strength and rely on our weaknesses. The USSR, because of its political and economic system, will always be able to maintain a large military force. The US may not. A larger standing army, with its associated costs, may not have the support of the American public or its political leaders (7:16). The present level of defense spending is already being sharply criticized; thus it is hard to envision the increased spending needed for a simpler defense force being accepted. If correctly handled, advanced technology can lead to a more effective military capability (7:16). It is in technology that the US still maintains a edge over the Soviet Union.

> The United States must not fail to take advantage of the advantages it has--economic, political, ideological, or any other. And among all these, the US technological advantage is one of the most important and valuable. [7:26]

Problem Development

Unfortunately, the maintenance of the US's vital qualitative edge has had numerous problems. As noted, one problem may lie in a potential for mis-focusing on weapon system characteristics, such as speed, payload, and range, to the detriment of other equally important factors, like the weapon's reliability, maintainability, availability, and operability. The military often demands advanced capability beyond present requirements simply because it appears feasible (11:106). The tendency is to obtain the best possible theoretical weapons system characteristics and to use high technology predominately for that purpose (7:23).

Factors in the Military Balance

This approach overlooks that quality is only one factor in the military balance. The German Army, in both World Wars, maintained a qualitative advantage in basic miitary hardware--tanks, artillery, aircraft (7:17). Yet they were ultimately defeated by foes with less sophisticated, but more numerous, weapons. Superior weapons alone are not enough to insure military success. Subjective factors, such as morale, training, strategy, tactics, and leadership, are often equally decisive (7:18). There are many examples of military victory by inferior forces with proper doctrine, morale, and superior generalship (7:17-18). Better weapons can greatly affect the military balance but only in concert with other equally important, but less measurable factors.

Weapons Technology vs. Military Technology

Another cause for this possible mis-focus on weapon system characteristics may be a misperception of just what military technology is (13:545). Military technology is often equated with weapons system characteristics. However, weapons system characteristics are more a measure of weapons technology; military technology encompasses more than just weapons.

> Military technology is the set of skills and techniques that contribute to the production, operation, and maintenance of weapons and other military equipment. Technological progress...is simply the ability to accomplish objectives that were not possible to achieve [before] or to reach presently achievable objectives more cheaply or efficiently. [13:545]

Military technology is thus not a matter of just weapon system characteristics or capability, it is a matter of total force capability.

Adverse Consequences

There have been several unfortunate outcomes of these misperceptions. The first and foremost is the increased cost of acquiring, operating, and maintaining our weapon systems. To obtain the best possible weapon system characteristics, pursuit of leading edge technology is required. This increases risks and ultimately leads to higher prices and cost overruns (11:106). The pursuit of maximum performance is also costly in terms of system reliability and maintainability (7:23). The weapon system may indeed have outstanding theoretical performance characteristics; but, when fielded, its performance is often much less. Operators may not have the training or experience to fully utilize the weapon's performance capabilities. Doctrine may preclude its use altogether. For example, restrictive rules of engagement prevented optimal use of air-to-air missiles in Vietnam. Maintenance is not only expensive in material and manpower, but may even be beyond the capability of the system's user to perform. The C-5A is a good illustration of this. Obtaining the best possible performance characteristics is a difficult, strenuous task. Many times deployment of a critically needed weapon is delayed as the "bugs" are worked out of its leading edge technology. Technology which gives the system performance that may not be really necessary. "Better is the enemy of good enough (11:106)."

Requirements Process

The root problem may lie in the US military requirements process. As noted by Colonel Richard G. Head, there is a large asymmetry in the US and USSR requirements process. The Soviets reject the thesis that weapons dictate strategy; they use military doctrine to produce military requirements, to 'pull' technology (13:548). In contrast, "doctrine is only one of many determinates of US weapon design (13:548). The US 'doctrine of quality' and the misperception of military technology have often led to the basing of US military requirements on the adversaries' weapon characteristics--the "threat". New weapons are required when the enemy increases the performance characteristics of the weapons he possesses. However, weapons, by themselves, are only part of the real threat. It is how these weapons are to be used, in what environments, by what troops, for what objectives--these and other dynamic factors determine the true capability of a weapon and the threat it may pose. To react to changes in an enemies' weapon characteristics is simple, but it can be expensive if based on imperfect information. The dynamic factors are more subjective and less subject to simple quid-pro-quo increases in weapon system characterictics.

Role of Doctrine

Doctrine can play a vital role in the complex task of defining weapon system requirements. It can lessen the uncertainty of the dynamic factors involved. One reason for requiring the best possible weapon performance characteristics is the desire to cover all future possibilities--a very difficult if not impossible task. Proper use of doctrine can establish bounds on the future possibilities, by defining future mission requirements. It can thus shift the focus of the process from weapon system performance to total force capability. Doctrine can also highlight areas where advanced technology is needed. This can enhance the efficiency of technological changes and can limit the number of unnecessary advances. Doctrine can give needed discipline not only to the requirements process, but also to weapons system acquisition. However, one problem lies in the interactive nature of doctrine and technology. Doctrine can indeed 'pull' technology, but technology can also 'push' doctrine. Given the rapid advance of technology in certain areas, a means of dealing with this paradox is needed.

The Evolutionary Approach

An evolutionary approach to weapon system acquisition may offer one way of dealing with this problem. Traditionally, weapon system characteristics were rigidly defined early on in the program, based on projected 'threats' far into the future. As noted, this tends to drive requirements towards unproven leading edge technology, to guarantee the system's viability over this uncertain period. In an evolutionary approach, initial weapon system characteristics are based on present doctrine, technology, and threats. This initial design has inherent growth potential, so that as technology, doctrine, or threats change, the system can evolve as needed to meet the new requirements. This acquisition approach can apply equally to a 'pull' or 'push' situation. In fact, present evolutionary acquisition approach definitions can be divided along such lines. One, termed evolutionary acquisition or EA [developed by the Armed Forces Communications and Electronics Association (AFCEA)], leans toward a 'pull' approach in defining system requirements (3). As defined by the American Defense Preparedness Association (ADPA), the other, called pre-planned product improvement (P3I) tends more towards a 'push' approach. This thesis, to simplify matters, will refer to any evolutionary acquisition approach as P3I. Current Department of Defense (DOD) directives address the concept of evolutionary acquisition as P3I, and, as will be shown further in the thesis, there may be some validity in treating EA (as defined) as a subset of the DOD's general P3I concept.

CHAPTER III

PRE-PLANNED PRODUCT IMPROVEMENT

Acquisition Improvement Program

In 1981, the Department of Defense initiated an Acquisition Improvement Program (AIP)-- an effort to improve the results of DOD weapons policies and to institute an series of reforms (16:17). It is based on former Deputy Secretary of Defense Frank C. Carlucci's thirty-two acquisition initiatives, one of which is P3I. The basic concept behind P3I is to plan right from a system's origin to incorporate improvements over the course of the system's life (6:1). This is not a new concept in its entirety (4:27). The US military has been improving its existing weapons from many years. The B-52 aircraft, for example, has evolved from a high altitude, penetration strategic bomber to a stand-off, cruise missile launcher. The present version of the M-60 tank, the M-60A5, is much improved over its earlier brethren. It has IR sensors, laser guidance, and a shoot on the move capability that the initially fielded version did not possess. P3I differs from these past modification efforts in that it stresses preplanning for improvements while the system is still in the initial design stages (6:2). P3I proponents characterize it as a coherent modification strategy which plans for multiple system upgrades far into the future, in contrast to the reactive, ad hoc modifications presently undertaken (5:12).

P3I supporters feel that this acquisition approach offers several substantial benefits. P3I, if properly implemented, should lessen technological risks, since advanced, leading edge technology is no longer required in the weapon system. The system can now grow with the technology as it matures. This should lead to shorter acquisition times, and lower acquisition costs. Less risk means better attainment of program cost, schedule, and performance goals. P3I allows a system, through its growth provisions, to keep pace with a changing mission and threat environment. This should lower modification costs as well as lengthen the system's usable life. (4,11,15,16,19)

Industry has used a P3I strategy (though not labeled as such) quite successfully (19:18). P3I has the support and interest of many, not only in DOD, but also in the General Accounting Office (GAO), and in Congress (5:11). Despite this interest, the P3I concept remains vague and ill-defined (6:3). Its advantages have received much attention and press but still are theoretical and abstract (5:11).

Research Objective

The research objective of this thesis is to evaluate previous aircraft program examples that have utilized an evolutionary (P3I) approach to determine if the expected benefits accrued.

Research Questions

This thesis focused on the following research questions:

What is P3I? What is the relationship between P3I and EA?

Does use of P3I enhance a programs achievement of cost and schedule goals?

Does P3I use lessen acquisition times?

CHAPTER IV

RESEARCH METHODOLOGY

Scope and Limitations

This thesis looked at past military aircraft programs to find any which, in some way, anticipated or planned for quality improvements in its initial design. There were few such programs (6:23). One, the Navy's F-14 fighter program, had sufficient, readily available data for analysis. As noted by Captain Sickels in his thesis, civilian use of P3I has been more commonplace (19:18). But the data for these projects is difficult (if not impossible) to obtain and their widely varying formats would make analysis impractical (19:18,45). This thesis will concentrate on the cost and schedule achievement of the F-14 program and compare it to the cost and schedule performance of 1960s and 1970s weapon system programs. Performance goals were not evaluated since some programs' performance data were classified (The F-14 was one of these programs). Thus this aspect of P3I was not analyzed.

Study Framework

The study framework includes an initial effort to establish a broad, encompassing definition of P3I. Then the P3I example is compared with other non-P3I programs to assess relative attainment of cost and schedule goals. A comparison of respective cost drivers between the P3I program and selected, similar programs was drawn to further highlight P3I benefits. Finally, the length of acquisition time for these programs is analyzed to see if P3I does shorten the process.

Data Collection Plan

Question One: What is P3I? What is the relationship between P3I and EA?

Data collection began with a focused search for P3I related literature, P3I program examples, and P3I related studies. The review also included articles and reports on EA. The initial intent of the literature search was to enhance definition of P3I and to relate EA to P3I.

Question Two: Does use of P3I enhance a program's achievement of cost and schedule goals?
Question Three: Does P3I lessen acquisition times?

A review of past military aircraft program studies was undertaken to find P3I examples and to gather comparative data on non-P3I programs. This information was examined to see if P3I use did improve achievement of cost and schedule goals. Acquisition times were also extracted to assess P3I's impact on program length.

Data Analysis Plan

Question One: What is P3I? What is the relationship between P3I and EA?

A review of the various articles and reports on P3I and EA established a basic understanding of the concepts. Utilizing the definitions of P3I and EA espoused by their respective supporters, the two concepts were compared and contrasted to highlight differences and similarities. This effort enhanced understanding of the relationship between EA and P3I.

Question Two: Does use of P3I enhance a program's achievement of cost and schedule goals?
Question Three: Does P3I lessen acquisition times?

This thesis uses the Navy's Grumman F-14 Tomcat fighter aircraft as an example of P3I use in a major weapon system program. The F-14's cost and schedule performance was compared and contrasted with other non-P3I programs to answer research question two. Acqusition times were also compared to resolve research question three.

Data Sources

The data for the quantitative portion of this thesis was obtained from four primary sources. Two Rand reports, "System Acquisition Strategies"(18) and "Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s"(10), supplied the necessary data for prior weapon system acquisitions. These reports also provided the methodology used to make required data adjustments to compensate for the effects of inflation and any variations in the procurement quantity (Appendix A). The data format of the Rand studies was also utilized since it provided an excellent means of comparing and contrasting the various program results. The F-14 data came from two mid-1970s studies: "The Study of The Cost Growth of a Major Weapon System", an unpublished masters thesis by Lt. Col. D. E. Webb, and "The F-14 and F-4", a comparative analysis undertaken for the US Navy by the Columbia Research Corp. (Appendix B). This data was adjusted using the above methods to conform to the Rand format, thus allowing valid comparisons to be made.

Data Format

The Rand studies used a result vesus goal approach in their data analysis (10:25). Raw data was drawn from system program offices, contractors, and various reports for pre-1968 weapon systems (18:1) and from the Selected Acquisition Reports (SAR) for post-1968 programs (10:5).

For analysis of program costs, the development estimate (DE) was divided by the current estimate (CE) to produce a goal-result ratio (10:25). A ratio of unity (1) signifies achievement of the goal (the DE) while a ratio of less than unity (<1) indicates a cost underrun or a cost 'savings'. A ratio greater than unity (>1) means a cost overrun. The CEs were adjusted accordingly to allow comparison in terms of constant dollars and production quantities. For program schedule, the ratio of the number of months actually taken to the number of months originally scheduled was used. Again, the preferred ratio is unity or less than unity. To analyze program length (the Rand ratio only measures accomplishment of the stated goal), this thesis measured the time from the initiation of full scale development (FSD) to the delivery of the first production model. This measure avoids the difficult task of accurately determining the amount of time spent in the conceptual and demostration/validation phases (10:59). The use of the date of the first production model delivery as a stop date avoids the problem of analyzing production schedule deviations due to quantity changes or program stretch-outs. These schedule deviations are usually due to budgetary turbulence, which may or may not reflect internal program factors. The difficulty of correctly assessing the cause of such changes, whether political, economic, or technical, is thus avoided.

CHAPTER V

FINDINGS

Question One: What is P3I? What is the relationship between P3I and EA?

Literature Review

The American Defense Prepardness Association (ADPA) was one of the first defense related organizations to research the strategy of planning for improvements in a weapons initial design. It was the ADPA who labeled the strategy pre-planned product improvement or P3I (19:18). In April 1980, the ADPA and the Defense System Management School sponsored a three day seminar and workshop to discuss P3I and recommend how to implement it in the DOD (19:21). The proceedings of this seminar (the ADPA P3I Seminar and Workshop Proceedings) was the first comprehensive discussion of P3I (19:22). The January 1981 issue of the ADPA's National Defense magazine published several articles based on the findings of the seminar and workshop. Dr. Hylan B. Lyon, the ADPA P3I committee chairman, gives a brief overview of P3I in his article, "Pre-Planned Product Improvement" (15). He highlights its benefits, the difficulties it faces, and how it needs to be managed. In "P3I Competition, Standardization, and System Engineering", Joseph F. Grosson discusses the competitive aspects of the P3I strategy (12). Norman R. Augustine, Vice President, Operations, Martin Marietta Aerospace, also gives a general overview of P3I in his article, "P3I: An Idea Whose Time Has Come...Again" (4). He contrasts P3I with other modification strategies, looks at Soviet examples of evolutionary acquisition, highlights P3I benefits and problems, and proposes actions to implement P3I.

Captain Stephen W. Sickels' AFIT thesis, "Pre-Planned Product Improvement (P3I)", advanced the P3I concept by providing a better understanding of the P3I process (19). Captain Sickels studied the nature of P3I by reviewing specific examples of P3I use in military and commercial programs. The Boeing 727 aircraft provided the commercial P3I example; the Boeing Air Launched Cruise Missile (ALCM) gave an example of P3I in a military weapons program. Another military example was provided by the General Dynamics F-16 Multinational Staged Improvement Program (MSIP). These case studies highlighted the P3I process and the role it can play in a program. Methods to effectively select and plan improvements were also evaluated. This illustrated how P3I can actually help reduce long range uncertainty. Captain Sickels' overall recommendation was to implement P3I not through formal regulations and policies but by relaxing current regulations to support the P3I efforts of industry. This assumes that P3I is already inherent in industry's design practices. This may be true of the companies studied, but may not be typical of all.

About a year after the ADPA's seminar, the Armed Forces Communications and Electronic Association (AFCEA) formed a study team to evaluate command and control (C2) system acquisition. Out of this effort came a similar concept to P3I, which the AFCEA termed Evolutionary Acquisition or EA. Since the AFCEA study focused on C2 (versus the general focus of the ADPA seminar), it is not too surprising that many aspects of EA are oriented to C2 requirements. The findings of the AFCEA study were compiled in the Command and Control (C2) System Acquisition Study Final Report (3). This report provides a detailed overview of EA; how it was developed, the benefits it can offer, and the obstacles to its use. EA was also discussed in several articles in the August 1982 issue of the AFCEA's Signal magazine. Mr. John Smith, Director, Major System Acquisition, Office of the Secretary Of Defense, in his speech, "New Initiatives in Defense Acquisition" compares EA and P3I (20). It is his contention that P3I and EA are "exactly the same thing (20:56)." Mr Smith submits that EA is merely P3I applied to C2 systems. Like Captain Sickels, Mr. Smith feels that P3I (and thus EA) can be implemented without major changes in the existing acquisition process. Several EA advocates strongly disagree; they feel that the present acquisition policies inhibit and hinder use of EA (3:IV). They therefore recommend major changes in policy and in the acquisition process itself (3:VI-VII).

In their article "A Cultural Change: Pre-Planned Product Improvement", Lieutenant Colonel Garcia E. Morrow and Dr. Jules J. Bellaschi contend that P3I implementation requires a cultural change, not a procedural one (16:20). Their article discusses how P3I differs from past modification programs, what criteria need to be considered when applying P3I, and the benefits P3I offers, especially in program flexibility and adaptability. The basic thrust of Lt. Col. Morrow and Dr. Bellaschi's work is that the conviction and persistance of the program manager is vital to an effective P3I effort. Given the present short tenure of many program managers (10:15), this may be a serious hinderance to P3I implementation and success. Like most P3I advocates Lt. Col. Morrow and Dr. Bellaschi integrate P3I into the present acquisition system. Indeed, they stress how P3I must fit into the Five Year Defense Plan (FYDP) and the Planning, Programming, and Budgeting System (PPBS) process.

"P3I-Help in Reducing Weapon System Costs" by Lieutenant Commander Marlene M. Elkins gives another general overview of the P3I approach. Cmdr. Elkins provides some insight into why weapons costs are escalating rapidly and identifies how P3I can help alleviate this trend. Lt. Cmdr. Elkins emphasizes the importance of early planning in an effective P3I effort. Like Lt. Col. Morrow and Dr. Bellaschi, Lt. Cmdr. Elkins feels that the "major obstacle to the acceptance of [P3I]...is the cultural mindset of the user and engineering community... (11:116)."

The Rand Note, "Pre-Planned Product Improvement and Other Modification Strategies: Lessons Learned From Past Aircraft Modification Programs", is a less positive assessment of P3I. Authors Federick Biery and Mark Lorell reviewed past aircraft modification efforts; focusing on those aircraft with some discernable preplanning for future improvements. Unfortunately, only three such aircraft programs existed, the Northrup F-5, the Grumman F-14, and the Northrup N-102; one of which (the N-102) never even advanced beyond the conceptual stage. Thus Biery and Lorell evaluated long lived, often modified aircraft on the premise that some common factor could have accounted for these aircraft's adaptability and extended lifespans. In their work, they also break

P3I into three distinct categories. The first, general or non-specific P3I, attempts to facilitate any and all types of future improvements. The second, subsystem specific P3I, concentrates on subsystems known or anticipated to be available in the near future. The third type of P3I defined takes advantage of the benefits of standardization in design, interfaces, and architecture to apply a building block approach to improvements. Also known as 'modularization', its use in avionics has received much study, thus Biery and Lorell do not specifically address it in their study. This unfortunately may have ignored its possible benefits in aircraft applications (19:75). Based on their research, the two authors conclude "that preplanning far into the future is probably unworkable (6:VII)." But that short range preplanning based on specific subsystems (the second type of P3I), could be worthy of future consideration (6:VII). This conclusion can be faulted in two ways. One is the noted scarcity of P3I examples in their study group. While it is true that past examples of P3I use in military programs is rare, commercial applications are more numerous (19:18) and could have been included in their study sample. Second, their major premise is that designers can not anticipate future weapon system requirements and the improvements thus needed. But, as ably described by Captain Sickels in his thesis, uncertainty can be managed and P3I can be a vital aid dealing with it (19:87). Biery and Lorell do highlight some very valuable lessons learned from post modification programs; applicable to P3I and non-P3I programs alike. Interestingly, one of the lessons cited by the authors, to minimize technical risk by pursuing incremental advances, is an inherent benefit of the P3I approach.

P3I Definition

Despite the sizable number of articles and studies on the subject, there is still uncertainty and debate over just what P3I is. One major disagreement is between the proponents of EA and P3I supporters. EA advocates feel that their evolutionary approach differs from P3I. P3I supporters insist that their concept incorporates EA; it is simply a more detailed, C2 specific P3I application.

The ADPA defined P3I as follows:

> P3I is a systematic and orderly acquisition strategy beginning at the system's concept phase to facilitate evolutionary, cost effective upgrading of a system throughout the life cycle to enhance readiness, availability, and capability.
>
> The modular baseline configuration design shall permit growth to meet the changing threat and/or to take advantage of significant technological and/or operational oppurtunities through future modification or product improvements at appropriate time intervals.
>
> The baseline technological risk will be mini-

> mized and provide early availability by utilizing well known and established technology to the maximum extent feasible, limiting advanced technology to the subsystem(s) offering substantial operational or cost benefits. [19:114]

The AFCEA Defines Evolutionary Acquisition as follows:

> Evolutionary Acquisition is a system acquisition strategy in which only a basic or 'core' capability is acquired initially and fielded quickly, based on a short need statement that includes a representative description of the overall capability needed and the architectural framework within which evolution will occur. Subsequent increments or 'blocks' are defined sequentially, based on continuing feedback provided from lessons learned in operational usage, concurrent evaluation of adequecy of hardware/software configuration, and judgements of improvements or increased capabilities that can result from application of new technology, when feasible. [3:VII]

Both definitions stress shortening the time needed to field new systems; P3I through use of proven technology, EA through building only a basic 'core' system (Implicitly this 'core' must also be based on existing technology.) In EA, however, the system does not explicitly meet present requirements. Both definitions emphasis sequential upgrades, based on changing requirements (the "threat" in P3I, "evolving needs" in EA) and on technological advances. EA limits incorporation of advanced technology to that which is feasible. P3I evaluates application of advanced technology by its benefits and thus may ignore it's costs. EA does not specifically call for growth provisions in the initial 'core' design. It may be that such provisions are not cost effective in C2 equipment. However, design techniques such as modularization and form, fit, and function (F3) specification may provide the needed growth capability. EA bases its growth capability on its requirement for a definite architectural framework. Programs such as the Modular Automatic Test Equipment (MATE) program have succesfully utilized this approach. But as it name indicates, MATE also relies on its hardware's modularity to insure growth capability. EA's reliance on system architecture may reflect the software intensive nature of C2 equipment. This architecture must be precise, to insure effective upgrades, as well as flexible, to allow for unanticipated changes like new technology; a difficult goal to achieve.

The major difference between P3I and EA is that EA is process oriented, P3I is more design or hardware oriented. EA has a final desired goal-a system that fulfills a specified need. It utilizes user feedback and technological evolution to determine how to reach that goal. In P3I the initial system meets all requirements (hopefully) when it is deployed. Its designed-in growth provisions allow it to react to new technology, threats, and changing missions. The EA process emphasizes user involvement since C2 systems are traditionally user intensive and the man/machine interface is often a critical factor in them. The EA process is an iterative one, with increments based on user assimilation of system advances and his subsequent refinement of system capabilities needed to achieve the stated goal. In EA, the 'end' (the goal) is defined, the 'means' to this end are evolved in the dynamic operational and technological environment. In P3I the 'end' is undefined, the dynamic technical, operational, and threat environment determines overall system requirements. P3I defines the 'means' to achieve these requirements by incorporating specific growth provisions in its initial design. One could say that the EA process 'pulls' technology to meet its final goal, and that P3I allows technology to 'push' its systems requirements.

This asymmetry may not be due to a fundamental conceptual difference but could be a simple reflection of the different focus of each approach. EA is focused on C2 system acquisition, P3I seems to focus on weapon systems or hardware. C2 systems are, as noted, very software intensive. Software is inherently flexible and has great growth potential, so much so that a system architecture is often needed to control and direct improvements. Thus the EA concentration on defining such an architectural framework. In contrast, hardware does not have inherent growth potential-it must be designed into the system. Thus the P3I emphasis on incorporating upgrade provisions in the initial system design. Both approaches stress preplanning for future upgrades; EA through its system architecture, P3I through its hardware's initial design.

The problem could be simply that both the ADPA's P3I definition and the AFCEA's EA definition are too detailed and specific. Therefore, this thesis will use a more general definition of the evolutionary process, published in a July 6, 1981 memorandum of then Deputy Secretary of Defense Frank C. Carlucci.

> P3I is an acquisition concept which programs resources to accomplish the orderly and cost effective phased growth of or evolution of a system's capability, utility, and operational readiness. [19:129]

This definition is basically the same as the ADPA one, just less detailed. How one "programs resources" is left to the specific program, thus EA can be classed as an adaptation of this definition to the unique needs of C2 system acquisition. However a problem may arise in determining what definition of P3I (the general DOD one or the specific ADPA one) is being discussed. The general definition is useful in describing common traits of an evolutionary acquisition approach, yet the two specific definitions (the ADPA's P3I definition and the

AFCEA's EA one) are more precise and much more useful in particular situations. Probably the best solution for this problem is to use a more generic term such as Technology Improvement Program (TIP) for the general definition and recognize that P3I (as defined by the ADPA) and EA are subsets of TIP

Question Two: Does use of P3I enhance a program's achievement of cost and schedule goals?
Question Three: Does P3I lessen acquisition times?

The F-14 Aircraft

The Grumman F-14 Tomcat is the Navy's premier air superiority fighter, performing primarily in the Fleet Air Defense role. It is a twin engine, supersonic carrier based aircraft with variable sweep wings, armed with a mix of long, medium, and short range missiles (the AIM-54 Phoenix, the AIM-7 Sparrow, and the AIM-9 Sidewinder) plus a 20mm cannon (the M61A1 Vulcan)(25:33). Its two man crew operates an array of sophisticated avionics, including an automatic sweep control system which gives the aircraft superior maneuverability as well as increasing its range and loiter time (21:8). The F-14's AWG-9 weapons control system (WCS) can track up to twenty four targets and simultaneously guide six Phoenix missiles to six separate targets (25:34). This capability is presently unmatched by any other fighter aircraft.

F-14 Development

The F-14 evolved from the Navy's VFX program, which was initiated when it became apparent that the F-111B aircraft would not meet all of the Navy's air superiority fighter requirements (25:34). The related Navy Fighter Study (NFS), conducted in 1968, concluded that the desired fighter performance could be achieved with an advanced airframe in combination with the developed AWG-9 WCS and the TF-30 engine from the F-111B program (25:36). The NFS stressed growth potential as a vital factor in the aircraft's design to provide flexibility in accepting system changes with minimal penalties in cost and weight (25:36). Five contractors responded to the VFX's (now designated the F-14) Request For Proposal (RFP). The Grumman proposal was ultimately selected, chiefly because of its technical superiority, lesser development risk, and greater growth potential (25:38). It was not the lowest cost bid. Grumman not only had experience with swing wing technology (its XF-10F was the US's first swing wing aircraft) but also had benefited from its previous work with the specified engine and avionics as a subcontractor on the F-111B program (21:4,8,14). This knowledge was a important factor in Grumman's selection as the F-14 prime contractor (21:29).

F-14 Growth Provisions

The F-14 was designed from the start to incorporate an advanced engine, the F-401, the Navy's version of the Air Force's F-100 engine (now installed in the F-15 and F-16) which was then in development. The aircraft was also designed to accomodate various avionics and armaments improvements, specifically in infra-red (IR) detection and targeting (21:6-7). These variants were subsequently designated the F-14B and the F-14C.

It is apparent that the F-14 program has most of the elements of a P3I approach. It made maximum use of existing technology: the aircraft's armament, engine, and major avionics were either already fielded or developed. It utilized a subsystem approach in planning for subsequent upgrades. Provisions were made in the initial design for the fitting of an advanced engine, the F-401, and for anticipated avionics improvements. This thesis thus recognizes the F-14 as a good example of P3I use in a weapons system acquisition. This program will be compared and contrasted with other, non-P3I programs to see if the theorized benefits of P3I were, in fact, realized.

Results

The data for the F-14 program was adjusted as per the Rand data format and the results are shown in the Table One.

TABLE 1

F-14 vs. 1960s and 1970s Programs
Cost and Schedule Performance

COST

F-14 Ratio	1.27
1960s Program Mean Ratio	1.44 (1)
1970s Program Mean Ratio	1.34 (1)

SCHEDULE

F-14 Ratio	1.10
1960s Program Mean Ratio	1.15 (1)
1970s Program Mean Ratio	1.13 (1)

(1) Program mean ratios are from the Rand reports.

As can be seen, the F-14 program did better than the mean in its achievement of both cost and schedule goals. However, the above means are for all weapons systems in the respective study groups. This includes not only fighter aircraft but also transports, bombers, and helicopters, as well as tanks, missiles, artillery, and electronic systems. A better comparison may be to compare the F-14 with similar fighter aircraft. This thesis selected the F-4, F-15, F-106, and F-111 aircraft as analagous aircraft to the F-14. Each is a high performance fighter with advanced (for their times) avionics. The F-4 is the F-14's immediate predecessor as the primary Fleet Air Defense (FAD) aircraft. The F-106 was the most advanced interceptor of its day. The F-111, in its F-111B version, was once planned to be the next FAD fighter. The F-15 is the F-14's contemporary, with a similar air superiority role. The results of this selected comparison are shown in the Table Two. (The averages shown are simple arithmetic averages of this fighter group's cost and schedule performance. They can not be directly compared to the Rand results, as these are mean values)

TABLE 2

F-14 vs. Other Fighter Programs
Cost and Schedule Performance

COST RATIOS

F-14	1.27
F-4	1.25 (2)
F-15	1.25
F-106	2.06
F-111	2.07
Average	1.58

SCHEDULE (months) (1)

F-14	42
F-4	77
F-15	59
F-106	47
F-111	77
Average	60.4

(1) Schedule ratios could not be obtained from the present data sources thus the use of the months from DSARC II to the first production version.

(2) The F-4 cost ratio is from a estimate in the Columbia Research Corp. study.

The F-14 once again does better than the average in both cost and schedule. However, the F-14 cost ratio is worse than its immediate predecessor, the F-4, and its contemporary, the F-15. Further study was therefore made of the causes of the F-14 cost growth versus those for the F-15. SARs break down cost variances into nine categories and this analysis focused on them. The F-14, due to its evolutionary approach, should have shown less cost growth in internal cost variance categories, like engineering and scheduling. And this was borne out by the results of the evaluation. The F-14 showed a .1% negative variance in engineering cost versus a 17% positive variance for the F-15. Schedule deviation for the F-14 was 21.7% against 46% for the F-15. The largest variances for the F-14 were in the quantity and economic categories (25:51). These were due to the decision to cut the F-14 buy to 332 aircraft (down from 469 aircraft), and to Grumman's miscalculation of the inflation rate in their original bid. Because of the economic downturn in the early 1970s, Grumman lost a large portion of its commercial business, forcing the F-14 program to carry more of Grumman's overhead costs. Some feel that Grumman's initial program costing was very unrealistic and amounted to a 'buy-in' (21). With realistic DEs the F-14 could have performed even better in achieving its cost goals.

The F-14's schedule performance is one area where it shows a significant improvement over related programs. The F-14's schedule length of just 42 months is 18 months less than the average for the sample group. This means that the F-14 was in the field one and a half years earlier than comparable aircraft. The only other aircraft to have a similarly short acquisition time was the F-106. However, this aircraft was, in reality, a major product improvement of a existing aircraft, the F-102, which may explain its short acquisition time.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSION ONE: EA is a Command and Control (C2) specific subset of the general P3I approach.

As seen in the review of literature, EA, as presently defined seems to be simply P3I applied to the unique requirements of command and control (C2) system acquisition. The problem appears to be one of overly detailed definitions of the process. The P3I definition espoused by the ADPA is very hardware oriented, thus the apparent conflict with the AFCEA's C2 oriented EA definition. When one moves up a level of abstraction to a more general definition of P3I, such as the one used in the Carlucci Memorandum (19:129), the conflict is resolved. EA can be viewed as P3I adapted to the specific requirements of C2 acquisition. To avoid confusion it may be necessary to label the general definition TIP or some other generic term, since the ADPA's P3I definition is useful in specific applications. Thus one could say that both EA and P3I (as defined by the AFCEA and ADPA) are specific subsets of the general evolutionary acquisition approach (TIP).

CONCLUSION TWO: P3I can enhance achievement of cost and schedule goals as well as lessen acquisition times.

The comparison of the F-14 program, which utilized a

P3I like acquisition approach, to other weapon system acquisitions seems to show that P3I use can benefit cost and schedule performance. The F-14 program not only did better than most 1960s and 1970s programs in both categories, but also outperformed analogous fighter aircraft programs in cost goal attainment. The F-14 cost variations that did occur were generally in non-technical areas, futher reinforcing the perception that the P3I approach can lower technical risk. The relatively short length of the F-14 acquisition also supports the contention that P3I can help lessen acquisition times. However, some caveats must be made. First, the F-14 is only one program and its success with a P3I approach does not necessarily prove that P3I will improve all acquisitions. Many other factors could have lead to the F-14 program's excellent cost and schedule performance. For example, the Navy's critical need for a F-4 replacement due to the failure of the F-111B program may have been a major element in the the F-14's short acquisition length. More studies are necessary to state with certainty that P3I will indeed produce as hypothesized. Nevertheless, the results of this initial analysis are significant in that they show, in one case at least, that P3I can benefit weapon system acquisitions. The advantages of P3I are no longer abstract and theoretical but can be seen in hard figures.

Recommendations

The F-14 program does not, unfortunately, provide any support for P3I as a force modernization strategy. The growth provisions in the F-14 have not, to date, be utilized. This, in fact, points out a serious disadvantage in the P3I approach; its vulnerability to funding cuts in the program's outyears (6:33). Further study of other P3I programs should be undertaken to assess this aspect of the concept. The F-16 Multinational Staged Improvement Program (MSIP) may be one viable candidate for such an effort. The MSIP is a subsystem specific P3I program to insure that the F-16 aircraft can economically and effectively incorporate future avionics and armament systems (19:75). An evaluation of the F-16 Derivative Fighter Entry (DFE) could also fill this need. This program takes advantage of the growth potential provided by the modular design of the F-16's major components. A new wing, advanced engine, and improved avionics were easily fitted to the basic F-16 airframe. The F-16 DFE has a higher bomb load, longer action radius, better manueverability, and increased take off and landing performance than earlier F-16 versions (19:72). A difficulty in these studies could be a lack of comparative data. Aircraft modifications, unlike aircraft acquisitions, are managed in a multitude of ways (19:13). Detailed data, such as the SARs, may not be available.

Further study of the effect of P3I in initial weapon system acquisition should also be undertaken. This will broaden the P3I program sample size and allow more rigorous assessment of the concept's benefits. A concurrent study of EA applications could also highlight whether EA is truly a subset of P3I, as this thesis contends, or if it is actually a separate and distinct acquisition approach. These studies may bring out additional benefits of the P3I approach and evaluate how to effectively apply it to specific programs. Hopefully, with all the present programs incorporating some aspect of P3I, a result of former Deputy Secretary of Defense Frank C. Carlucci's directives and the AIP, enough P3I examples and related data will be available to make such studies possible. One research approach would be to duplicate the Rand "Acquisition Policy Effectiveness" report (which was an assessment of the effects of the early 1970s reforms instituted by then Deputy Secretary of Defense David Packard) and provide a quantitative evaluation of the effects of all the Carlucci initiatives, including P3I, on weapon system acquisitions.

APPENDIX A

RAND STUDY METHODOLOGY

Appendix A

BASIC METHODOLOGY FOR ASSESSING PROGRAM COST GROWTH

INTRODUCTION

Program cost data used throughout this study were drawn from Selected Acquisition Reports. The Office of the Assistant Secretary of Defense (Comptroller) (OASD(C)) also uses that source to develop measures of acquisition cost growth. However, some of the analytical methods used by OASD(C) differ from the methods we used, and this can lead to somewhat different results from what appear to be similar measures of cost growth. To avoid misinterpretation of our study results, in this appendix we explain our cost analysis methods and indicate how they differ from those used by OASD(C).

Program cost is the cost of the whole acquisition program, including the development and testing of the system, the production of system units (with their spares and peculiar support), and any directly related military construction. Program cost growth is the change in program cost over time. The more general terms "cost variance" and "cost change" are sometimes used in place of cost growth, because they are consistent with both increasing and decreasing costs. Here we understand cost growth to include both negative and positive changes. "Cost variance" is the term usually employed in the Selected Acquisition Reports.

We are interested in cost growth over the full lifetime of the acquisition program. Ideally, this involves a comparison between an initial cost estimate or cost projection[1] and the actual costs incurred in bringing the program to completion. In our study of 1970s programs, the initial or baseline program costs are the Development Estimates (DEs) prepared at the time of DSARC II; that is, at the program milestone between the validation phase and full-scale development. A program's DE is rarely changed, and for most programs it provides a fixed point from which to measure subsequent growth.[2] The costs used in the cost growth calculations are not, however, full term actuals, because no program in our 1970s sample has reached completion, although two have been cancelled.[3] Thus, the cost growth calculations presented here (and in most of the defense acquisition literature) are really comparisons between two estimates: an early estimate and an estimate made later in the program's evolution. For these later estimates we relied

---

[1]The term "cost projection" is sometimes preferred as implying an estimate of a long time-stream of costs.

[2]For two programs—Harpoon and Condor—the DEs given in the recent SARs do not reflect the estimates used at the time of Milestone II. To be consistent with our study objective we adopted baseline cost estimates for these two programs derived from the Current Estimates (CEs) reported in the SARs at DSARC II. This is explained in Appendix C.

[3]The two cancelled programs are the B-1 bomber and the Condor missile. For these the costs are estimates as of the time these programs were cancelled. We understand that further cost growth was expected in these programs if they were not terminated.

on the Current Estimates (CEs) that are updated quarterly in the SARs. The CEs used in our cost growth calculations are those given in the March 1978 SARs.

To summarize: The program cost growth considered here is the difference between the CE and the DE, the CE being the more recent (and usually the larger) estimate. The period over which program cost growth is measured is the time between the date of the DE (approximately the date of DSARC II), and the March 1978 SAR. When the cost growth of several different programs is compared or aggregated, it is common to express cost growth not in dollar terms, but in terms of a percentage increase, or the ratio CE/DE, which we refer to here as the "cost-growth ratio."

ADJUSTING FOR CHANGES IN PRODUCTION QUANTITY: TWO ALTERNATIVE METHODS

As already explained in the text, we express both CE and DE in terms of constant FY 1979 dollars, to eliminate the effect of inflation on the program dollar totals. We also express program costs in terms of the original (DE) production quantity contemplated at Milestone II. Reference to some baseline production quantity is needed to negate the effect of any change in production quantity ("quantity change" or "quantity variance") that may occur. Such changes are common, and sometimes occur more than once in the course of a program's lifetime. Program cost is highly sensitive to the number of items produced, and without such a baseline it would be misleading to compare the CE/DE cost growth ratios of several different programs if some programs held production quantities constant and others did not.

When the CE production quantity is different from the DE production quantity there is more than one way to adjust program cost to eliminate the cost effect of this change in quantity. One method is to use the *DE production quantity* as the baseline, as we have done. In this case, the CE, which is reported in the SAR in terms of the currently approved quantity, is "adjusted" or normalized on the basis of the DE quantity. Thus, if the production quantity has been reduced since DSARC II (a common occurrence), an addition to the CE is required to bring the program cost back up to what it would be if the originally programmed quantity were to be procured; if the production quantity has been increased, a reduction of the CE is required. This is accomplished simply by deleting the cost change attributed in the program's SAR to quantity variance.

Another method is to use the *currently approved (CE) quantity* as the baseline. When this is different from the quantity for which the DE was calculated, then the DE must be recalculated for the new quantity. For example, if the new quantity is less than the DE quantity, a reduction in the DE is necessary, equal to the quantity cost variance reported in the SAR. In this approach the denominator of the cost-growth ratio changes with each change in planned production. This is the method adopted by the Office of the Assistant Secretary of Defense (Comptroller) (OASD(C)).[4]

If quantity-induced cost changes were the only cost changes that occurred, it

[4] See the periodic report published by the Office of the Assistant Secretary of Defense (Comptroller), *SAR Program Acquisition Cost Summary*.

obviously would make no difference which of these two methods was followed. Whether we delete the variance from the CE or add it to the DE, the cost growth, after adjustment to either baseline quantity, would be zero (the cost-growth ratio would be unity). But quantity-induced cost variance is only one of the many types of cost variance encountered in acquisition programs and reported in the SARs. (For a description of the cost variance categories, see Section III of the text and Appendix B, below.) When other types of variance are involved, the baseline quantity has a direct bearing on the size of the computed cost-growth ratio. Moreover, when program cost variance includes both a change in quantity and a change in the cost per unit, the order in which the quantity variance is calculated (that is, whether before or after the cost-per-unit change is taken into account) can affect the share of total variance attributed to the change in quantity and hence to the size of the quantity adjustment. The result is that the cost growth ratio normalized to exclude the effects of quantity changes can differ depending on the way the magnitude of quantity variance is estimated and on the way its effect on cost growth is eliminated. These considerations will be demonstrated below to indicate why the cost growth estimates calculated by OASD(C) for some programs differ from those shown in this study. Our approach was dictated, of course, by the basic ground rule of the study—to measure changes from the DSARC II benchmark.

Although the SARs designate many categories of cost variance, from a computational point of view these fall into four basic types of changes: (1) quantity, (2) recurring cost-per-unit, (3) cost-quantity curve slope, and (4) nonrecurring. These are illustrated in Fig. A.1, where total cost is measured vertically and quantity is shown on the horizontal axis. Because the logarithmic scale gives a good visual representation of percentage differences (the greater the vertical distance from the baseline the greater the proportional change) and also because cost-quantity curves are conventionally represented by straight lines in a log-log grid[a] we chose logarithmic scales for both axes in Figs. A.1 through A.4.

The DE and CE cost-quantity curves reveal their total costs at each indicated quantity. The quantity designated "Q_o" is a reference point representing a hypothetical baseline output of 40, programmed at the time of DSARC II. The total DE baseline cost, C_o, is measured at the point of intersection of Q_o and the baseline DE cost-quantity curve. The CE total cost shown on each graph, C_c, indicates the effect on cost growth of the specified amount and type of variance. These are measured at the DE quantity—except, of course, for the variance caused by a change in quantity.

[a]A log linear cumulative average cost-quantity curve implies that the average recurring cost per unit will decline at a constant rate with each doubling of the quantity, i.e., assuming a production cost-quantity curve with an 80 percent slope and a Unit 1 cost of 5 cost units (as in our examples), the average cost of Units 1 and 2 will be 4, Units 1 through 4 will average 3.2, etc. The equation for deriving a cumulative average recurring cost (c) is

$$c = U \cdot Q^{b}$$

where U = Recurring cost at Unit 1
Q = Quantity
b = Cost-quantity curve slope expression: log slope/log 2.

For convenience, the illustrations in Figs. A-1 through A-4 transform the average cost values into total costs at each indicated quantity, e.g., at Unit 1 the total cost is 5 cost units, at Unit 2 the total cost is 8, at Unit 4 the total is 12.8, etc. The equation for deriving total cost (C) is

$$C = U \cdot Q^{(b + 1)}$$

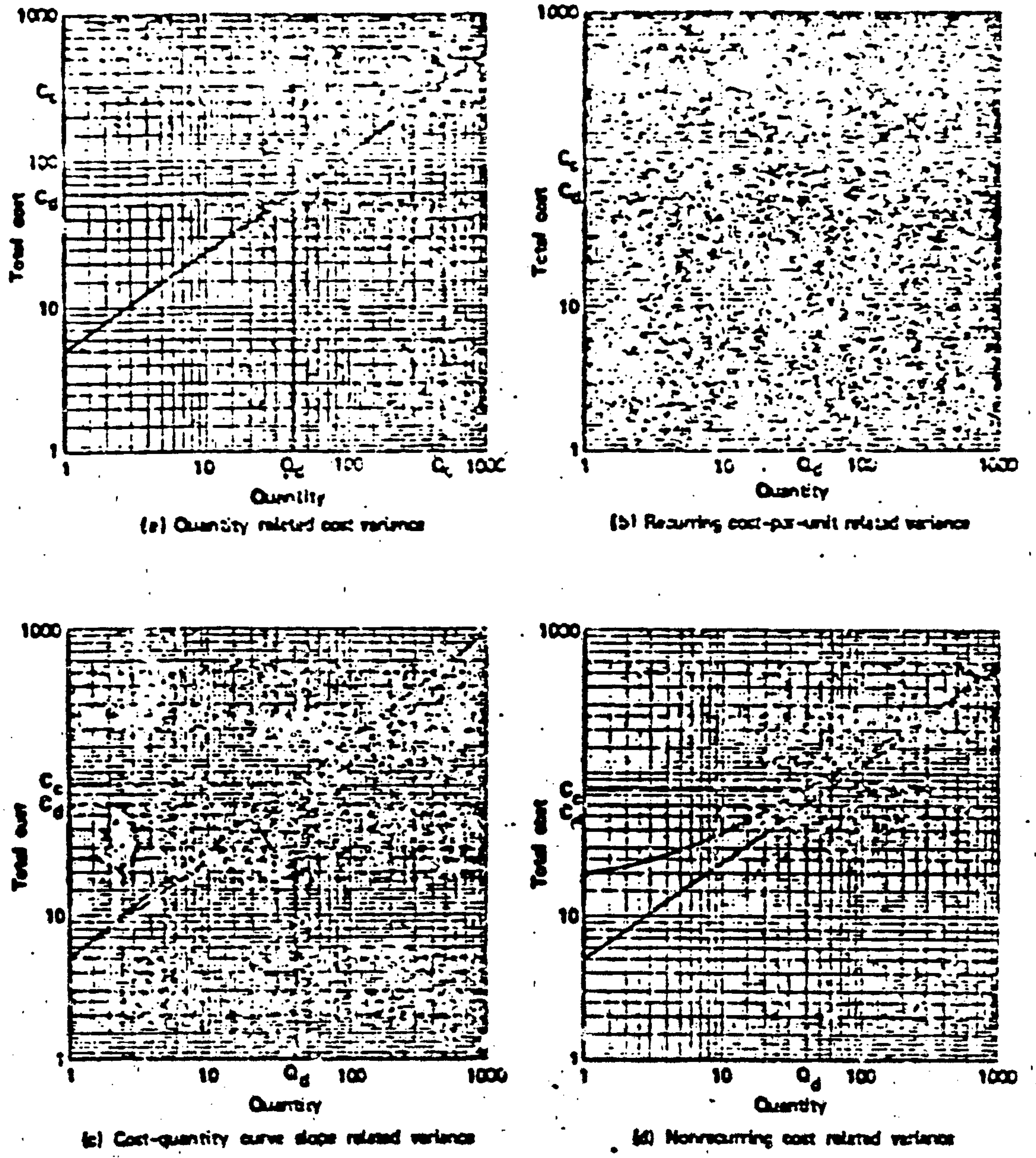

Fig. A.1—Four types of cost variance
(note use of log-log scale)

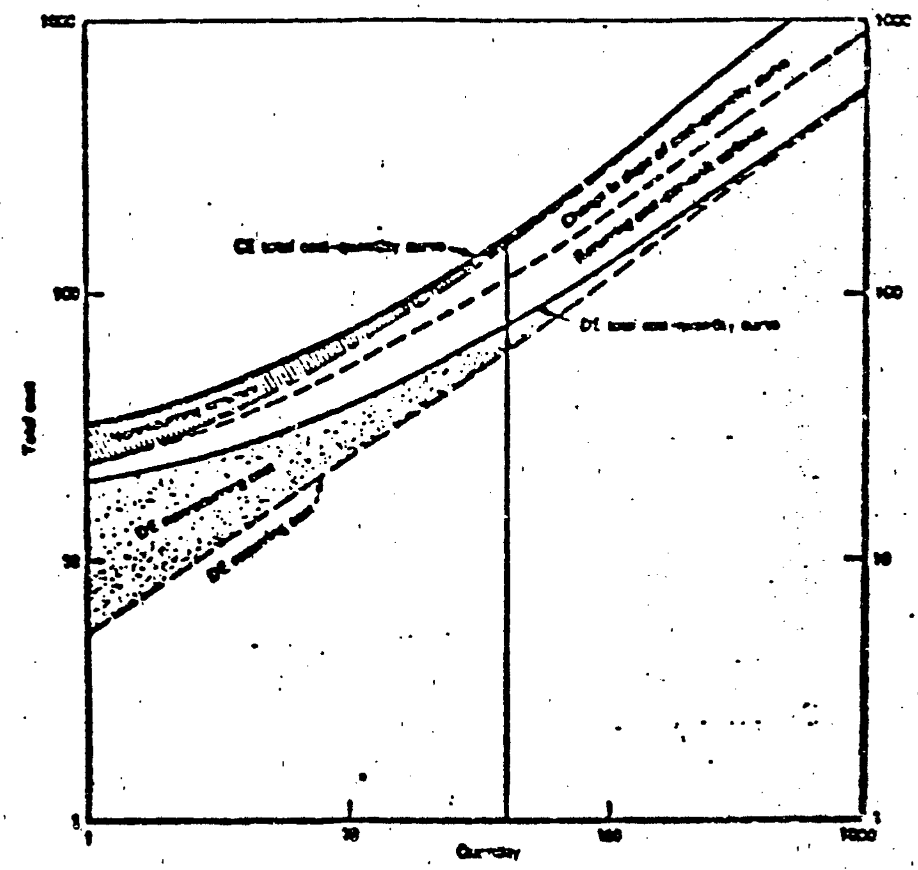

Fig. A.2—Components of cost growth
(note use of log-log grid)

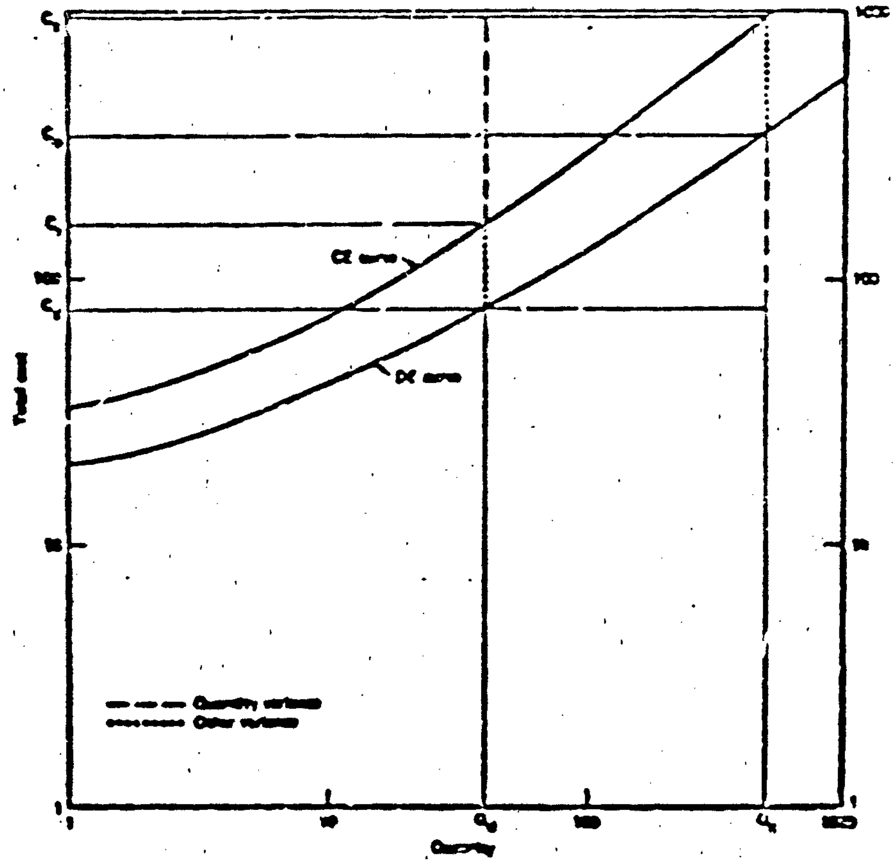

Fig. A.3—Cost growth in terms of DE or CE quantity
(note use of log-log grid)

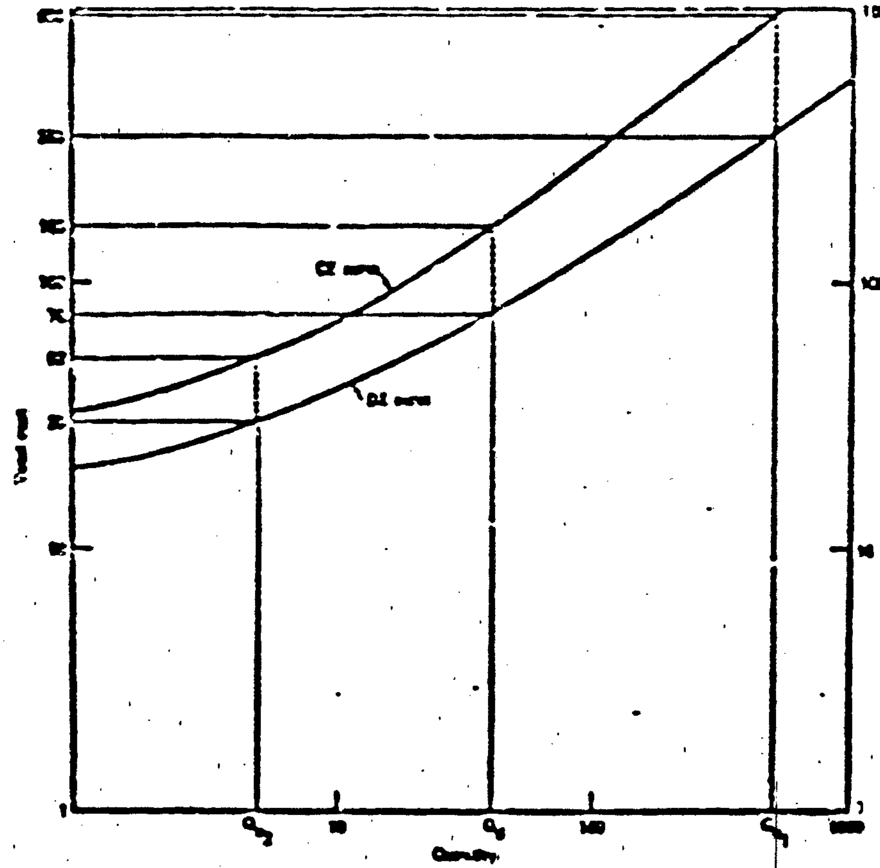

Fig. A.4—Effect of quantity on cost growth percentages (and ratios) (note use of log-log grid)

Quantity-induced changes (Fig. A.1(a)) have already been discussed; they simply scale the program along the given cost-quantity curve to the new CE quantity, Q_c. Recurring cost per-unit variance includes the kinds of engineering changes and corrections of estimating errors that shift the program to a new cost-quantity curve having the same slope as the DE curve but with a different initial recurring cost at Unit 1. An increase of 2 "cost units" at Unit 1 is illustrated in Fig. A.1(b). Figure A.1(c) illustrates variance that results from a change in the slope of the cost-quantity curve, in this case from 80 percent to 85 percent. This reflects a more pessimistic projection of the expected rate of cost reduction as production proceeds and results in the indicated increase in total costs. A slope change in the other direction would, of course, decrease total costs.

Nonrecurring cost variance, such as a change in development costs, is represented by a constant dollar increment (Fig. A.1(d)). In the example, the increment is 10 cost units. (The apparent decrease in the nonrecurring cost at higher levels of total cost results from the graph's logarithmic scale, which reflects the reduced proportional value of the fixed cost relative to the increased baseline; the absolute magnitude of the cost increment remains constant throughout.)

For simplicity we chose, in Fig. A.1, to illustrate the four types of variance, one at a time, as additions to a baseline DE curve that is represented as a straight line on the log-log grid. In effect, we limited the baseline to recurring costs which were assumed to exhibit the cost reduction characteristics of an 80 percent cost-quantity "learning" curve.

In Fig. A.2, the picture is more complete. Here we show the underlying structure of a complete DE baseline cost-quantity curve and a CE curve. The total DE cost-quantity curve includes both recurring and nonrecurring costs, and the total CE cost-quantity curve combines the DE baseline curve with additions of all four types of cost variance.[4] The cost and quantity numbers indicated in Fig. A.2 are hypothetical. In practice, it is not uncommon for an increase in one type of variance to be offset, at least partly, by a decrease in another. Fig. A.2 indicates how each component of the program cost responds to quantity changes.

Figure A.3 reproduces the total DE and CE cost-quantity curves from Fig. A.2. As noted earlier, the height of the DE cost-quantity curve at the baseline quantity, Q_b, establishes the total DE baseline cost, C_b. The CE total cost, C_c, results from the increase in quantity to Q_c plus a combination of the three types of variance shown in Fig. A.2 that cause the shift to the higher CE cost-quantity curve.

Figure A.3 illustrates our method and the method used by OASD(C) to eliminate the effect of such quantity changes from the cost growth assessment. As noted earlier, our method measures cost variance in terms of the DE cost projection established at DSARC II. Therefore, referring to Fig. A.3, we measure cost growth on the basis of the original quantity, Q_b. The cost variance due to the change in quantity is computed in terms of the known current unit cost, on the CE curve. Its share of the total cost growth is indicated in Fig. A.3 by the dashed vertical line $(C_c - C)$ drawn at quantity Q_c. Following this approach, the program cost growth is converted to constant (DE) quantity terms by deleting the quantity cost variance.

---

[4]Also, again to simplify the analysis, we assume a single cost-quantity curve for the equipment recurring costs of the example program. Actually, a complex program might have several curves, with different slopes, for its various major subsystems.

from the total cost growth. This leaves the remaining "adjusted" cost variance—indicated by the *dotted* vertical line ($C_c - C_d$) at quantity Q_d—in terms of the DE quantity, and this is the method we used in calculating cost growth.

The same figure illustrates the method used by OASD(C) in adjusting the DE to offset the effect of quantity change. In this latter method, cost growth is measured in terms of the currently programmed quantity. The quantity adjustment is made by adding to the DE cost a dollar amount equal to the quantity-induced cost variance. First the quantity cost variance is computed *in terms of the original DE cost-quantity curve*. Thus, referring to Fig. A.3, the share of the total cost growth attributed by OASD(C) to quantity cost variance is the amount ($C_v - C_d$), the dashed vertical line drawn at the new quantity, Q_c. Cost growth using the OASD(C) approach is then calculated on the basis of the adjusted DE cost at the new total quantity, i.e., the amount ($C_c - C_v$) shown in the figure as the dotted vertical line between the two cost-quantity curves at quantity Q_c.

The two dotted lines in Fig. A.3, representing cost growth adjusted for quantity change by the two methods, are clearly different in length. Thus, the DE and CE curves are not parallel, and, as the scale is logarithmic, it follows that the cost growth ratios computed at these two different quantities are not the same.[1]

The example presented in Fig. A.4 demonstrates how the choice of baseline quantity can influence the value of the OASD(C) cost-growth ratio when it is adjusted to "offset" the quantity-induced cost variance. The DE and CE total cost curves are the same as before except that alternative CE quantities are included—

---

[1] The essence of the difference can be shown algebraically. The equation for total cost (C) assuming a log-linear cumulative total recurring cost-quantity curve is

$$C = U \cdot Q^{(B+1)}$$

where U = Recurring cost at Unit 1
Q = Quantity
B = Cost-quantity curve slope expression: log slope/log 2.

The nonrecurring costs, F, are then added in. If we subscript these to designate the DE, CE, and variance parameters—d, c, and v, respectively—the equation for the DE total cost (C_d) is

$$C_d = F_d + U_d \cdot Q_d^{(B_d+1)}$$

The equation for the CE (C_c) adds in the variances

$$C_c = (F_d + F_v) + (U_d + U_v) \cdot (Q_d + Q_v)^{(B_d + B_v + 1)}$$

As c = d + v, the latter equation can be simplified as follows

$$C_c = F_c + U_c \cdot Q_c^{(B_c+1)}$$

A comparison of the adjusted cost-growth ratios resulting from the two different methods and the cost and quantity numbers shown in Fig. A.3 will show that they are not equivalent. Our adjusted cost-growth ratio R_r is

$$R_r = \frac{F_c + U_c \cdot Q_d^{(B_c+1)}}{F_d + U_d \cdot Q_d^{(B_d+1)}}$$

whereas the OASD(C) ratio, R_o, is

$$R_o = \frac{F_c + U_c \cdot Q_c^{(B_c+1)}}{F_d + U_d \cdot Q_c^{(B_d+1)}}$$

The two ratios will differ if F_c is not equal to F_d, and B_c is not equal to B_d, because the numerator and denominator of the OASD(C) ratio will not vary proportionally as quantity Q_c increases or decreases from Q_d.

an increase over the DE baseline quantity to Q_+, and a decrease to Q_-. The DE baseline total cost at a quantity of 40 is 76 cost units. Including the quantity-induced cost variance, the Q_+ total cost at a quantity of 500 is 956 cost units. With a drastic cut in production leaving only 8 development articles, the total cost at Q_- is 52 cost units.

If we apply the OASD(C) method for adjusting for the effect of a change in quantity, an increase from the DE quantity (Q_0) to the quantity Q_+ in Fig. A.4 would result in quantity-induced variance of 353 − 76 = 277 (measured on the basis of the original DE baseline cost-quantity curve). This amount added to the DE is 277 + 76 = 353 and the cost-growth ratio is 956/353 = 2.71. On the other hand, with the same nonrecurring cost variance and the same changes in curve slope and recurring cost-per-unit variance (that is, the same DE and CE cost-quantity curves), a decrease from the DE quantity to the quantity Q_- in Fig. A.4 would result in quantity cost variance of 30 − 76 = −46 and an adjusted cost-growth ratio of 52/(76 − 46) = 52/30 = 1.73. Thus, when there are substantial changes in production quantity, the OASD(C) method of negating quantity cost variance can lead to large differences in the resulting adjusted cost-growth ratios. Or, to put it another way, the OASD(C) method of adjusting for quantity changes uses a floating baseline and this can lead to inconsistent cost-growth results.

These inconsistencies are avoided (at least in principle) in the method adopted in this study. In our approach, the DE quantity, Q_0, is a fixed baseline; the cost variance attributed to any change(s) in production quantity is subtracted from the total cost growth; and the result of this subtraction is the variance attributed to non-quantity-induced cost changes. In both the Q_+ and Q_- examples in Fig. A.4 the result is the same: 160 − 76 = 84. The quantity-adjusted cost growth is thus independent of the sign and magnitude of the quantity change. When the cost-growth ratio is calculated for these two examples, the results are [956 − (956 − 160)]/76 = 160/76, and [52 − (52 − 160)]/76 = 160/76. In both cases the cost-growth ratio is 2.11. In practice, differences of this magnitude are rare. Except for programs that have been changed extensively, cost growth measured by either method is similar.

COST GROWTH TIME TRENDS

To estimate the average annual rate of cost growth for our 1970s cost analysis sample of 31 programs, we plotted their March 1978 growth ratios against the number of years past DSARC II for each of the programs. The results appear in Fig. 11 of the text.

Lacking statistical support for the expected flattened curve, or S-shaped curve with start-up lag* (see Figs. 9 and 10 of the text with the accompanying discussion of programs in the production phase), we opted for a linear curve showing a constant average annual growth rate as the best way to describe the data. The linear regression of the data points in Fig. 11 indicated that this set of programs

---

*For example, a modified exponential curve such as the Gompertz or "logistic" curves.

had an average annual cost growth rate of 5.6 percent.[a] It should be noted that we designated the Y-intercept of the regression line to show zero growth (a growth ratio of unity) at DSARC II. Also this procedure minimized the influence of programs that suffered unusually high growth rates soon after DSARC II. Experience suggests that programs with early high growth are likely to be restructured. Allowing the regression calculation to find its own Y-intercept might result in pulling up the origin of the trend line above unity, the true baseline at the time of DSARC II, thus decreasing the slope of the trend line (the more programs that had high initial growth rates, the lower the sample's marginal or incremental annual growth rate would appear to be).

OASD(C) obtained a somewhat lower aggregate cost growth rate for the programs current at this time, about 3.6 percent a year. A part of the difference between the two results derives from the differing methods used for adjusting for quantity-induced cost changes, as explained earlier.[b] But the primary reason for the different growth rates is the difference in the program samples. OASD(C) includes the 53 programs reported in Congressional SARs, minus the IFV, plus 5 additional programs that are covered in SARs not reported to the Congress. The sample we used excludes ships, programs that entered full-scale development before 1969 (and hence should be little influenced by the Packard policies), and programs with ambiguous data. When we used the complete OASD(C) sample but employed our computational method, the annual cost growth rate was 4.3 percent. The remaining difference between our 4.3 percent growth rate and OASD(C)'s 3.6 percent rate was almost completely accounted for by the different methods used for representing annual cost growth. Our percentage rate is simply a linear, average annual growth rate, whereas OASD(C) uses a compound growth rate.

---

[a]The regression was performed with the CURVES computer program. H. F. Bowen, Jr., and G. W. Corwin, *CURVES: A Cost Analysis Curve Fitting Program*, The Rand Corporation, R-1762/1-PR, September 1976.

[b]Actually, the different methods for dealing with quantity cost variance had only a small effect on the overall annual cost growth rates in this comparison. This is because the OASD(C) sample omitted the IFV and the [illegible] differences in cost-growth ratios were mixed, some higher than ours and some lower, and they tended to cancel each other out.

APPENDIX B

F-14 COST DATA

F-14 COST DATA

Program Acquisition Cost ($ millions)	(1) Development Estimate (DE)	(2) Changes	(3) Current Estimate (CE)
Base Year (1969) Cost	(FY69-76)		(FY 69-77)
Development			
RDT&E (F-14A)	678.0	166.4	1044.4
RDT&E (F-14B)	221.5	121.1	342.6
Total RDT&E	899.5	487.5	1387.0
Procurement[2]			
Total Flyaway	3323.4		2904.5
Support	471.1		692.3
Initial Spares	697.4		381.5
Total Procurement	4491.9	-513.6	3978.3
Construction[3]	0	6.1	6.1
Escalation			
Economic Change	774.6	202.8	977.4
Program Related		-3.4	-3.4
TOTAL PROGRAM COST	6166.0	179.4	6345.4
Quantities			
Development	6	6	12[4]
Procurement	463	-141	322
Total	469	-135	334
Unit Cost F-14A Program	12.63	5.26	17.89

[1]DE covers FY 69-73, CE for F-14A covers FY 69-75.

[2]CE change principally a function of quantity changes.

[3]CE covers FY's 71, 73, and 74.

[4]Result of Congressional transfer of funds from PAMN to RDT&E.

Source: F-14 Selected Acquisition Report, Confidential, 31 March 1974.

(Webb,1974:Fig.5)

F-14 COST VARIANCE

	($ in millions) DEV	PROC	CONST	Escalation Provisions	Total Program Cost
Development Estimate	889.5	4491.9	0	774.6	6616.0
1. Quantity	269.3	-1095.4		-179.6	-1005.7
2. Engineering		-2.8		.6	-2.2
3. Schedule	101.9	275.6		99.6	477.1
4. Economic				202.8	202.8
5. Unpredictable					
6. Performance Incentive	5.5			.5	6.0
7. Contract Cost Overrun	67.6			5.5	73.1
8. Support		242.6	6.1	80.3	329.0
9. Estimating	43.2	66.4		-10.3	99.3
Current Estimate	1387.0	3978.3	6.1	974.0	6345.4

(Webb,1974:Fig.6)

SELECTED BIBLIOGRAPHY

A. REFERENCES CITED

1. Alexander, Arthur J. "Patterns of Organizational Influence in Soviet Military Procurement." Unpublished research note, N-1327-AF, Rand, Santa Monica CA, April 1982.

2. Alexander, Arthur J. "Soviet Science and Weapons Acquisition." Unpublished research report, R-2942-NAS, Rand, Santa Monica CA, August 1982.

3. Armed Forces Communications and Electronics Association. "Command and Control (C2) System Acquisition Study Final Report." Unpublished research report,unnumbered, AFCEA, Falls Church VA, September 1982.

4. Augustine, Norman R. "P3I, An Idea Whose Time Has Come... Again," National Defense, January 1981, pp.27-31,62.

5. Biery, Federick P. "Are Other Acquisition Strategies Superior To The P3I Approach?" Defense Management Journal, First Quarter 1983, pp.11-15.

6. Biery, Federick P. and Mark Lorell. "Pre-Planned Product Improvement and Other Modification Strategies: Lessons Learned From Past Modification Programs." Unpublished research note, N-1794-AF, Rand, Santa Monica CA, December 1981.

7. Brown, Harold. "Technology, Military Equipment, and National Security," Parameters, VolXIII, No.1, pp.15-27.

8. Cockburn, Andrew. The Threat. New York: Random House, 1983.

9. DeLauer, Richard D., Under Secretary of Defense, Research and Engineering. The FY 1984 Department of Defense Program for Research, Development, and Aquisition, Statement to the 98th Congress. Washington DC: Government Printing Office, March 1983.

10. Dews, Edmund, Giles K. Smith, Allen Barbour, Elwyn Harris,and Micheal Hesse. "Acquisition Policy Effectiveness: Department of Defense Experience in the 1970s." Unpublished research report, R-2516-DR&E, Rand, Santa Monica CA, October 1979.

11. Elkin, Lieutenant Commander Marlene M., USN. "P3I-Help in Reducing Weapon System Costs," Concepts, Spring 1982, pp.105-110.

12. Grosson, Joseph F. "P3I Competition, Standardization, and System Engineering," National Defense, January 1981, pp.25-26.

13. Head, Colonel Richard G., USAF. "Tecnnology and the Military Balance," Foreign Affairs, April 1978, pp.554-563.

14. Johnson, Major Herbert W., USAF. "Air Force Fighters: Simple or Complex?" Air University Review, May-June 1983, pp.24-35.

15. Lyon, Dr. Hylan B. "PrePlanned Product Improvement," National Defense, January 1981, pp.20-25.

16. Marrow, Lieutenant Colonel Garcia E., USAF, and Dr. Jules J. Bellaschi. "A Cultural Change: PrePlanned Product Improvement," Concepts, Summer 1982, pp.16-25.

17. McKitrick, Jeffrey S. "A Military Look at Military Reform," Comparative Strategy, Vol IV, No.1, pp.51-64.

18. Perry, Robert, Giles K. Smith, Alvin J. Harman, and Susan Henricksen. "System Acquisition Strategies." Unpublished research report, R-733-PR/ARPA, Rand, Santa Monica CA, June 1971.

19. Sickels, Captain Stephen W., USAF. "Pre-Planned Product Improvement (P3I)." Unpublished masters thesis, LSSR 59-81, AFIT School of Systems and Logistics, Wright Patterson AFB Ohio, September 1981. ADA 110971

20. Smith, John, Director, Major System Acquisition, Office of the Secretary of Defense. "New Initiatives in Defense Acquisition," Signal, August 1982, pp.55-57.

21. Sponsler, George C., Norman M. Rubin, D. Gignoux, and Eugene Dare. "The F-4 and the F-14." Unpublished research report, N0014-72-C-0339, Columbia Research Corp., Gaithersburg MD, May 1973.

22. Tamlin, Captain Eric H., USAF. "Comparisons and Results of Soviet and American Military Approaches To Research and Development." Unpublished technical report, unnumbered, AFIT School of Systems and Logistics, Wright Patterson AFB OH, September 1980.

23. Taylor, John W.R. "Gallery of Soviet Areospace Weapons," Air Force Magazine, March 1983, pp.79-94.

24. Ulsamer, Edgar. "Will Economic Weakness Increase Soviet Militancy?" Air Force Magazine, March 1983, pp.41-47.

25. Webb, Lieutenant Colonel Donald E., USMC. "The Study of the Cost Growth of a Major Weapon System." Unpublished masters thesis, unnumbered, Naval Postgraduate School, Montery CA, December 1974. ADB 001397

B. Related Sources

Barbers, Major General Donald M., USA. "P3I, Pre-Planned Product Improvement," Signal, July 1982, pp.11-16.

Berman, M.B. and C.L. Batten. "Increasing Future Fighter Weapon System Performance by Integrating Basing, Support, and Air Vehicle Requirements." Unpublished research note, N-1985-1-AF, Rand, Santa Monica CA, April 1983.

Boyes, Vice Admiral Jon L., USN(Ret). International President, AFCEA. "Evolutionary Acquisition," Signal, March 1983, p.9.

Brabson, Colonel G. Dana, USAF. "DOD Acquisition Improvement Program," Concepts, Autumn 1981, pp.59-74.

Brabson, Colonel G. Dana, USAF. "Can We Afford the DOD Acquisition Improvement Action?" Concepts, Winter 1982, pp.45-54.

Forney, Major William A., USMC. "A Case Study on the Procurement of the F-14." Unpublished research study, unnumbered, Air Command and Staff College, Air University, Maxwell AFB AL, May 1977. ADB 0183431

Goldstein, Lieutenant Colonel Micheal J., USAF. "Reducing the Bow Wave in Defense System Budgeting," Concepts, Winter 1981, pp.75-78.

Gregory, William H. "Mods and Pods," Aviation Week and Space Technology, November 27, 1981, p.11.

Gregory, William H. "Streamlining the Acquisition Process," Aviation Week and Space Technology, May 4, 1981, p.9.

Lamar, Brigider General Kirby, USA(Ret). "C-E Development Strategies: New Emphasis on the Theory of Evolution," Signal, July 1981, pp.18-23.

Spangenberg, George A. "Cheap Fighters: The Impossible Dream," Armed Forces Journal, April 1974, pp.33-34.

Supko, Charles J. "Today's Weapons-Tommorrow's Requirements: Upgrading Existing Systems vs. New System Development -A Case in Point." Unpublished study report, unnumbered, Defense Systems Management College, Ft. Belvoir VA, May 1976.

Thayer, Paul, Deputy Secretary of Defense. "Guidance on the Acquisition Improvement Program (AIP),. DOD Memorandum, Washington DC: Government Printing Office, June 1983.

"Time Spurs New Design Approach," Aviation Week and Space Technology, December 8, 1981, pp.57-59.