DEVELOPMENT OF STANDARDIZED S CURVES FOR THE EVALUATION OF MAJOR DEPARTMENT OF DEFENSE PURCHASES

THESIS

Richard E. Knepp, B.S.
Captain, USAF

Michael E. Stroble, B. S.
GS-12, USAF

AFIT/GCA/LAS/93S-7

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

Wright-Patterson Air Force Base, Ohio

AFIT/GCA/LAS/93S-7

DEVELOPMENT OF STANDARDIZED S CURVES FOR THE EVALUATION OF MAJOR DEPARTMENT OF DEFENSE PURCHASES

THESIS

Richard E. Knepp, B.S.
Captain, USAF

Michael E. Stroble, B. S.
GS-12, USAF

AFIT/GCA/LAS/93S-7

The views expressed in this thesis are those of the authors and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

AFIT/GCA/LAS/93S–7

DEVELOPMENT OF STANDARDIZED S CURVES FOR THE EVALUATION OF MAJOR DEPARTMENT OF DEFENSE PURCHASES

THESIS

Presented to the Faculty of the School of

Logistics and Acquisiton Management of the

Air Force Institute of Technology Air University

in Partial Fulfillment of the Requirements for the

Degree of Master of Science in Cost Analysis

Richard E. Knepp, B.S.
Captain, USAF

Michael E. Stroble, B. S.
GS-12, USAF

September 1993

Acknowledgments

The authors wish to express their gratitude to our thesis advisor Major David S. Christensen for his expert guidance and sincere interest in our efforts.

Additionally, and most importantly, we would like to thank our families for their immeasurable patience and support. Many hours were sacrificed in the name of completing the thesis. Yes kids, dad can now go out and play.

Richard E. Knepp

Michael E. Stroble

Table of Contents

Page

List of Figures

Figure Page

List of Tables

Table | Page

AFIT/GCA/LAS/93S–7

Abstract

The increasing cost of Department of Defense acquisitions combined with the shrinking Defense budget puts a premium on continuing the funding of only those programs that are practical and affordable. This emphasizes a need for good methods of monitoring the progress of programs. Current methods of controlling and evaluating cost performance are limited.

It is our belief that the generation of S-curves using current Cost and Schedule Control Systems Criteria (C/SCSC) data will provide a mathematical and/or graphical approach to assist in the control of program costs. This thesis attempted to plot the percentage of time for a contract's completion against the percentage of actual cost spent during that period. Each contract was separated into a sub-category, averaged and then plotted. This developed a signature curve for categories of contracts.

Using the signature S-curves, a program manager can compare their program's percentage complete to percentage of cost to the standard for similar programs and determine if their program is on track.

This thesis did not result in the distinctive S curve pattern anticipated for an average of program contracts for various categories. The averaging of the contracts resulted in a smoothing of the S-curve into a nearly linear pattern. The resulting standard average curve for a category of programs would provide little insight into the status of a single program when used in comparison to that program.

DEVELOPMENT OF STANDARDIZED S CURVES FOR THE

EVALUATION OF MAJOR DEPARTMENT OF DEFENSE PURCHASES

I. Introduction

Overview

One of the strongest and most consistent trends in the Department of Defense over the last 30 years has been the spiraling costs of weapon systems (1:218). These huge increases in the cost of defense have resulted in an atmosphere of skepticism among the general population regarding the efficiency of the defense department, particularly in their procurement policies. Headlines highlighting stories of $437 hammers and $3,046 crash-proof coffee pots are rampant (2:31). In order to curtail the spiraling cost of weapon systems and eliminate the tales of overpriced merchandise the Department of Defense in the late 60's instituted an extensive overhaul of its procurement system that was centered on the Cost/Schedule Control Systems Criteria. Department of Defense Instruction 7000.2, implemented December 22, 1967 defined 35 criteria that all contractor management control systems were required to meet before their systems could be used on government contracts. The idea was to standardize the various contractors' systems data provided to government program offices for the monitoring of procurement contracts and controlling the cost of weapon systems.

Today the program offices are awash in valid data provided by the contractor. Additionally, a variety of methodologies are currently used to analyze contractor performance. Yet, program cost growth continues to remain uncontrolled (1:15). It is possible that a contributing factor to the problem is the lack of standardized tools that structure the data to identify problems in the programs early enough so that they can receive management attention and be rectified (13:18). The Department of Defense is constantly looking for new and more efficient ways of focusing on the data provided to the program offices so that it can be used efficiently.

General Issue

A new technique was recently developed and used by the Office of the Undersecretary of Defense for Acquisition Policy and Program Integration / Performance Measurement (OUSD(A)). This technique is the calculation of S-curves for defense programs that reflect the cumulative financial status of the programs over time. The S-curve utilized by OUSD(A) plots the cost of a project as measured by the Actual Cost of Work Performed (ACWP) as a percentage of the projected total cost of the program against the percentage completion of the program over time. This technique was utilized by OUSD(A) in evaluating the A-12 aircraft program (3:2). The A-12 program was a Navy effort to design and build the next generation, carrier based medium attack aircraft to replace the A-6. The A-12 program was a risky program because it incorporated new composite material technology. Analysis of the program was based on an EAC methodology that consistently produced low estimates (3:2). The result was project cost overruns that were not accurately estimated, particularly early in the estimate. Mr. Christie and Mr. Abba of OUSD(A) plotted the percentage of cost incurred against the percentage of contract completion for several aircraft projects with a resulting S-curve profile. An S curve envelope was developed which reflected the pattern for normal aircraft projects. A comparison of the envelope to the A-12 program revealed a significant divergence of this program from previous successful programs (Figure 1). This analytical tool was instrumental in showing that the A-12 program was in trouble and ultimately contributed to the cancellation of the program.

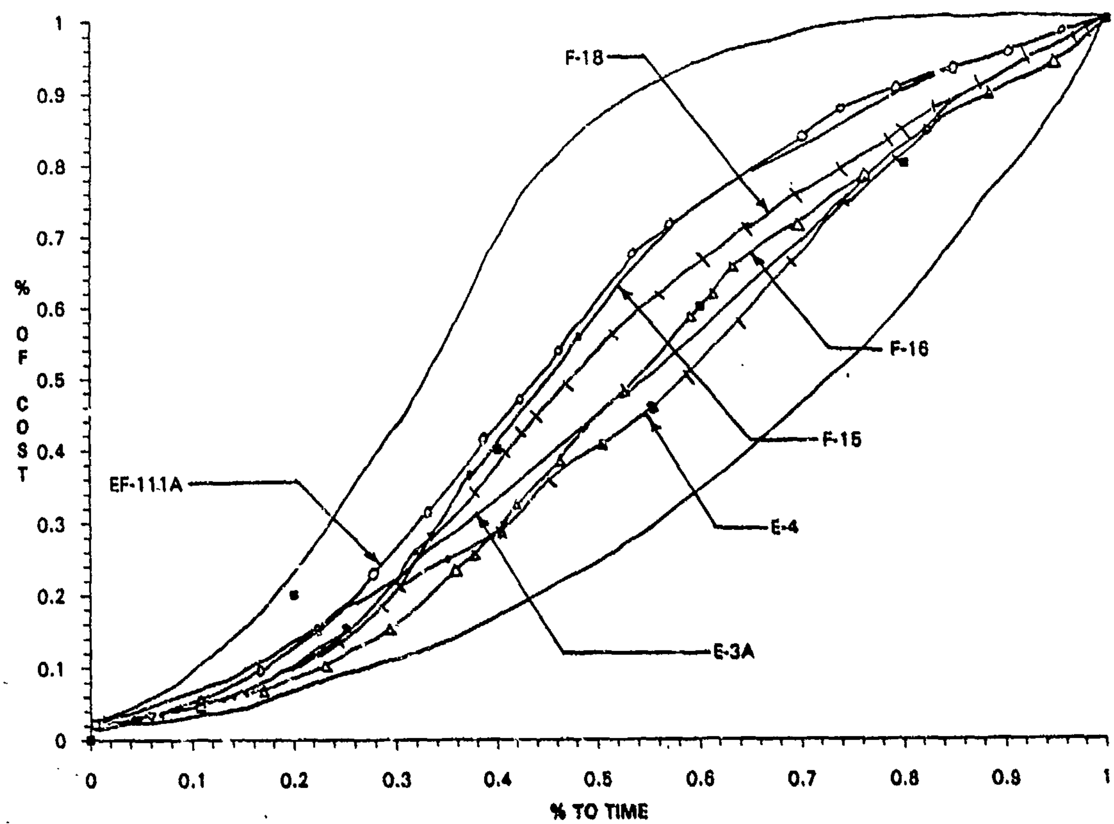

Figure 1. Hand drawn S-Curve developed by Mr. Christle and Mr. Abba.

This technique was very persuasive in the A-12 case and it could be very useful to the project offices in evaluating the progress of their current programs. Yet the technique is currently not widely used by the command level project offices.

Specific Problem

Analysis of defense projects needs to be commonly applied and understood by both the project offices and upper levels of command. If different levels of the defense organization are using different measures of the progress of a project, it is difficult to reach agreement on the overall status of the project. Therefore, it is important that common analysis techniques be employed by both upper levels of the defense organization and the project offices. OUSD(A) has developed and successfully utilized S curves in presenting analysis of aircraft projects to the Office of the Secretary of Defense (OSD). This technique needs to be analyzed and understood by all levels of the defense organization. In order for this tool to be generally used it needs to be developed to the point where it can be easily applied by the project offices. A common database and readily available computer tools would greatly facilitate the use of this technique. Furthermore, the technique needs to be extended to see if it is applicable to defense projects other than aircraft so that it can be broadly applied as a measurement tool across the breadth of defense projects.

Hypothesis

S curves as an analytical tool have been hand-developed and applied to specific projects. The object of this thesis is to construct a database that can readily be used to develop S-curves so that broad categories of projects can be compared and analyzed using S curves. The specific hypothesis to be tested is that S-curves are applicable in the cost analysis of all defense acquisition programs. A defense acquisition program is a directed, funded effort that is designed to provide (the Department of Defense) a new or improved material capability in response to a validated need (16:2).

Investigative questions to be answered are:

1. What research has examined applying S-curve theory to DOD cost estimating?

2. Can the Defense Acquisition Executive Summary (DAES) database be used to produce S curves?

3. How is percentage of time defined and derived?

4. How is percentage of cost defined and derived?

5. Are S curves different for various categories of programs?

6. How can S-curves be used by program managers and analysts?

Scope of the Research Project

This study was confined to the analysis of the S-curve technique in measuring project status. The S-curve technique was applied to the database of over 500 completed contracts available from Defense Acquisition Executive Summary Reports (20). This database was reviewed for its applicability for use in S curve analysis. Only sub-categories of the data that contained sufficient data points to develop an average for the sub-category were developed. Programs considered for inclusion in the analysis were restricted to those with enough history to provide a reasonable S-curve profile. For this study this consisted of contracts that were at least 75% complete and that had data in the database from the 25% completion point. One disadvantage of this selection criterion was that the database only included successful programs. Unsuccessful programs were usually terminated prior to the 75% completion point. This is not perceived as a serious flaw, as the intend of this study was to derive S curves which model successful programs.

The following chapters describe the relevant literature, the methodology of this study, the results of the analysis, conclusions, and recommendations for further research.

II. Literature Review

Cost/Schedule Control Systems Criteria

The Cost/Schedule Control Systems Criteria (C/SCSC) are a set of standards that a contractor's management system must meet in order for the contractor to participate in a major defense program. Basically, C/SCSC ensures that the data provided by contractors in their monthly cost performance reports are accurate. There are thirty-five criteria in the C/SCSC Joint Implementation Guide (4:11-B-2-1). These criteria define the standards a contractor's management system must meet regarding organization, planning and budgeting, accounting, analysis, revision and access to data.
Cost Performance Reports (CPR) are required to be submitted by contractors on all contracts meeting the C/SCSC dollar thresholds as specified in DOD Instruction 5000.2. Cost performance reports provide current and cumulative cost and schedule information for a particular contract. On smaller contracts, C/SCSC compliance is not required and Cost/Schedule Status Reports (C/SSR) are submitted by contractors instead of the CPR. The C/SSR contains the same basic information as a CPR. The main difference between CPR's and C/SSR's is that the contractors submitting the C/SSR's do not have to meet the requirements of a full C/SCSC–compliant management system.

Cost Performance Reports and C/SSR's include five data items that are the cornerstones of CPR analysis. These five data items are: ACWP, BCWP, BCWS, BAC and EAC (4: 11-B-2-1).

Actual Cost of Work Performed (ACWP) is the cost incurred and recorded in accomplishing the work performed within a given time period.

Budgeted Cost of Work Performed (BCWP) is the sum of the budgets for completed work packages and completed portions of open work packages, plus the applicable portion of the budgets for level of effort and apportioned effort.

Budgeted cost of Work Scheduled (BCWS) is the sum of budgets for all work packages, planning packages, etc., scheduled to be accomplished (including in-process work packages), plus the amount of level of effort and apportioned effort scheduled to be accomplished within a given time period.

Budget at Completion (BAC) is the total BCWS for the entire program. It is the "spend plan" for the contract.

Estimate at Completion (EAC) is the contractor's estimate of the total expected costs of a program. EAC is the current ACWP plus the budget of any work that still needs to be completed.

Performance data flow from the contractor to the government program offices via the CPR and C/SSR, which are collectively known as cost management reports. This data are used by the program offices in analysis and reporting to upper management. One such report is the quarterly Defense Acquisition Executive Summary (DAES) report that is submitted by major programs to the Office of the Under Secretary of Defense (Acquisition) where it is compiled into a database of information regarding major weapon systems (20). It is the responsibility of the Under Secretary of Defense (Acquisition) in conjunction with the Comptroller of the Department of Defense to maintain an automated cost data segment of the DAES database. This database is the basis from which the research in this thesis is drawn (20:16-5).

Information from cost management reports has been used in a variety of ways in analyzing the progress of programs. A major use of this data has been along the lines of Estimate at Completion (EAC) analysis. However, it is also the main data used by a handful of researchers who have applied Rayleigh-

Norden theory in the analysis of program growth. The next sections of this chapter will examine theory involving the use of S-curves in the analysis of cost growth in programs.

Rayleigh-Norden Curve Theory

Lord Rayleigh initially developed his theory to explain the biological growth patterns of plants. The growth of plants as a percentage of growth over time resulted in a bell shaped curve. The cumulative representation of this curve was an S-curve which modeled the growth of all plants (23). This pattern of growth was later extrapolated to represent the growth of all systems that followed a pattern of slow initial growth followed by a rapid period of expansion in the middle and a tapering off of growth at maturity. The equation representing this S-curve is as follows:

$$\gamma = 2kat(e^{a(t^2)}) \qquad (1)$$

where

1. γ = growth during each period,
2. k = total cumulative growth of the plant,
3. a = shape parameter (governing time to peak growth),
4. t = elapsed time from start of cycle.

This theory was extended to the analysis of complex projects where there is a pattern of manpower buildup and phase-out by Norden (24). The Rayleigh-Norden Curve theory or the S-Curve was central to the research done by Weida in exploring the uses of the S-Curve as a cost forecasting tool (10).

Weida developed a general model for cost forecasting based on the expenditure pattern analysis of twenty-two current acquisition contracts.

Weida's data all came from CPR reports from major programs. The major problem in modeling S-shaped growth curves is keeping control of the higher order polynomials required to express the complicated S-shape. Weida observed that S-curves are merely derivatives of a variety of bell shaped curves, each of which has an inflection point. This inflection point became the division where Weida broke the S-curve in half and developed a mathematical model for each half of the curve. This allowed Weida to express the S-curve in the form of two relatively simple logarithmic or quadratic equations. The two mathematical models combined represented the entire growth cycle of the project. This type of modeling was applied to fifteen new and completely different test cases with good accuracy, demonstrating that the S-Curves could be used for forecasting the costs of DOD programs.

Watkins also examined the use of S-Curves in estimating project completion costs (13). Watkins used the Rayleigh-Norden model on actual data combined with regression and computer analysis to forecast total contract costs. Current quarterly ACWP and elapsed time were the input parameters to the adopted Rayleigh-Norden model. Watkins converted the Rayleigh-Norden higher order polynomial equation into a linear equation to facilitate regression. Watkins substituted t^2 for $\frac{1}{2}a$, where t^2 was the time of peak ACWP. Both sides of the equation were then divided by t and transformed into logarithmic equations. The resulting equations:

$$\ln\left(\frac{y}{t}\right) = \ln\left(\frac{K}{t^2}\right) + \left(-\frac{1}{2t^2}\right)t^2 \qquad (2)$$

were in the familiar linear form $Y = a + bx$. Watkins used regression on the first 4 quarters of contract data to solve the equation for a and b. These were used to solve for Y which in Watkin's thesis became the next quarter's incremental ACWP. When the next quarter's data became available it was plugged into the equation and the following incremental ACWP was then predicted. Thus a prediction of each subsequent incremental ACWP was derived. These predicted incremental ACWP's were compared to the actuals for accuracy. The result was a less than 1% error between the predicted value and the actual value after 13 quarters of application of this methodology.

The weakness of Watkins methodology is that by the time you got to the accuracy of the 13th quarter the average program was 86% complete. At that point in the program it was to late to do anything about correcting the program if predictions based on Watkin's methodology showed that the program was in trouble. Finally, Watkins, while drawing from a sample of thirty programs in his research, only used three programs in the derivation of his statistics. This is a very limited sample size. However, despite the weaknesses in Watkins methodology, the net result of this research supported the use of Rayleigh-Norden S-curves in the prediction of cost for acquisition programs.

Table 1 summarizes the characteristics of the studies reviewed for this thesis.

Table 1. Relevant Characteristics of Reviewed Literature.

AUTHOR	YEAR	# OF CONTRACTS	CPR OR C/SSR	RESULTS
WEIDA	1977	37	CPR	Supported S-curve analysis
WATKINS	1982	3	C/SSR	Supported S-curve analysis

Another use of the S-Curve in DOD program analysis involved an adoption of Weida's methodology by Mr. Gary Christle, OUSD (A) (14). Mr. Christle plotted the percentage of cost incurred (ACWP/FINAL ACWP) against the percentage of contract completion. Percentage of contract complete was calculated as percentage of time to that point over total time as measured by the final report date. The results were data points that followed an "S" shaped curve. According to this methodology, Mr. Wayne Abba, OUSD (A), states that the EAC can be predicted by comparing percentage spent and the percentage complete of a contract to its expected position on the S-Curve (15). The difference between the contract data point and its expected point on the S-Curve gives an estimate of the expected cost overrun in percentage of BAC. According to this methodology, if the observation of percentage spent for a particular program is significantly different from the S-curve for similar programs, then the contract will not be completed within budget. This methodology was used by OUSD(A) as evidence that the A-12 program was not going to be completed within budget (3:2).

This chapter examined the investigative question number one, "What research has examined applying S-curve theory to DOD cost estimating?" Several research efforts had explored the application of S-curves to DOD cost estimating. Three methodologies were examined in this literature review. It is the methodology of Mr. Christle and Mr. Abba which was pursued in this research.

In the next chapter the methodology used to adapt the DAES database to S-Curve construction for analysis of programs is presented. Subsequent chapters present the results of this research and discuss conclusions drawn from the research.

III. Methodology

Explanation of Method

This chapter describes the steps taken in manipulating the DAES database for the purpose of determining whether S-curves can be constructed which are appropriate for analyzing cost growth on DOD projects. The second investigative question posed in this thesis asked if the database could be used to construct S curves similar to those hand-crafted by OUSD(A) in its analysis of the A-12 program (Refer to Figure 1). The DAES database in its original form did not contain the necessary raw data to construct S-curves. Additional data fields had to be created. In order to accomplish this the database had to be reformatted to allow for mathematical manipulation of the raw data. The preliminary step in explaining the methodology used in this thesis will be a description of the DAES database.

The Database. The database used in this study was the DAES database. This database came from OUSD (A) and contains information covering the period from June 1970 to November 1992. The DAES database is a compilation of quarterly information provided on major defense programs or other programs designated for inclusion by the Under Secretary of Defense for Acquisition. The information in the DAES database comes from a number of sources including the Comptroller of the Department of Defense, OSD Cost Analysis Improvement Group, Service Acquisition Executives and the Program Executive Office. The primary producer of the quarterly reports that feed into the database is the program manager and his project team. The project office draws on the information provided by contractors in cost performance reports (CPR's) or cost/schedule status reports (C/SSR's) to complete the DAES reports.

The initial review of the database itself revealed that the database consists of three separate tables. They are: 1) Dcontract.dbf; 2) Contract.dbf; and 3) Hist_pno.dbf. See Tables 4, 5, and 6 in appendix A. Inspection revealed that the format of many of the fields in the database were in a character format versus a numeric format. This did not lend itself to spreadsheet manipulation or analysis. The appropriate field descriptions were therefore converted to numeric format. The DAES database encompassed a wide variety of information, most of which was not required for the purposes of this thesis. Selection of the fields necessary to calculate S-curves developed by OUSD(A) were identified. In order to calculate percentage of cost or percentage spent, fields for ACWP and TABUDG were required. In order to calculate percentage of time, the field for SUBMITDATE was required. Only contracts that contained records over the period before 25% complete to at least 75% complete were included in this research effort. This requirement stemmed from the need to have contracts that had sufficient data points to create a plot of a complete program. To calculate percentage of contract completion the fields for BCWP and CBBASE were required. Finally, in order to sort the programs by phase, branch of service, type of program and contract type the fields for PPHASE, WSDATE, ECDATE, OTBDATE, CTYPE, CDES, SERVICE, PNASHORT, and PNALONG were required. The use of these fields in this research will be described in the following sections of this chapter.

The DAES database was reduced to those fields required for use in this research. The fields required are identified in Table 2.

Table 2. Required Fields from the Relevant Databases and their Descriptions.

FIELD	DESCRIPTION	DATABASE
PNO	Program Number	DCONTRCT.DBF CONTRACT.DBF HIST_PNO.DBF
CNO	Contract Number	DCONTRCT.DBF CONTRACT.DBF
SUBMITDATE	Date of Report Submission	DCONTRCT.DBF CONTRACT.DBF
PPHASE	Program Phase: Development or Production	DCONTRCT.DBF
WSDATE	Work Start Date	DCONTRCT.DBF
BCWP	Budgeted Cost of Work Performed	DCONTRCT.DBF
ACWP	Actual Cost of Work Performed	DCONTRCT.DBF
CBBASE	Contract Budget Base	DCONTRCT.DBF
TABUDG	Total Allocate Budget	DCONTRCT.DBF
ECDATE	Estimated Completion Date	DCONTRCT.DBF
OTBDATE	Over the Budget Authorization Date	DCONTRCT.DBF
CTYPE	Contract Type: Cost Plus or Fixed Price	CONTRACT.DBF
CDES	Contract Description	CONTRACT.DBF
SERVICE	Branch of Service: A=ARMY, N=NAVY, F=AIR FORCE, K=COAST GUARD	HIST_PNO.DBF
PNASHORT	Short Program Description	HIST_PNO.DBF
PNALONG	Long Program Description	HIST_PNO.DBF

In order to manipulate the database, each record had to be uniquely identified. The identification process required the determination of a suitable primary key. A primary key for a database is used to uniquely identify an individual record within each table, also the primary key should be consistent within each table. The primary key is then used to perform key manipulations of the database such as sorting and joining tables as well as retrieving and deleting specific records. The field that uniquely described each record was defined by:

Primary Key = PNO + CNO + SUBMITDATE.

The Dcontract.dbf contains 59 fields (See Table 4, appendix A). The Dcontract.dbf contained 15895 records on 182 programs covered by 1632 different contracts. A substantial number of these records did not contain sufficient information to make them usable and were deleted. Generally this consisted of records with zero values in the BCWP or ACWP fields. Deleting these records left 146 usable programs and 912 contracts. The Contract.dbf consisted of 14 fields (See Table 5, appendix A). The Hist_pno.dbf contained 7 fields (See Table 6, appendix A). The stripped down DAES database which still consisted of three separate tables was now joined into one table. First Dcontract was joined with Contract, then this combined table was joined with Hist_pno.

Creating New Fields. The database was inserted into an Excel spreadsheet so that the numerical data could be mathematically manipulated. BCWP was modified to create a new field called RBCWP (revised BCWP), described as:

$$RBCWP = BCWP * \left(\frac{CBBASE}{TABUDG} \right) \quad (3)$$

RBCWP was created for the cases where the contract went over target budget (which happened on 12 records). An Over Target Baseline (OTB) is a Performance Measurement Baseline (PMB) resulting from formal reprogramming by the contractor, with customer approval, which establishes budget allocation in excess of the Contract Budget Base (CBB).

A new field, CMPLT, was created to determine a contract's percentage of completion. It is described as:

$$CMPLT = \frac{RBCWP}{(FINAL)\ TABUDG} \quad (3)$$

This field was used to determine which contracts could be used in the development of our graphical analysis. Only those contracts that contained information prior to the 25% completion point and after the 75% complete were desired. In order to effectively model S-curves that represented the life of a program it was necessary to choose data that represented contracts that were nearly complete. Additionally, these contracts had to have records that reflected the complete history of the program. The percentage complete measurement allowed selection of those contracts that provided sufficient data to effectively model the cost growth of the entire contract.

The 25% to 75% completion criterion had some limiting effects on this research. First it reduced the database from 146 programs and 912 contracts to 81 programs and 312 contracts. The 312 contracts still presented a large enough database to examine many different types of programs by category. Secondly, the reduced database eliminated all contracts that were terminated prior to the 75% completion point. Therefore the final database only represented successful programs. This was not considered a liability because this study set out to develop S-curves to compare against current programs. The intent was to develop a signature S-curve for healthy programs and therefore the deletion of failed programs actually aides in the derivation of S-curves that are representative of successful programs.

Initially, the current value of TABUDG was used to determine the percent complete instead of the final value. However, it was determined that all other key calculations were going to be based on final values, therefore we choose to use the final reported TABUDG.

Two other fields were created to assist in the refinement of the database, they were MINCMPLT and MAXCMPLT. These fields allowed for queries designed to extract only those contracts that were within the required limits of percentage complete. They simply consisted of the minimum and maximum values of percentage complete for each contract.

Once the database was refined to include only the contracts of interest (25% to 75% complete), two other fields were created in support of our need to graphically represent the data in a usable format. Specifically, these fields were TIME and COST.

TIME represents the percentage of time for a given point in the history of contract and is plotted on the X axis. It is described as:

$$\text{TIME} = \frac{(\text{Current SUBMITDATE} - \text{First SUBMITDATE})}{(\text{Last SUBMITDATE} - \text{First SUBMITDATE})} \quad (4)$$

The Y axis value (COST) is the percentage of costs associated with a given percentage of time period. It is described as:

$$\text{COST} = \frac{\text{Current ACWP}}{\text{Final TABUDG}} \quad (5)$$

The Final Database. The final database consisted of 41 fields and is described in Table 3.

Table 3. Final Fields Incorporated into the Database and their Descriptions.

FIELD	DESCRIPTION	FIELD	DESCRIPTION
PNO	Program Number	P_0	Percent of Cost at 0% Time
CNO	Contract Number	P_5	Percent of Cost at 5% Time
SUBMITDATE	Accounting Period Cut Off Date	P_10	Percent of Cost at 10% Time
WSDATE	Date Work Started on the Contract	P_15	Percent of Cost at 15% Time
ECDATE	Estimated Completion Date	P_20	Percent of Cost at 20% Time
BCWP	Cumulative Budgeted Cost of Work Performed	P_25	Percent of Cost at 25% Time
RBCWP	Revised Budgeted Cost of Work Performed	P_30	Percent of Cost at 30% Time
ACWP	Cumulative Actual Cost of Work Performed	P_35	Percent of Cost at 35% Time
TABUDG	Sum of All Budgets Allocated to the Contract	P_40	Percent of Cost at 40% Time
MAXTAB	Final Total Allocated Budget	P_45	Percent of Cost at 45% Time
PPHASE	Program Phase: Development or Production	P_50	Percent of Cost at 50% Time
OTBDATE	Over Target Baseline Date	P_55	Percent of Cost at 55% Time
CBBASE	Sum of Negotiated Cost for the Contract	P_60	Percent of Cost at 60% Time
CDES	Contract Description	P_65	Percent of Cost at 65% Time
CTYPE	Contract Type: Cost Plus or Fixed Price	P_70	Percent of Cost at 70% Time
SERVICE	Branch of Service: A=ARMY, N=NAVY, F=AIR FORCE, K=COAST GUARD	P_75	Percent of Cost at 75% Time
PNASHORT	Short Program Description	P_80	Percent of Cost at 80% Time
PNALONG	Long Program Description	P_85	Percent of Cost at 85% Time
CMPLT	Percent of Contract Completion	P_90	Percent of Cost at 90% Time
MINCMPLT	Minimum Percentage of Contract Completion	P_95	Percent of Cost at 95% Time
MAXCMPLT	Maximum Percentage of Contract Completion	P_100	Percent of Cost at 100% Time
TIME	Percent of Time Completion		
COST	Percent of Cost Expended		

The first two fields are the program number (PNO) and contract number (CNO) assigned by OUSD(A) to identify specific programs and contracts contained in the database. The fields: SUBMITDATE, BCWP, RBCWP, ACWP, TABUDG, PPHASE, and CBBASE are all described in the methodology chapter of this thesis. WSDATE is the date the work started on the contract. ECDATE is the expected completion date reported by the program manager. MAXTAB is the largest total allocated budget reported by any of the quarterly reports for a specific contract. OTBDATE is the date the contract exceeded its target budget if this situation occurred. CDES contains a brief description of the contract. This field was used to identify program type. CTYPE identifies the contract type. The SERVICE field identifies the branch of the service managing the program. CMPLT is the percentage of completion of the program for a particular report date. Equation 3 describes how this field was calculated. MINCMPLT and MAXCMPLT represent the lowest and highest percentage of completion reported for each contract. TIME is calculated as in equation 4, and COST is calculated in equation 5. The final 21 fields all contain the normalized percentage of time from 0% to 100% in 5% intervals for each contract.

The final database used in the development of this thesis contained 81 programs composed of 317 contracts. The contracts averaged 15.35 records per contract. Generally these records consisted of quarterly reports. However instances of monthly reports were found. The database is derived from DAES reports which are submitted quarterly as directed by DOD 5000.2-M, Section 16. The average contract length was 46.05 months or 3.84 years. The database was pared down to include only programs that went from reporting prior to or on 25% complete to at least 75% complete. Therefore the length of contract is representative of completed contracts since it excludes contracts terminated early. The longest contract contained 49 records and encompassed 147 months or 12.25 years. The average number of contracts per program was 3.91 contracts. Another descriptive statistic is the number of contracts that went over- the-budget (OTB). These are contracts that exceeded the target budget initially established for the program. Interestingly, only 12 of the 317 contracts contained in the database were OTB. Of these 12, two were Army contracts, and 10 were Navy contracts.

The earliest record in the database was 6/25/70 and the latest record was 3/25/91. The database encompassed over 20 years of data collection.

Tables 7, 8, and 9 in appendix B provide a statistical analysis of the Total Allocated Budget (TABUDG), the Actual Cost of Work Performed (ACWP), and the Estimated Completion Date (ECD).

At this point a substantial portion of the thesis effort was completed. There now existed a database that could be used to develop a series of graphs displaying an S curve growth pattern of percentage of cost versus percentage of time for a particular subsection of the database.

Developing the Graphs. An example of how the database can be used to categorize types of programs is now presented. Contracts that were associated with airframes were selected. There exist in the database 8 contacts for airframes. Specific identification of contracts and or contractors was prohibited OUSD(A). An initial graph was plotted using the raw data from the database (See Figure 2).

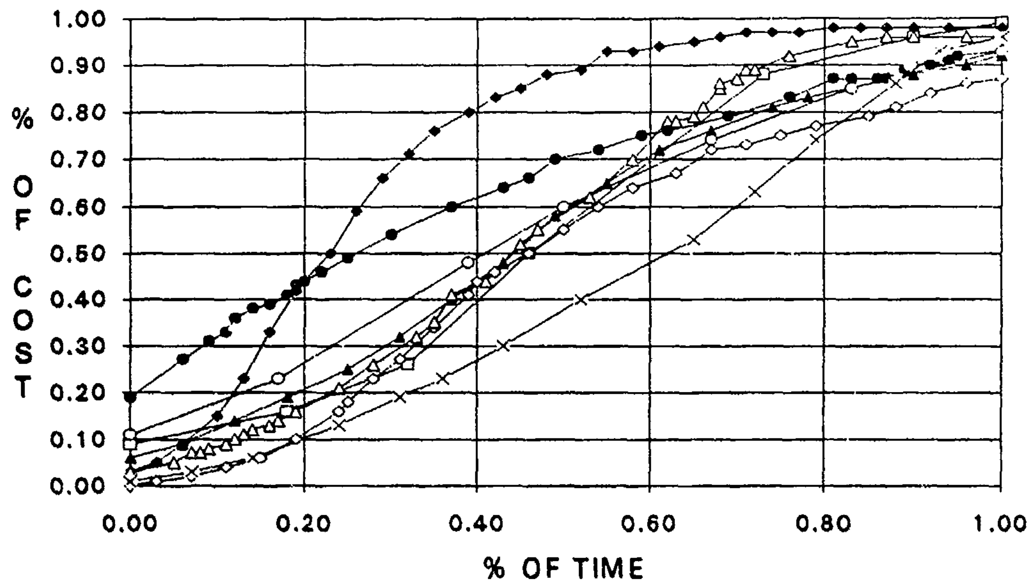

Figure 2. Graph of Airframes using raw data of Time versus Cost.

The results were extremely encouraging because the airframe contracts displayed the S-curve anticipated for DOD acquisition programs. Normalization of the database was required to obtain equal intervals of TIME for all contracts so that a group of contracts could be averaged. The data was normalized to 5% intervals of time. To normalize the data the TREND function in EXCEL for WINDOWS was used. This function is used primarily for linear data. To use the TREND function in this situation it had to be applied to overlapping ranges of data, iteratively. Even this method did not truly automate the process. An extensive portion of the normalization process involved subjective selection of cost percentages around the 5% completion intervals. To the best of our knowledge, there does not exist a function within EXCEL for WINDOWS that will fit data to an S curve.

To validate the normalized data, an identical plot of normalized airframe data was overlaid on the original plot of non-normalized airframe data (See Figure 3). To avoid cluttering the graph, only three contracts were used.

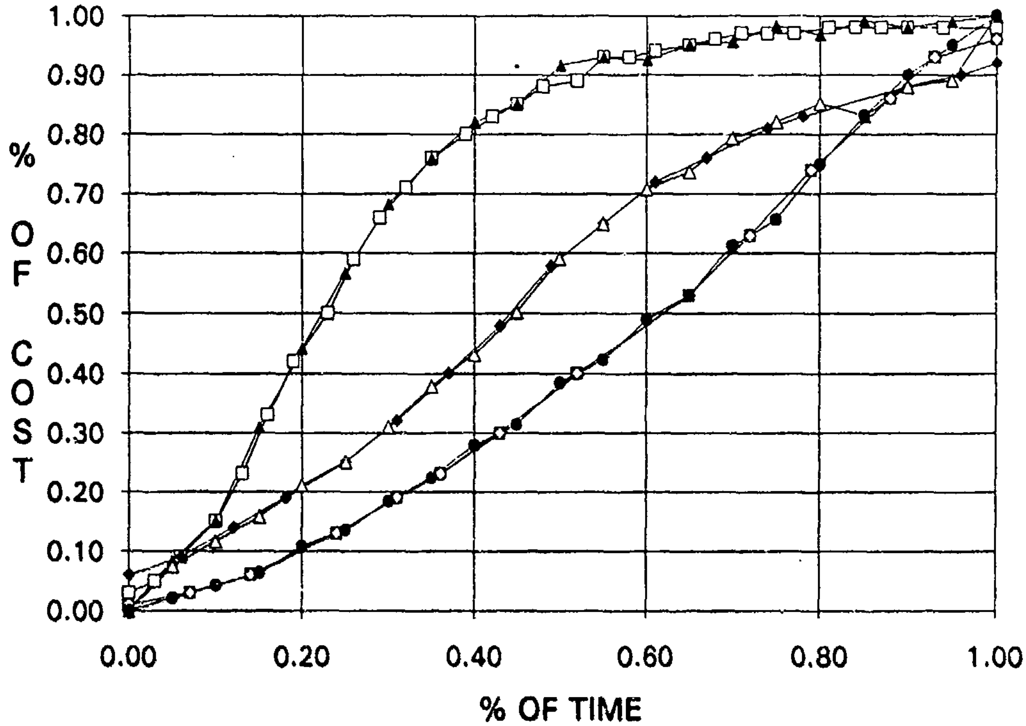

Figure 3. Airframes plotted using normalized versus raw data.

Visual inspection revealed that the normalization process did not materially distort the plot. In instances where there was a large amount of close data points, the normalized plot was almost an exact replica of the original plot. The next step was to develop Figure 4, a plot showing the average and two standard deviations for the airframe data.

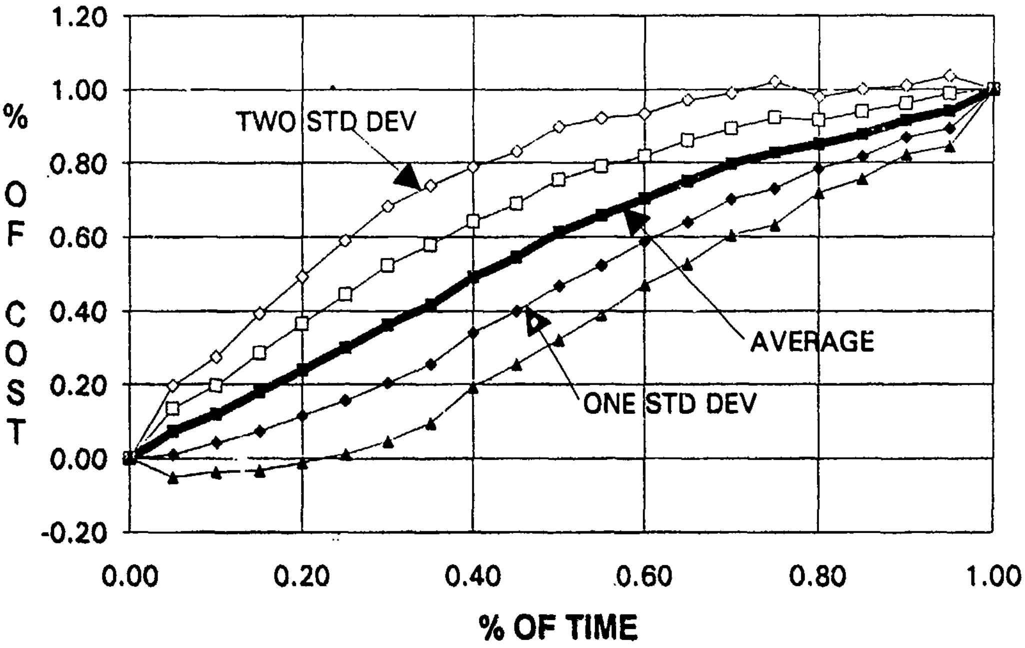

Figure 4. Airframe data averaged plus one and two standard deviations.

Finally, an airframe program was plotted by itself as an overlay against the averaged plot with the standard deviation envelope. Figure 5 is a demonstration of how a program manager could use the composite S-curve as a tool to evaluate the progress of a current program. The program would be plotted against the background of an S-curve constructed from the average of several successful programs similar to the current program. If the current program's path overlaid the S-curve or was within a standard deviation its progress would be verified as normal. If however the programs growth pattern was outside of two standard deviations of the S-curve then the program would need to be examined for causes of the atypical behavior.

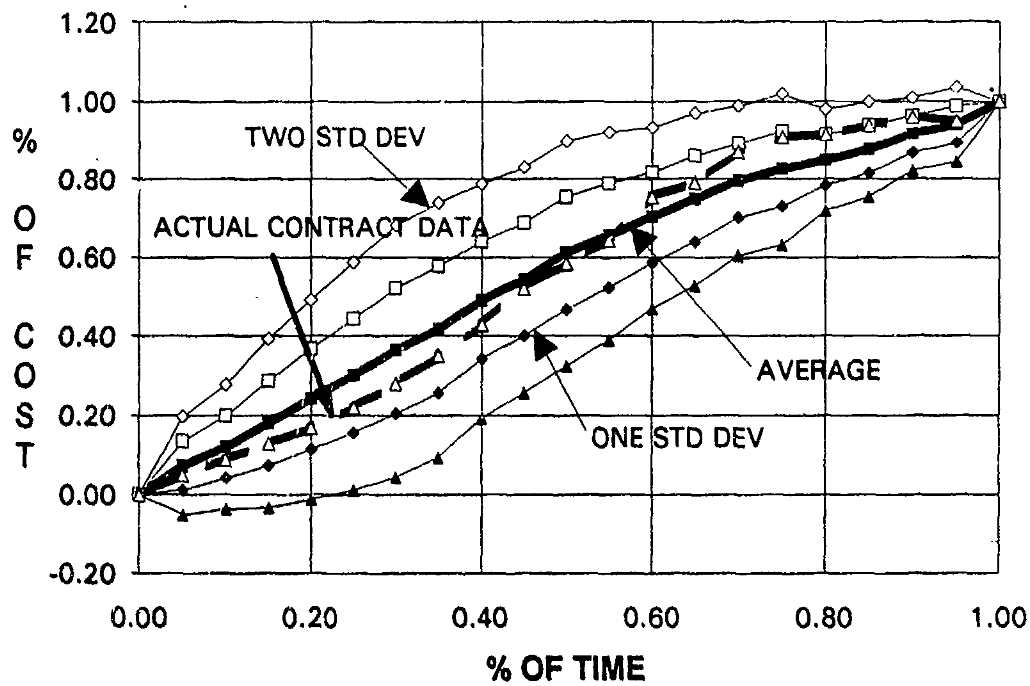

Figure 5. Actual contract data plotted on Airframes-Averaged.

Sub-files were constructed in the database for Army, Navy and Air Force. These sub-files were constructed to make it easy to sort categories of programs or contracts based on the branch of the service. For the same reason sub-files were created for cost contracts, fixed-price contracts, production contracts and development contracts. Additionally sub-files were created for the different types of programs of: airframe and helicopters. These selected sub-files were used to graph categories of programs. The results are presented in Chapter 4.

IV. Results

This chapter presents a detailed description of the final database developed during this research. The database was constructed for the development of S curves for different categories of defense contracts. A sample of the various S curves developed from the database will also be presented in this chapter.

Graphical Results

All Programs. Figure 6 is a plot of the average of the data points for all 81 programs (317 contracts) in the database. The anticipated result was a composite S curve for DOD programs. Instead the plot is very nearly linear in nature. Envelopes one and two standard deviations wide were created around this composite plot of the percentage of cost versus the percentage of time for DOD programs sampled. The envelope takes on more of the shape of an S curve but it is not sharply defined and it is very broad in area. At the 50% of time point a two standard deviation envelope would cover programs from 25% to 85% complete. That is a difference of approximately 60% complete. Such a wide envelope would do very little to delineate between successful and unsuccessful programs.

The linear nature of the plot of the composite DOD programs graph possibly represents a smoothing out of the S curve resulting from the variations in the curves of the different contracts. The net result is that a plot of programs against this composite graph could not be used as intended. A program at the 50% completion point could be as much as 84% spent and still be within two standard deviations of the curve derived from the average of the programs. Therefore a Program Manager in this situation would not be able to tell from a comparison plot if the program was behaving normally or was over spent.

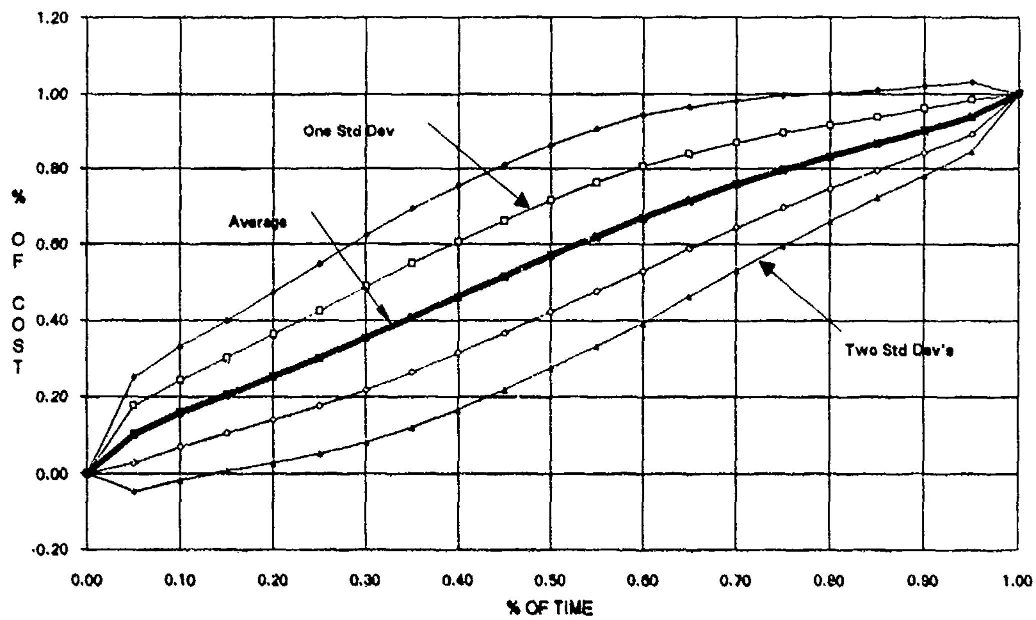

Figure 6. Average graph of all programs.

By Service: Air Force, Army and Navy. Figures 7, 8 and 9 show the averaged and standard deviation data for the Air Force, Army and Navy respectively. All three average plots resembled a linear pattern rather than the anticipated S-curve. Once again this is apparently a result of the smoothing effect that happens when a composite of a number of programs is graphed. Apparently programs the ramp up early tend to balance out programs that ramp up late. The result is the smoothing of the composite S-curve for a category. Another interesting observation is that if the inflection point of the S-curve as addressed by Weida (10) was common to all programs then there would be a narrowing of the envelope at the inflection point. Since this does not occur it is an indication that the inflection points of programs may vary among programs.

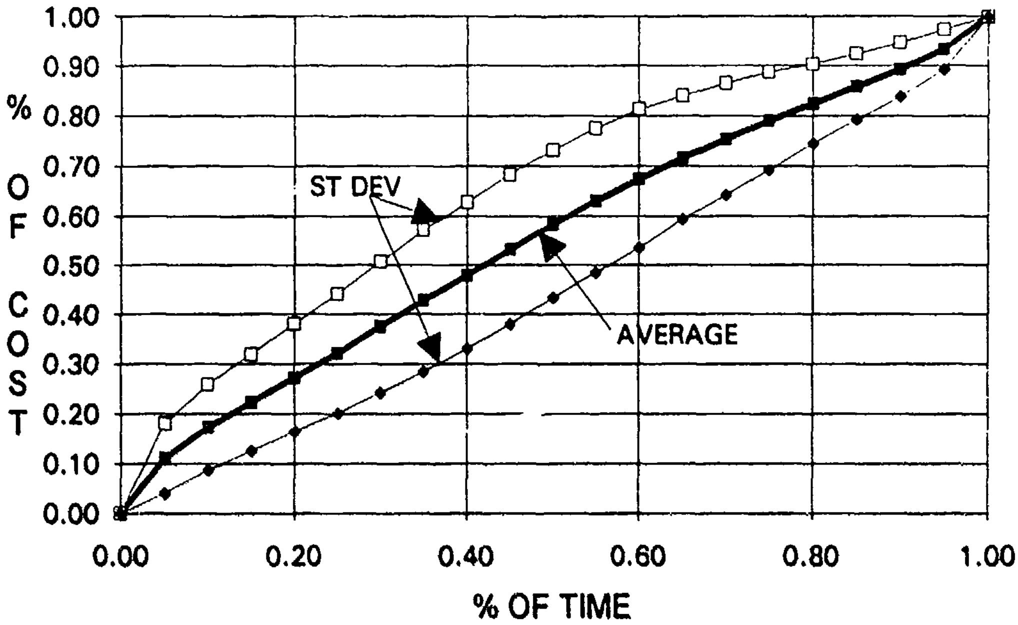

Figure 7. Air Force Contracts.

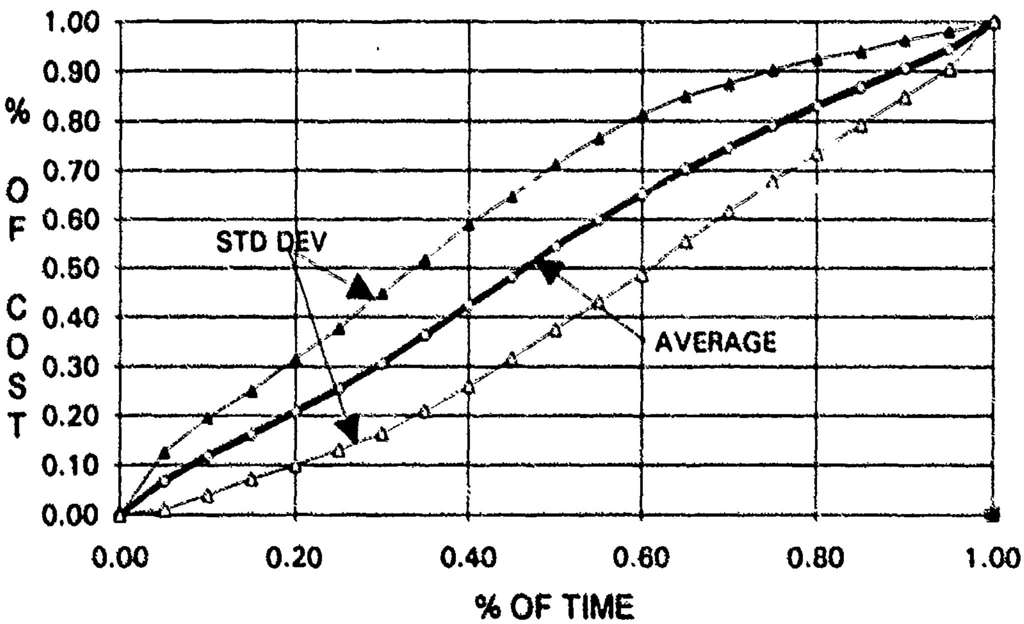

Figure 8. Army Contracts.

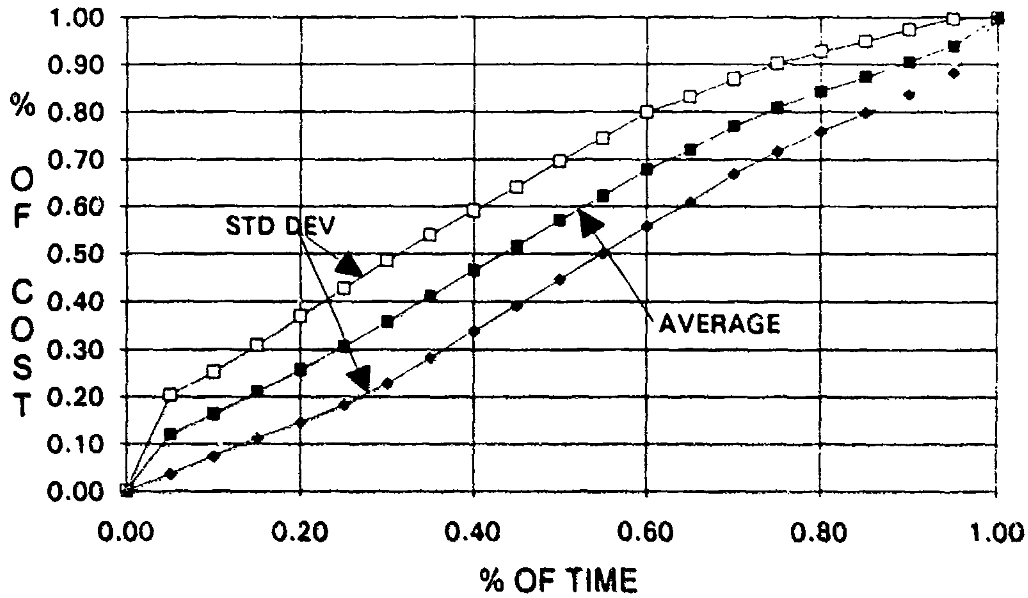

Figure 9. Navy Contracts.

Figure 10 provides a comparison of the services by overlaying the graphs of the service averages. Very little differentiation exists between the services.

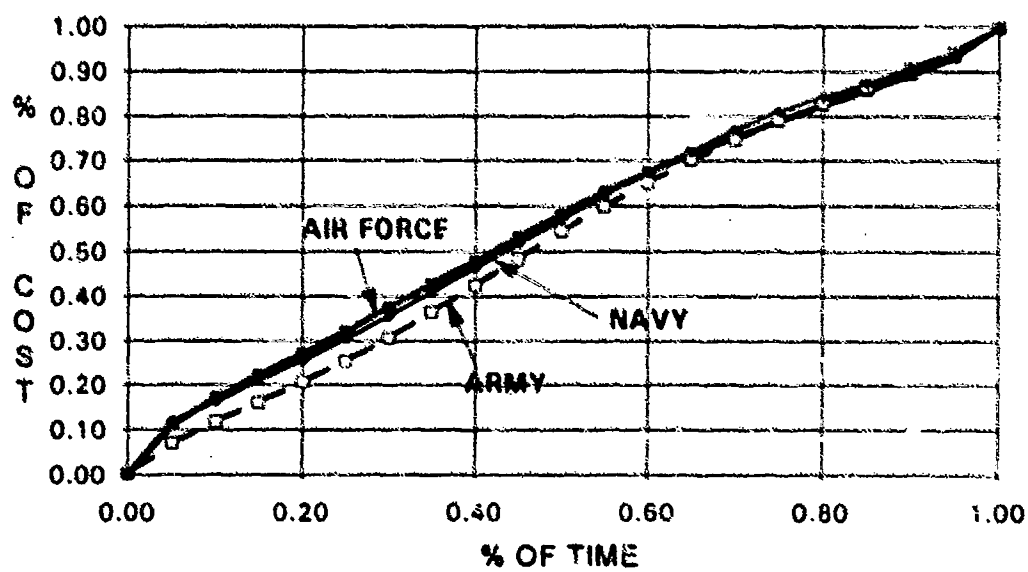

Figure 10. Comparison of Service Averages.

By Contract Type: Cost Plus and Fixed Price. The next categories of programs plotted were sub files that contained cost plus versus fixed price contracts. Figure 11 demonstrates the now familiar smoothed out curve for both types of contracts.

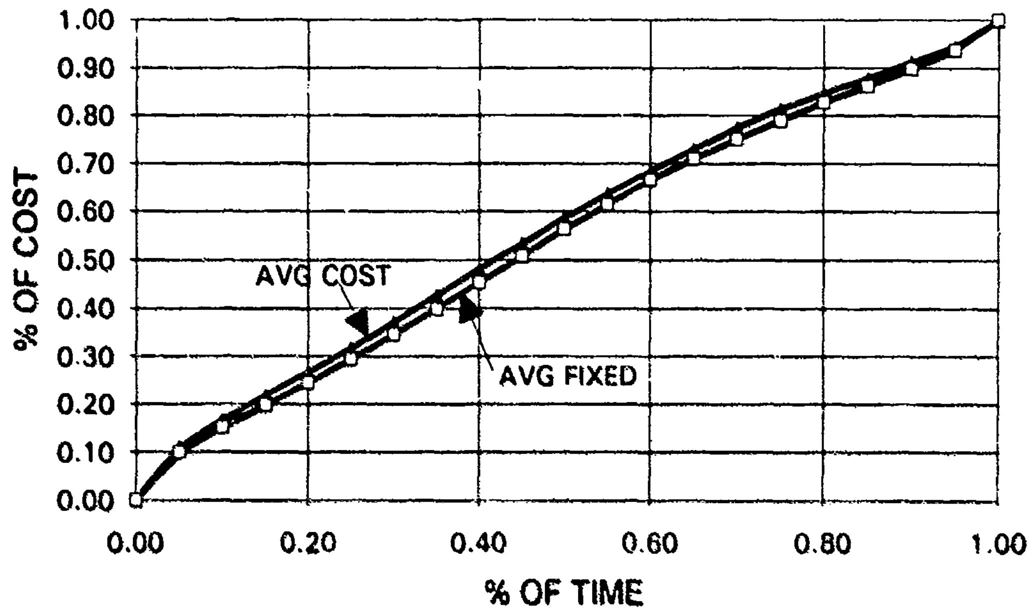

Figure 11. Averages of Cost Plus versus Fixed Price Contracts.

By Program Phase: Development and Production. Another major logical division of programs that was examined was development programs versus production programs. Figure 12 depicts a graph of the average of all development contracts versus a plot of the average of all production contracts. The two plots were overlaid against each other and this plot revealed little differentiation between the program phases. Production contracts displayed more of a weak S shape than did development programs.

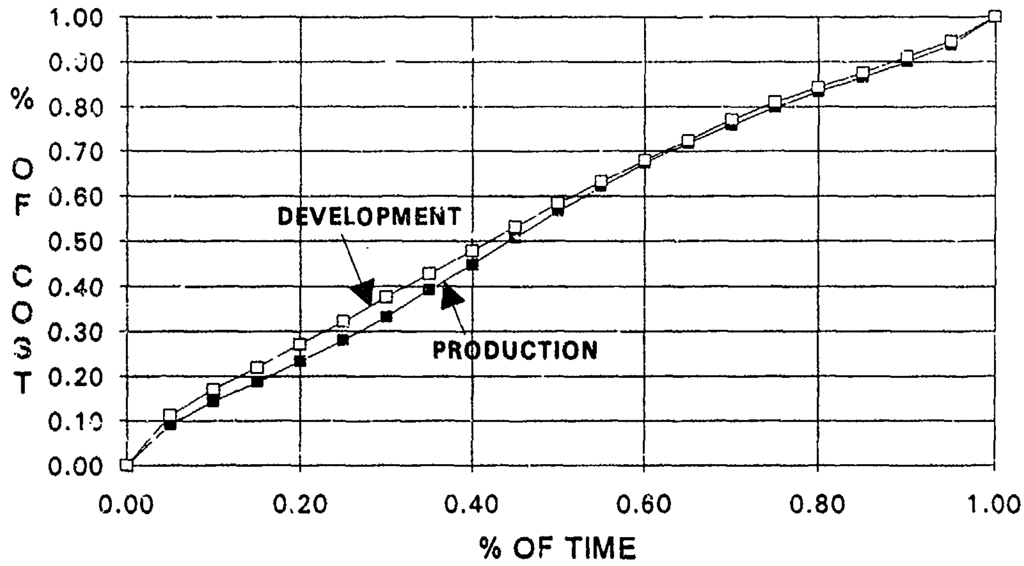

Figure 12. Averages of Production versus Development Contracts.

By Specific Program: Helicopters. S curve anticipated in programs was established in theory by Rayleigh and Norden and demonstrated by Weida and Watkins in their research. Figure 13 is a plot of 10 helicopter programs and shows the anticipated S curve shape for the individual programs.

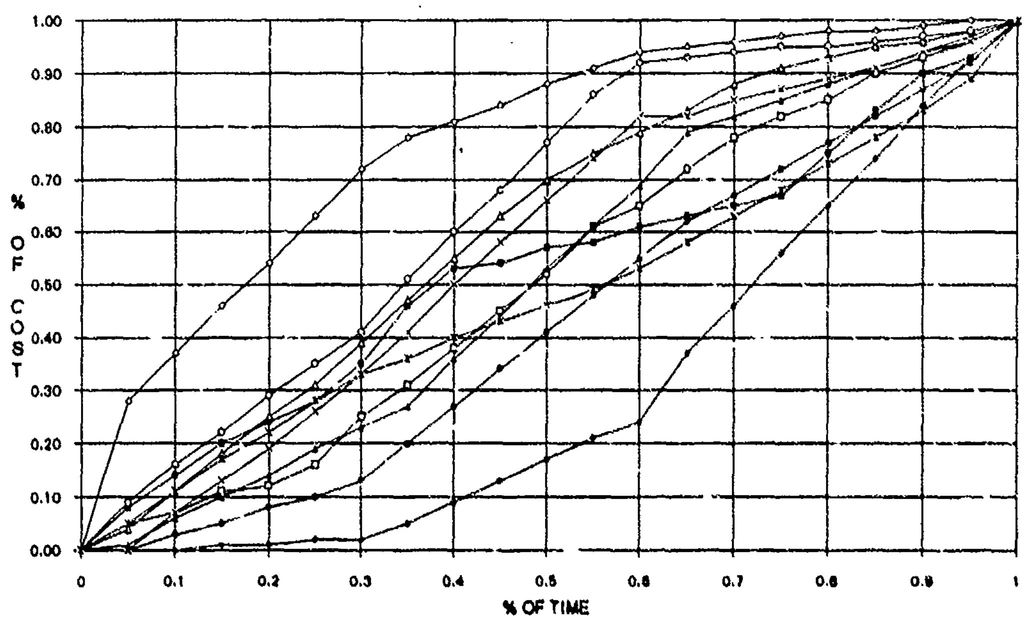

Figure 13. By specific programs using Helicopters.

Figure 14 is a plot of the average for the helicopter programs and shows the smoothed out plot exhibited by the other subdivisions of programs when plotted as an average. In this plot an envelope of one and two standard deviations wide is graphed around the average plot for helicopter programs.

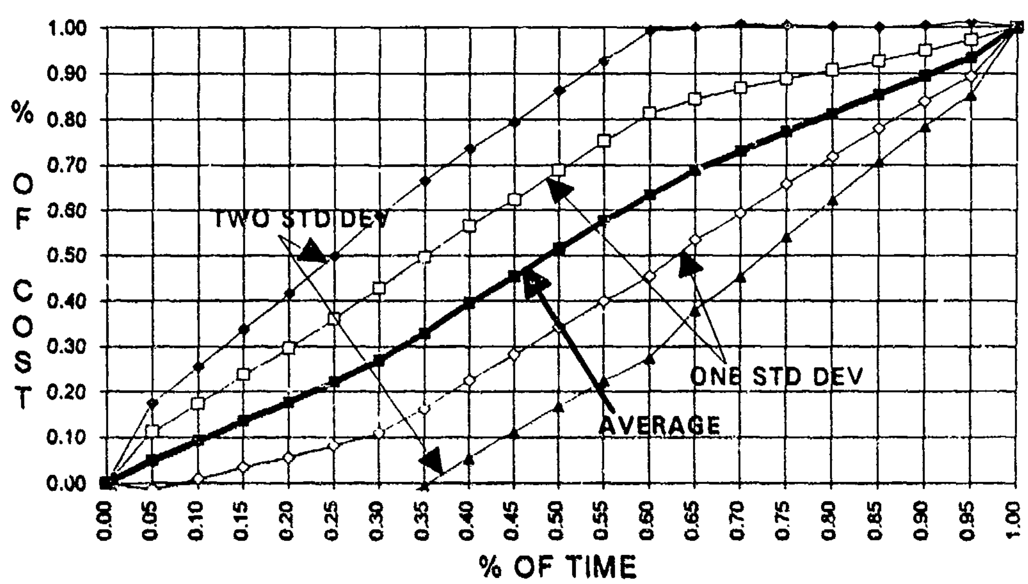

Figure 14. Average and Two Std Dev for Helicopter Contracts.

Next Figure 15 plots a specific helicopter overlaid on the graph and is compared to the helicopter envelope. This particular program appears to lie outside two standard deviations from the average up to 55% of time. Without additional history on this program no explanation of the deviation is attempted here. This graph does indicate that an envelope can be created around a type of program for comparison with a specific program as a result of the development of the database constructed during this research. The smoothing of the S curve due to averaging mitigates the benefits realized from such a comparison because the resulting two standard deviation envelope is so large.

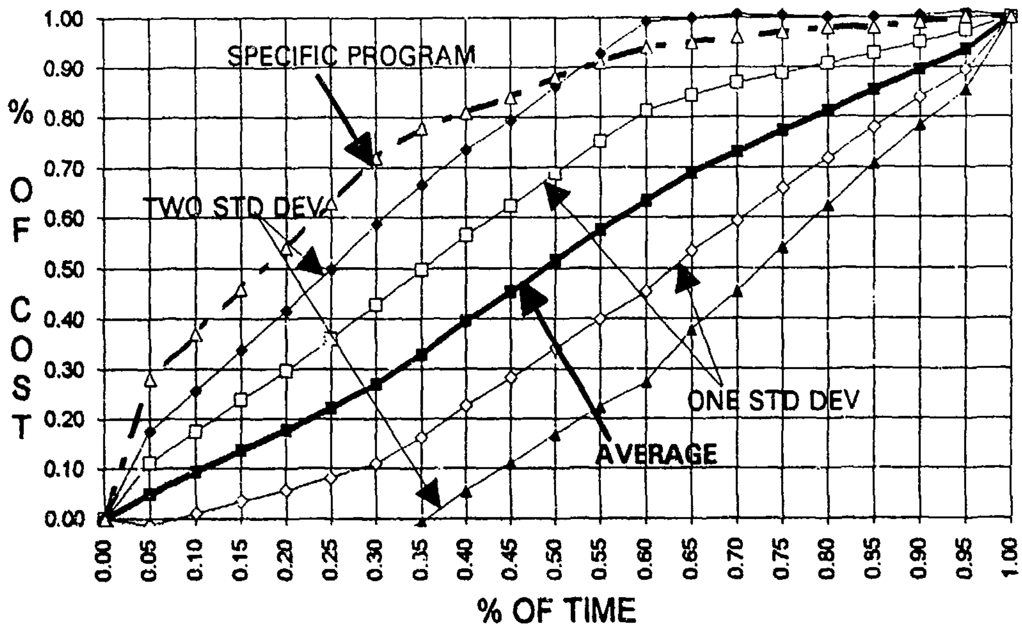

Figure 15. Standard Helicopter Graph with an Overlay

Remarks.. This chapter has presented the results of the research undertaken in this thesis. A database was developed which provided the capability of plotting percentage of cost versus percentage of time readily for a variety of different categories. The resulting graphs demonstrated the ability of the database to accomplish this. The next chapter will summarize these results and describe future avenues of research that could be accomplished by using this database.

V. Conclusion

A Review of the Hypothesis

The research hypothesis examined was a two part hypothesis. The first part was that the DAES database could be used in the creation of S curve plots of programs. This part of the hypothesis needed to be accomplished first because it is necessary in support of the second part of the hypothesis that is that S curves could be used in the analysis of current programs. Six investigative questions were addressed in exploring this thesis.

1. What research has examined applying S-curve theory to DOD cost estimating?
2. Can the Defense Acquisition Executive Summary (DAES) database be used to produce S curves?
3. How is percentage of time defined and derived?
4. How is percentage of cost defined and derived?
5. Are S curves different for various categories of programs?
6. How can S-curves be used by program managers and analysts?

Final Analysis

The literature review explored a study, a thesis and an application of the S-curve technique in the DOD cost estimating environment. Weida's research approached the application of S-curves by dividing the curve at the inflection point and using two separate quadratic equations to model the S-curve. This research confirmed the S-curve pattern hypothesized for DOD programs. Watkins thesis used the computer to calculate S-curve equations for a limited number of programs by simplifying the equations to linear form. Watkins purpose was to show the capability of the computer to accomplish such analysis. While his results were limited in scope and applicability they did demonstrate that DOD acquisition programs display the S-curve pattern and that this pattern can be predicted. Finally, Christle and Abba of OUSD(A) used hand calculated S-curves for airframe contracts to show that the A-12 program did not display the typical S-curve demonstrated by other successful airframe programs. Partially based on this analysis, the A-12 program was canceled. Thus S-curves have been explored theoretically for use in analysis of DOD cost estimates and practical application has been made of the S-curve theory.

This thesis was based on the belief that a database could be used to graph S-curves for various categories of programs. To this end the DAES database was secured from OUSD(A) and explored as a potential source of the type of information required for development of S-curves. After manipulation of the database, S-curves were successfully developed for single programs and categories of programs. The composite curves developed from the averages of several programs all exhibited a near linear form. This smoothing of the S-curve was unanticipated and apparently was the result of the averaging of the individual S-curves.

The third and fourth investigative questions addressed the mechanics of constructing S-curves. They dealt with the derivation of percentage of cost and percentage of time. Percentage of Cost was calculated as current ACWP divided by Final TABUDG (See Equation 5). Percentage of Time was calculated as current SUBMITDATE minus First SUBMITDATE divided by Last SUBMITDATE minus First SUBMITDATE (See Equation 4).

The fifth investigative question asked if different S-curves were produced for different categories of programs. The S-curves produced by averaging categories of programs were nearly linear in form for all categories of programs. The averaging effect of a number of programs apparently resulted in the smoothing out of the curve. As a result the graphs produced for various categories of programs were nearly identical because they were all nearly linear.

Finally, the last investigative question asked how S-curves could be used by program managers and analysts. The original premise of this thesis was that composite S-curves could be developed for categories of programs and program managers and analysts could plot their programs of interests against these plots to see how they compared. However, the resulting composite curves were so linear in nature that the did not provide a good basis for comparison to current programs.

The first part of the hypothesis was accomplished in that a modified database was constructed from the DAES database and it can be used to readily accomplish a variety of ways of examine programs based on comparison of percentage of time versus percentage of cost. The second part of the hypothesis was not accomplished in this thesis. A plot of the average of a number of programs, no matter how divided, presents more of a linear plot than the anticipated S curve that could be meaningfully compared to active programs. This linear appearance results from the averaging of different programs with varying S curve signatures in arriving at a graph of the average of a number of programs. A comparison of this type of linear plot to a specific program is not particularly revealing or valuable.

Recommendations for Further Research

Time did not allow this research to fully examine the potential uses of the database derived from the DAES database. The primary approach used to examine programs was to plot different cuts of the averages of programs by category. These averages did not provide the S curve signature anticipated of a plot of programs percentage of cost versus percentage of time. However, another possible approach to analyzing specific programs would be to plot them against analogous successful programs. A development program could be plotted against other successful development programs, not against an average of these programs. Standard deviation envelopes could be constructed around the individual successful programs to provide an indication of degree of divergence of the program under examination from the baseline program. This avenue of comparison may prove valuable as an analytical tool for program managers.

The primary product resulting from this research is the manipulated DAES database. This database offers many different venues of future exploration. It provides the capability of examining program data from a variety of different aspects, each of which could lead to future research topics.

Appendix A: Original DAES Table Structures

Table 4. Dcontrct.dbf table description.

Field	Field Name	Type	Width
PNO	PROGRAM NUMBER	CHARACTER	3
CNO	CONTRACT NUMBER	CHARACTER	2
SUBMITDATE	SUBMISSION DATE	DATE	8
IDCLASS	UNIQUE IDENTIFIER	CHARACTER	1
CTRDIV	CONTRACTOR DIVISION	CHARACTER	30
PPHASE	PROGRAM PHASE: PRODUCTION OR DEVELOPMENT	CHARACTER	16
CHANGENO	CHANGE ORDER NUMBER	CHARACTER	6
TOTQTY	TOTAL CONTRACT QUANTITY	CHARACTER	7
PLANQTY	PLANNED TO DATE DELIVERY QUANTITY	CHARACTER	7
DELQTY	ACTUAL QUANTITY DELIVERED TO DATE	CHARACTER	7
NEGCST	NEGOTIATED COST	CHARACTER	8
AUWORK	COST OF AUTHORIZED, UNPRICED WORK	CHARACTER	8
TPRICE	TARGET PRICE	CHARACTER	8
CPRICE	CEILING PRICE	CHARACTER	8
WSDATE	DATE WORK STARTED	CHARACTER	6
SECDATE	SIGNIFICANT EFFORT COMPLETION DATE	CHARACTER	6
RPD	REPORT DATE	DATE	8
SDOC	SOURCE DOCUMENT: CPR, C/SSR, OTHER	CHARACTER	7
RTYPE	REVIEW TYPE	CHARACTER	7
RDATE	REVIEW DATE	CHARACTER	6
BCWS	BUDGETED COST OF WORK SCHEDULED	CHARACTER	8
BCWP	BUDGETED COST OF WORK PERFORMED	CHARACTER	8
ACWP	ACTUAL COST OF WORK PERFORMED	CHARACTER	8
MR	MANAGEMENT RESERVE	CHARACTER	8
CBBASE	CONTRACT BUDGET BASE	CHARACTER	8
TABUDG	TOTAL ALLOCATED BUDGET	CHARACTER	8
CTREST	CONTRACTOR ESTIMATED COST	CHARACTER	8
PMEST	PROGRAM MANAGER ESTIMATED COST	CHARACTER	8
ECDATE	ESTIMATED COMPLETION DATE	CHARACTER	6
OTBDATE	OVER THE BUDGET DATE AUTHORIZATION	CHARACTER	6
OTBCVA	OVER THE BUDGET COST VARIANCE	CHARACTER	8
OTBSVA	OVER THE BUDGET SCHEDULE VARIANCE	CHARACTER	8
COMMENTS	PROGRAM MANAGER COMMENTS	MEMO	10
COMCLASS		CHARACTER	1
CRITNM1	CRITICAL MILESTONE 1	CHARACTER	20

Table 4. Dcontrct.dbf table description (continued).

Field	Field Name	Type	Width
CRITNM2	CRITICAL MILESTONE 2	CHARACTER	20
CRITD1	CRITICAL MILESTONE 1 DESCRIPTION	CHARACTER	6
CRITD2	CRITICAL MILESTONE 2 DESCRIPTION	CHARACTER	6
VARCLASS	VARIANCE CLASSIFICATION	CHARACTER	1
CVBASE	COST VARIANCE DATA	CHARACTER	8
CVUCER	COST VARIANCE DATA	CHARACTER	8
CVCUR	COST VARIANCE DATA	CHARACTER	8
CVBASEPER	COST VARIANCE DATA	CHARACTER	7
CVUCERPER	COST VARIANCE DATA	CHARACTER	7
CVCURPER	COST VARIANCE DATA	CHARACTER	7
SVBASE	SCHEDULE VARIANCE DATA	CHARACTER	8
SVUCER	SCHEDULE VARIANCE DATA	CHARACTER	8
SVCUR	SCHEDULE VARIANCE DATA	CHARACTER	8
SVBASEPER	SCHEDULE VARIANCE DATA	CHARACTER	7
SVUCERPER	SCHEDULE VARIANCE DATA	CHARACTER	7
SVCURPER	SCHEDULE VARIANCE DATA	CHARACTER	7
CBDATE	CONTRACT BUDGET BREACH DATE	DATE	8
CBBREACH	CONTRACT BUDGET BREACHED	LOGICAL	1
PMBEST	PROGRAM MANAGERS BEST ESTIMATE	CHARACTER	8
PMWORST	PROGRAM MANAGERS WORST ESTIMATE	CHARACTER	8
BASEDATE		DATE	8
OSDNOTES	OSD NOTES	MEMO	10
OSDCLASS	OSD CLASSIFICATION	CHARACTER	1
CAEST		CHARACTER	8

Table 5. Contract.dbf table description.

Field	Field Name	Type	Width
PNO	PROGRAM NUMBER	CHARACTER	3
CNO	CONTRACT NUMBER	CHARACTER	2
SUBMITDATE	SUBMISSION DATE	DATE	8
CDES	CONTRACT DESCRIPTION	CHARACTER	24
CID	CONTRACT IDENTIFICATION NUMBER	CHARACTER	16
CTYPE	CONTRACT TYPE - FIXED OR COST	CHARACTER	7
CTRNAME	CONTRACTORS' NAME	CHARACTER	25
CTRCITY	CONTRACTORS' CITY	CHARACTER	20
CTRSTATE	CONTRACTORS' STATE	CHARACTER	2
CTRZIP	CONTRACTORS' ZIP CODE	CHARACTER	10
COMPLETE	CONTRACT COMPLETE	LOGICAL	1
DEFINED		DATE	8
MAJOR		LOGICAL	1
RIC		CHARACTER	1

Table 6. Hist_pno.dbf table description.

Field	Field Name	Type	Width
PNO	PROGRAM NUMBER	CHARACTER	3
PNASHORT	SHORT PROGRAM DESCRIPTION	CHARACTER	10
PNA	PROGRAM DESCRIPTION	DATE	20
PNALONG	LONG PROGRAM DESCRIPTION	CHARACTER	70
SERVICE	BRANCH OF SERVICE: F - AIR FORCE, A -ARMY, N - NAVY, K - COAST GUARD	CHARACTER	1
CURRENT		LOGICAL	1
APB_NUMBER		CHARACTER	4

Appendix B: Descriptive Statistics of the database

Table 7. Statistical Analysis of Total Allocated Budget (TABUDG).

TOTAL ALLOCATED BUDGET (TABUDG)	ALL	COST	FIXED	DEV	PROD	AIR FORCE	ARMY	NAVY
Mean	347.47	346.89	348.97	470.38	358.84	428.62	165.90	382.67
Standard Error	49.63	66.11	65.18	105.44	89.46	102.85	21.81	65.95
Median	160.00	173.25	159.30	164.25	179.60	187.80	104.95	163.10
Mode	68.20	16.20	163.30	41.00	629.40	#N/A	63.20	629.40
Standard Deviation	883.64	641.00	971.19	943.11	1073.46	1203.88	192.62	659.52
Variance	780822.56	410875.53	943209.29	889462.53	1152324.08	1449333.89	37102.83	434962.78
Kurtosis	129.42	41.64	124.30	17.26	126.68	83.66	9.13	33.69
Skewness	10.18	5.75	10.31	4.04	10.94	8.61	2.75	5.06
Range	12745.50	5357.90	12745.50	5357.90	12739.80	12741.80	1093.40	5361.60
Minimum	10.50	14.20	10.50	14.20	16.20	14.20	12.90	10.50
Maximum	12756.00	5372.10	12756.00	5372.10	12756.00	12756.00	1106.30	5372.10
Sum	110146.60	32607.30	77472.40	37630.50	51673.60	58721.00	12939.90	38267.00
95% Confidence Level	97.27	129.58	127.75	206.66	175.33	201.59	42.75	129.26

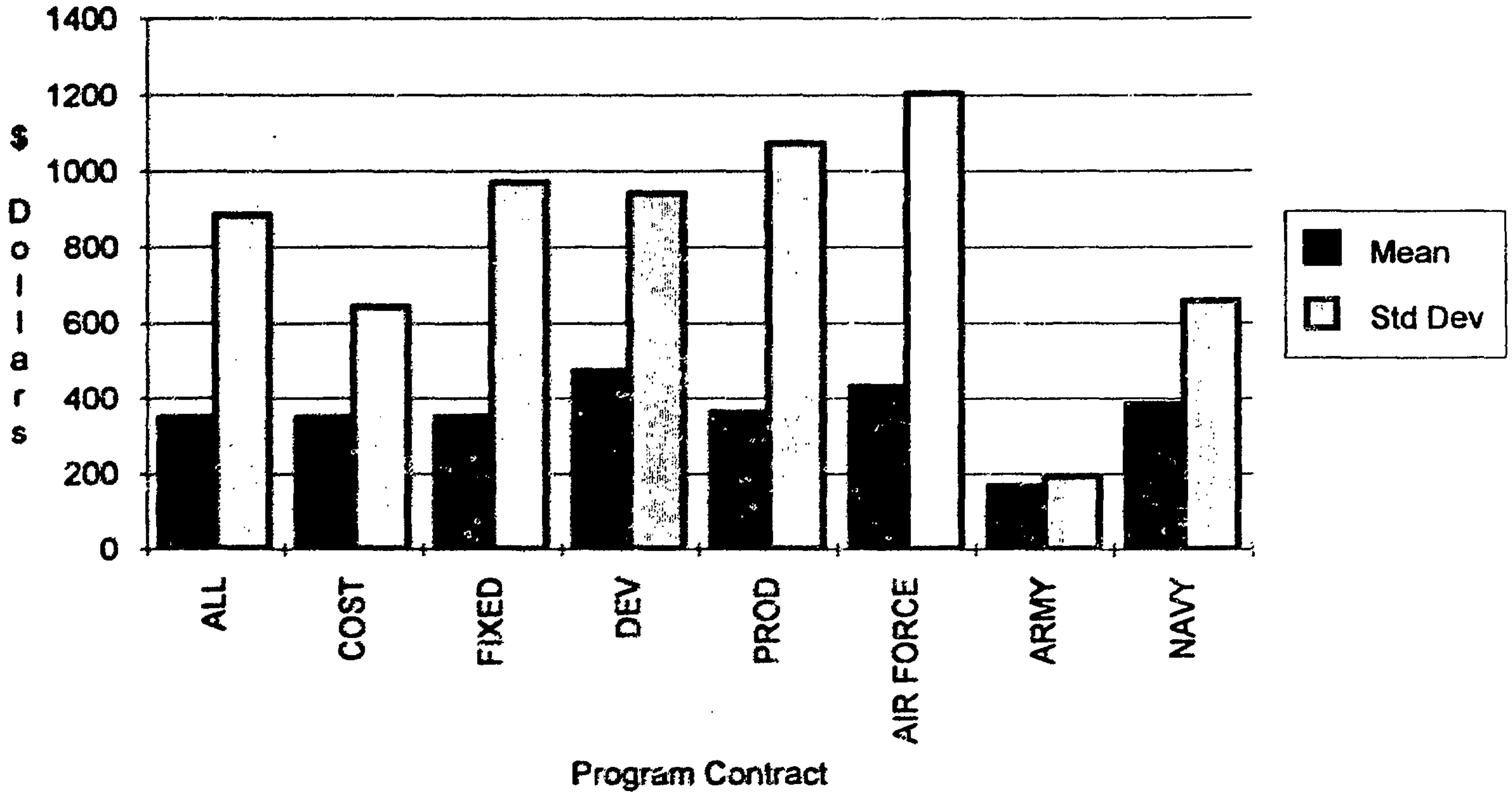

Figure 16. Total Allocated Budget Mean and Standard Deviation.

Table 8. Statistical Analysis of Actual Cost of Work Performed (ACWP).

ACTUAL COST OF WORK PERFORMED (ACWP)	ALL	COST	FIXED	DEV	PROD	AIR FORCE	ARMY	NAVY
Mean	353.27	337.42	361.32	500.89	356.77	437.81	168.65	386.33
Standard Error	52.65	64.73	70.08	126.55	89.20	110.64	20.85	66.03
Median	161.80	164.50	160.85	167.85	162.50	167.40	115.80	168.10
Mode	96.30	14.70	116.20	#N/A	572.90	196.40	#N/A	172.90
Standard Deviation	937.48	627.61	1044.18	1131.90	1070.35	1295.00	184.13	660.32
Variance	878880.97	393890.57	1090321.91	1281203.27	1145642.73	1677030.58	33904.91	436020.61
Kurtosis	106.60	43.11	96.94	20.11	125.40	64.86	9.97	31.45
Skewness	9.36	5.88	9.17	4.40	10.86	7.64	2.72	4.87
Range	12675.20	5284.50	12675.20	6950.50	12670.90	12672.40	1115.70	5287.30
Minimum	11.90	14.70	11.90	14.70	16.20	14.70	11.90	11.90
Maximum	12687.10	5299.20	12687.10	6965.20	12687.10	12687.10	1127.60	5299.20
Sum	111988.00	31717.40	80213.80	40071.00	51374.80	59979.40	13155.00	38633.20
Count (Number of Contracts)	317.00	94.00	222.00	80.00	144.00	137.00	78.00	100.00
Confidence Level (95%)	103.20	126.87	137.36	248.03	174.82	216.85	40.86	129.42

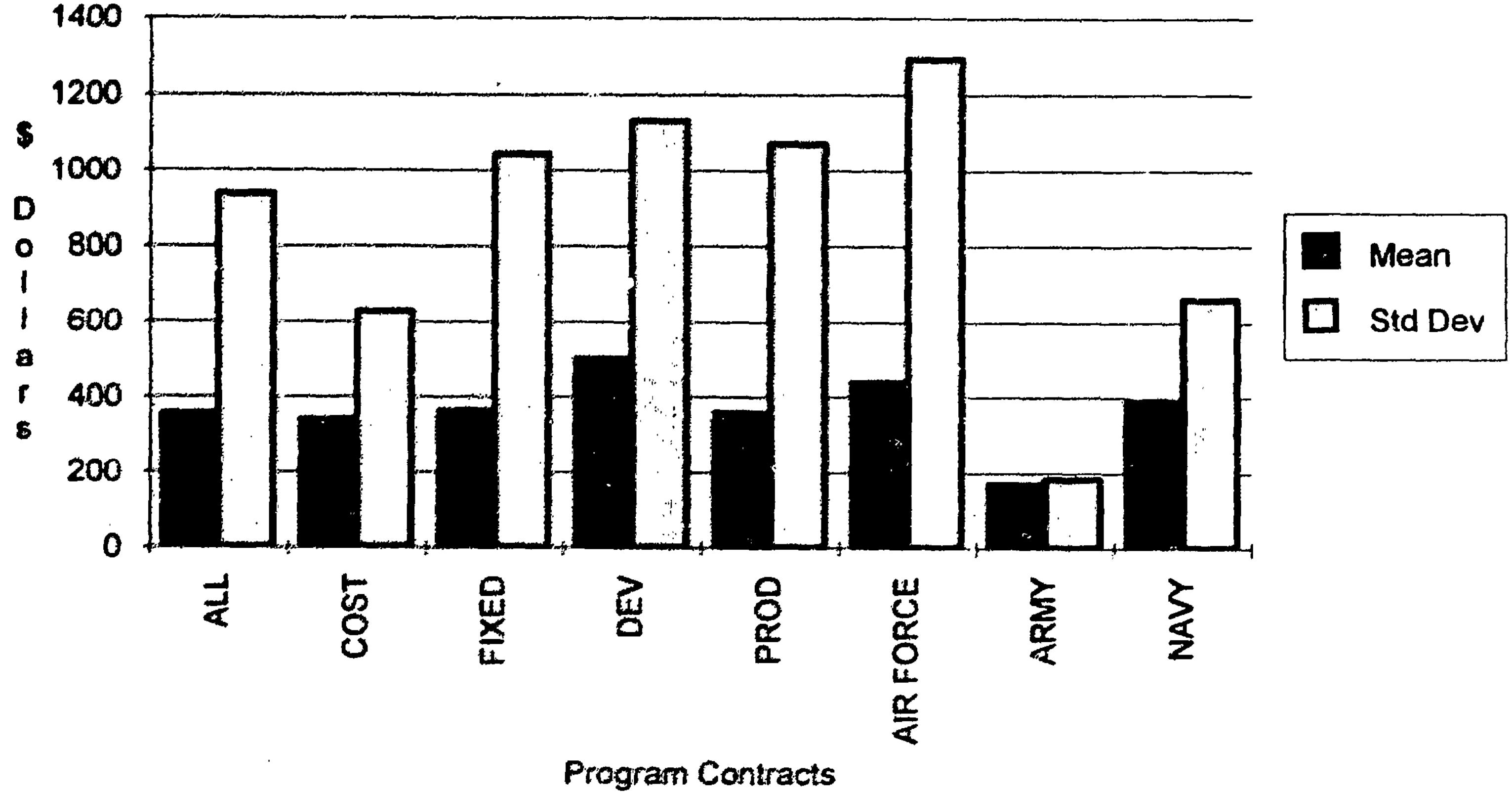

Figure 17. Actual Cost of Work Performed Mean and Standard Deviation.

Table 9. Statistical Analysis of the Slip in the Estimated Completion Date (ECD).

SCHEDULE SLIPPAGE USING THE FINAL ECD DATE	ALL	COST	FIXED	DEV	PROD	AIR FORCE	ARMY	NAVY
Mean	1.09	1.09	1.10	1.16	1.11	1.17	1.29	0.84
Standard Error	0.08	0.15	0.09	0.18	0.12	0.12	0.16	0.13
Median	0.67	0.88	0.67	0.96	0.71	0.75	1.00	0.50
Mode	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Standard Deviation	1.39	1.44	1.37	1.57	1.40	1.45	1.39	1.29
Variance	1.94	2.08	1.89	2.48	1.96	2.11	1.94	1.66
Kurtosis	2.25	3.00	1.94	1.88	2.76	1.76	1.81	3.10
Skewness	1.14	0.47	1.47	0.20	1.69	1.41	1.35	0.41
Range	10.09	10.09	7.42	10.09	7.17	7.42	7.17	8.76
Minimum	-3.75	-3.75	-1.08	-3.75	-0.83	-1.08	-0.83	-3.75
Maximum	6.34	6.34	6.34	6.34	6.34	6.34	6.34	5.01
Sum	346.20	102.01	244.35	92.67	160.25	159.84	100.93	83.84
Count (Number of Contracts)	317.00	94.00	222.00	80.00	144.00	137.00	78.00	100.00
Confidence Level (95%)	0.15	0.29	0.18	0.34	0.23	0.24	0.31	0.25

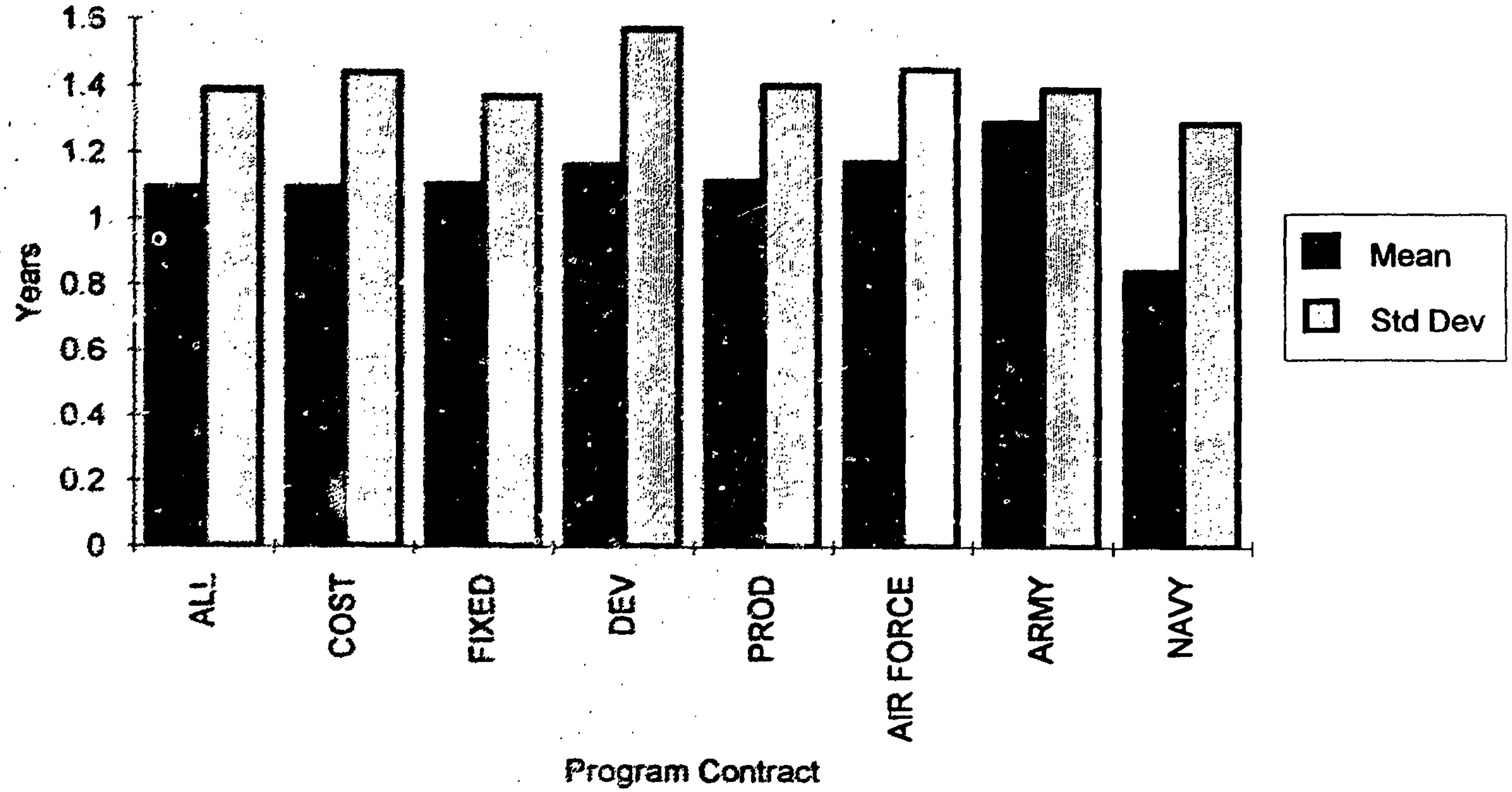

Figure 18. Schedule Slippage Mean and Standard Deviation.

Table 10. Sample of the final database.

PNO	CNO	SUBMITDATE	WSDATE	ECDATE	BCWP	RBCWP	ACWP	MAXTAB	PPHASE	OTBDATE	CBBASE
102	1	10/25/76	JAN 76	AUG 79	12.30	12.30	12.10	880.70		N/A	135.60
102	1	1/25/77	JAN 76	AUG 79	25.00	25.00	24.20			N/A	394.50
102	1	4/25/77	JAN 76	AUG 79	50.60	50.60	49.70			N/A	407.10
102	1	8/25/77	JAN 76	AUG 79	122.20	122.20	106.80			N/A	417.20
102	1	11/25/77	JAN 76	AUG 79	175.30	175.30	163.30			N/A	798.70
102	1	1/25/78	JAN 76	APR 80	207.80	207.80	196.00			N/A	799.20
102	1	4/25/78	JAN 76	APR 80	271.70	271.70	255.00			N/A	799.70
102	1	8/27/78	JAN 76	APR 80	357.00	357.00	339.90			N/A	808.60
102	1	1/29/79	JAN 76	APR 80	488.40	488.40	447.00			N/A	861.30
102	1	4/29/79	JAN 76	APR 80	565.10	565.10	534.90			N/A	868.80
102	1	7/29/79	JAN 76	APR 80	658.10	658.10	627.80			N/A	876.30
102	1	11/25/79	JAN 76	APR 80	756.60	756.60	726.20			N/A	877.20
102	1	1/27/80	JAN 76	MAR 81	797.10	797.10	783.10			N/A	879.10
102	1	4/27/80	JAN 76	MAR 81	825.40	825.40	811.40			N/A	880.70
102	6	11/25/79	APR 79	APR 81	43.90	43.90	43.20	429.20		N/A	379.60
102	6	1/27/80	APR 79	APR 81	67.20	67.20	69.30			N/A	382.70
102	6	4/27/80	APR 79	APR 81	139.00	139.00	146.40			N/A	391.20
102	6	8/24/80	APR 79	APR 81	240.60	240.60	247.20			N/A	397.60
102	6	11/23/80	APR 79	APR 81	306.20	306.20	322.70			N/A	405.40
102	6	1/25/81	APR 79	APR 81	335.30	335.30	356.10			N/A	406.10
102	6	4/26/81	APR 79	MAY 81	366.80	366.80	390.40			N/A	426.90
102	6	8/30/81	APR 79	DEC 82	371.50	371.50	396.10			N/A	429.20
103	4	8/25/77	AUG 77	MAY 79	47.10	47.10	45.80	276.00	PRODUCTION	N/A	225.60
103	4	11/25/77	AUG 77	MAY 79	70.60	70.60	65.80		PRODUCTION	N/A	239.90
103	4	1/25/78	AUG 77	MAY 79	89.60	89.60	85.00		PRODUCTION	N/A	241.80
103	4	5/25/78	AUG 77	MAY 79	133.70	133.70	131.20		PRODUCTION	N/A	246.20

Table 10. Sample of the final database (continued).

TABUDG	CDES	CTYPE	SERVICE	CMPLT	MINCMPLT	MAXCMPLT	TIME	COST
135.60	AIRFRAME(OPTIONS 3-6)	FPI	F	0.01	0.01	0.94	0.00	0.01
394.50	AIRFRAME(OPTIONS 3-6)	FPI	F	0.03	0.01	0.94	0.07	0.03
407.10	AIRFRAME(OPTIONS 3-6)	FPI	F	0.06	0.01	0.94	0.14	0.06
417.20	AIRFRAME(OPTIONS 3-6)	FPI	F	0.14	0.01	0.94	0.24	0.13
798.70	AIRFRAME(OPTIONS 3-6)	FPI	F	0.20	0.01	0.94	0.31	0.19
799.20	AIRFRAME(OPTIONS 3-6)	FPI	F	0.24	0.01	0.94	0.36	0.23
799.70	AIRFRAME(OPTIONS 3-6)	FPI	F	0.31	0.01	0.94	0.43	0.30
808.60	AIRFRAME(OPTIONS 3-6)	FPI	F	0.41	0.01	0.94	0.52	0.40
861.30	AIRFRAME(OPTIONS 3-6)	FPI	F	0.55	0.01	0.94	0.65	0.53
868.80	AIRFRAME(OPTIONS 3-6)	FPI	F	0.64	0.01	0.94	0.72	0.63
876.30	AIRFRAME(OPTIONS 3-6)	FPI	F	0.75	0.01	0.94	0.79	0.74
877.20	AIRFRAME(OPTIONS 3-6)	FPI	F	0.86	0.01	0.94	0.88	0.86
879.10	AIRFRAME(OPTIONS 3-6)	FPI	F	0.91	0.01	0.94	0.93	0.93
880.70	AIRFRAME(OPTIONS 3-6)	FPI	F	0.94	0.01	0.94	1.00	0.96
379.60	OPTION 7	FPI	F	0.10	0.10	0.87	0.00	0.10
382.70	OPTION 7	FPI	F	0.16	0.10	0.87	0.11	0.16
391.20	OPTION 7	FPI	F	0.32	0.10	0.87	0.26	0.33
397.60	OPTION 7	FPI	F	0.56	0.10	0.87	0.47	0.56
405.40	OPTION 7	FPI	F	0.71	0.10	0.87	0.62	0.73
406.10	OPTION 7	FPI	F	0.78	0.10	0.87	0.73	0.80
426.90	OPTION 7	FPI	F	0.85	0.10	0.87	0.89	0.88
429.20	OPTION 7	FPI	F	0.87	0.10	0.87	1.00	0.89
225.60	FY77 PROD	FPI	F	0.17	0.17	0.88	0.00	0.18
239.90	FY77 PROD	FPI	F	0.26	0.17	0.88	0.08	0.25
241.80	FY77 PROD	FPI	F	0.32	0.17	0.88	0.13	0.33
246.20	FY77 PROD	FPI	F	0.48	0.17	0.88	0.23	0.50

Table 10. Sample of the final database (continued).

P_0	P_5	P_10	P_15	P_20	P_25	P_30	P_35	P_40	P_45	P_50	P_55	P_60	P_65	P_70	P_75	P_80	P_85	P_90	P_95	P_100
0.00	0.02	0.04	0.06	0.11	0.14	0.18	0.22	0.28	0.31	0.38	0.42	0.49	0.53	0.61	0.66	0.75	0.83	0.88	0.95	1.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.07	0.15	0.19	0.25	0.32	0.38	0.44	0.48	0.54	0.60	0.66	0.71	0.77	0.77	0.82	0.79	0.84	0.89	0.94	1.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.23	0.28	0.36	0.45	0.51	0.57	0.64	0.70	0.78	0.80	0.84	0.87	0.88	0.89	0.90	0.91	0.93	0.95	0.98	1.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Bibliography

1. Gansler, Jaques S., The Defense Industry, The Massachusetts Institute of Technology Press, Cambridge MA 1981.

2. Fox, Ronald J., The Defense Management Challenge, The Massachusetts Institute of Technology Press, Cambridge MA 1989.

3. Beach, Chester Paul Jr, "A-12 Administrative Inquiry". Report to the Secretary of the Navy. Department of the Navy, Washington DC, 28 November 1990.

4. Department of the Air Force. Cost Schedule Control Systems Criteria Joint Implementation Guide. AFSCP/AFLCP 173-5. Washington: HQ AFSC, 1 October 1987.

5. Fleming, Quentin W. *Cost/Schedule Control Systems Criteria, The Management Guide to C/SCSC.* Chicago: Probus Publishing Company, 1983

6. Christensen, David S., Richard C. Antolini and John W. McKinney. "A Review of Estimate at Completion Research," *1992 SCEA Conference Proceedings*, Vol. 1992, 207–224. New Yorker Springer Verlag, 1992.

7. Schlotzhauer, Sandra D. and Ramon C. Littell. *SAS System for Elementary Statistical Analysis.* Cary NC: SAS Institute Inc., 1987

8. Newbold, Paul. *Statistics for Business and Economics.* Englewood Cliffs NJ: Prentice-Hall, 1991

9. Neter, John, William Wasserman and Michael H. Kutner. *Applied Linear Regression Models.* Homewood IL: IRWIN, 1989

10. Weida, William J. *A General Technique for R&D Cost Forecasting.* Final Report. USAF Academy CO, September 1977 (AD–A046105) (USAFA–TA–77–12)

11. Putnam, Lawrence H. "A General Empirical Solution to the Macro Software Sizing and Estimating Problem." *IEEE Transactions on Software Engineering,* Vol. SE–4, NO. 4. 345–361 (July 1978)

12. Parr, F. N. "An Alternative to the Rayleigh Curve Model for Software Development Effort." *IEEE Transactions on Software Engineering, Vol. SE–6, NO. 3.* 291–296 (May 1980)

13. Watkins, Harry III. *An Application of Rayleigh Curve Theory to Contract Cost Estimation and Control.* MS thesis. Naval Postgraduate School, Monterey CA, March 1982 (AD–A118213)

14. Christle, Gary. Program Analyst. Personal interview. Office of the Undersecretary of Defense (Acquisition), Washington DC., 20 November 1992.

15. Abba, Wayne. Program Analyst. Personal interview. Office of the Undersecretary of Defense (Acquisition), Washington DC., 20 November 1992.

16. Department of Defense. *Major System Acquisition Procedures.* DODI Directive 5000.2. Washington: GPO, 23 Feb 1991

17. Department of the Air Force. *Acquisition Program Management.* AFR 800.2. Washington: HQ USAF, 13 Aug. 1982

18. Secretary of Defense. *Federal Acquisition Regulations.* Washington. 1974

19. Department of Defense. *Work Breakdown Structure.* Military Standard 881–A. Washington: GPO, 25 April 1985.

20. Department of Defense. *Defense Acquisition Executive Summary.* DOD Directive 5000.2–M. Washington: GPO, 23 Feb 1991.

21. Emory, C. William and Donald R. Cooper. *Business Research Methods.* Homewood IL: IRWIN, 1991

22. Browning, Dave. "Relational Databases, New Blood, New Power". *PC Magazine, Vol. 12, Issue 9,* May 11, 1993.

23. Putnam, Lawrence H. "A General Empirical Solution to the Macro Software Sizing an Estimating Problem". *Software Cost Estimating and Life-Cycle Control: Getting the Software Numbers,* pp 138-154, *Computer Software Press,* 1980

24. Norden, P. "Using Tools for Project Management", *Management Production*, M.K. Starr Ed., Baltimore MD: Penguin, 1970

Vita

Captain Richard E. Knepp was born on 12 November 1958 in Hialeah, Florida. He graduated from Bellefonte Area High School in Bellefonte, Pennsylvania in 1976. He enlisted in the Air Force on 14 March 1977 and attended Basic Training at Lackland AFB, San Antonio, Texas. His first operational assignment was with the 6920th Security Service Squadron, Misawa Air Base, Japan. He was a Morse code operator. His next assignment was as an Engineer's Assistant with the 437th Civil Engineering Squadron, Charleston AFB, South Carolina. In 1982 he was selected for the Airmen Education Commissioning Program and attended Pennsylvania State University. In 1985 he received a bachelors' degree in Aerospace Engineering and attended Officer's Training School. His next assignment, from 1985 until 1989, was with the 2nd Satellite Control Squadron, Falcon AFB, Colorado. He served as a Satellite Engineering Officer; Standardization and Evaluation Branch; and Chief of Mission Plans and Scheduling. He then transferred to the 3518th USAF Recruiting Squadron, New Cumberland, Pennsylvania, as the Chief of Resource Management from 1989 until 1992. In June 1992 he entered the School of Systems and Logistics, Air Force Institute of Technology in the Graduate Cost Analysis program.

He is married to the former Georgina Zong of Bellefonte, Pennsylvania. They have 3 children; Carrie, age 16, Matthew, age 10 and Michael, age 7.

Permanent Address: 708 West Lamb Street
Bellefonte, Pennsylvania 16823

Vita

Michael E. Stroble was born July 7, 1946. He graduated from Fairborn High School, Fairborn, Ohio, in June of 1964. He then attended Wright State University and graduated with a Bachelor's of Science Degree in Business Administration in March of 1971. He worked 12 years for Internal Revenue Service in Dayton, Ohio, the last five years as a Revenue Agent. In 1983 he transferred to the Department of the Air Force and worked at Aeronautical Systems Center, Wright Patterson Air Force Base for the Comptroller Division as a Financial Specialist until June 1992. The first 6 years he worked as a budget manager and the last two years as a cost estimator. In June of 1992 he was assigned to the Air Force Institute of Technology for the purposes of obtaining a Master's Degree in Cost Analysis.

Permanent Address: 2863 Crone Road
Beavercreek, Ohio 45434

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
September 1993

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE
DEVELOPMENT OF STANDARDIZED S CURVES FOR THE EVALUATION OF MAJOR DEPARTMENT OF DEFENSE PURCHASES

5. FUNDING NUMBERS

6. AUTHOR(S)
Richard E. Knepp, Captain, USAF
Michael E. Stroble, GS-12, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology
WPAFB OH 45433-6583

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GCA/LAS/93S-7

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Wayne F. Abba, Program Analyst, Performance Management
The Pentagon, Room 3E1025, Washington, D.C. 20301-3000

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The increasing cost of Department of Defense acquisitions combined with the shrinking Defense budget puts a premium on continuing the funding of only those programs that are practical and affordable. This emphasizes a need for good methods of monitoring the progress of programs. Current methods of controlling and evaluating cost performance are limited.

It is our belief that the generation of S-curves using current Cost and Schedule Control Systems Criteria (C/SCSC) data will provide a mathematical and/or graphical approach to assist in the control of program costs. This thesis attempted to plot the percentage of time for a contract's completion against the percentage of actual cost spent during that period. Each contract was separated into a sub-category, averaged and then plotted. This developed a signature curve for categories of contracts.

14. SUBJECT TERMS
S Curves, Rayleigh-Norden, Defense Acquisition Executive Summary, Budgeted Cost of Work Performed

15. NUMBER OF PAGES
65

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited