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NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

A QUANTITATIVE ANALYSIS OF FACTORS AFFECTING WEAPON SYSTEM COST GROWTH

by

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March, 1994

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REPORT DOCUMENTATION PAGE

1a Report Security Classification: UNCLASSIFIED	1b Restrictive Markings
2a Security Classification Authority	3 Distribution/Availability of Report Approved for public release; distribution is unlimited
2b Declassification/Downgrading Schedule	
4 Performing Organization Report Number(s)	5 Monitoring Organization Report Number(s)
6a Name of Performing Organization Naval Postgraduate School — 6b Office Symbol *(if applicable)* 30	7a Name of Monitoring Organization Naval Postgraduate School
6c Address *(city, state, and ZIP code)* Monterey, CA 93943-5000	7b Address *(city, state, and ZIP code)* Monterey, CA 93943-5000
8a Name of Funding/Sponsoring Organization — 6b Office Symbol *(if applicable)*	9 Procurement Instrument Identification Number
Address *(city, state, and ZIP code)*	10 Source of Funding Numbers Program Element No / Project No / Task No / Work Unit Accession No

11 Title *(include security classification)*) A QUANTITATIVE ANALYSIS OF FACTORS AFFECTING WEAPON SYSTEM COST GROWTH

12 Personal Author(s) Pannell, Bobby J.

13a Type of Report	13b Time Covered	14 Date of Report *(year, month, day)*	15 Page Count
Master's Thesis	From To	March 1994	60

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

17 Cosati Codes			18 Subject Terms *(continue on reverse if necessary and identify by block number)*
Field	Group	Subgroup	Cost Growth, Selected Acquisition Report, Cost Variance

19 Abstract *(continue on reverse if necessary and identify by block number)*

This thesis quantitatively analyzes the factors that affect weapon system cost growth after Milestone II. The data from nine weapon systems was reconstructed by the Army and Navy from Selected Acquisition Reports (SARs) with the cost variances reclassified into a new categorization system to more readily determine the causes of cost growth. Each cost variance was classified as to whether it was attributable to a mistake in the cost estimating process or a post-Milestone II decision, with further classification into subcategories for a more detailed analysis. The cost variances were divided by the Milestone II Decision Estimate (DE) to form a cost growth ratio (CGR). The findings reveal that the Department of Defense has about 10.8% cost growth in the procurement process. Cost growth due to decisions outweigh mistakes by a factor of 2.3:1. A majority of the mistake cost growth is due to errors in the estimation of production costs. A majority of the decision cost growth is due to schedule slippage. Low cost systems have 2.4 times as much mistake cost growth as high cost systems. Newer missile systems have significantly less mistake cost growth when compared to other systems. Lastly, the Army and Navy have approximately equal cost growth on their newer systems.

20 Distribution/Availability of Abstract ___ unclassified/unlimited X same as report ___ DTIC users	21 Abstract Security Classification UNCLASSIFIED	
22a Name of Responsible Individual Dan C. Boger	22b Telephone *(include Area Code)* (408) 656-2607	22c Office Symbol AS\BO

DD FORM 1473,84 MAR — 83 APR edition may be used until exhausted — security classification of this page

All other editions are obsolete — Unclassified

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A Quantitative Analysis of Factors Affecting Weapon System Cost Growth

by

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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
March 1994

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ABSTRACT

This thesis quantitatively analyzes the factors that affect weapon system cost growth after Milestone II. The data from nine weapon systems was reconstructed by the Army and Navy from Selected Acquisition Reports (SARs) with the cost variances reclassified into a new categorization system to more readily determine the causes of cost growth. Each cost variance was classified as to whether it was attributable to a mistake in the cost estimating process or a post-Milestone II decision, with further classification into subcategories for a more detailed analysis. The cost variances were divided by the Milestone II Decision Estimate (DE) to form a cost growth ratio (CGR). The findings reveal that the Department of Defense has about 10.8% cost growth in the procurement process. Cost growth due to decisions outweigh mistakes by a factor of 2.3:1. A majority of the mistake cost growth is due to errors in the estimation of production costs. A majority of the decision cost growth is due to schedule slippage. Low cost systems have 2.4 times as much mistake cost growth as high cost systems. Newer missile systems have significantly less mistake cost growth when compared to other systems. Lastly, the Army and Navy have approximately equal cost growth on their newer systems.

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EXECUTIVE SUMMARY

A common perception among the public, in Congress, and even within the defense establishment is that weapon system cost growth results from poor managerial practices combined with an inability to accurately estimate weapons system costs. This oversimplification of a very complex problem is at the forefront of discussion now that reduced budgets, military downsizing, and decreased procurement are realities.

Many cost growth studies occurred in the early 1980s in response to the military buildup which began in 1980. Very little research has been done since then on the new high technology systems. This lack of adequate research combined with tighter military budgets shows a need for new research on the factors affecting cost growth. The objective of this research is not to predict or model particular systems, but to determine those factors that affect the cost growth of the Department of Defense (DoD) as a whole.

In order to more readily identify areas of cost growth, it is necessary to classify the cost variances into a more useable and more detailed categorization system. The new categorization system differentiates between decisions made that would knowingly increase weapon system cost and mistakes that misestimated aspects in the process which, if estimated correctly, would not have resulted in cost growth. The new categories also partition these two broad categories into six subcategories each to give insight into the most likely areas for cost growth to occur.

The data was analyzed to determine if factors such as system cost, service, and type of system affect cost growth. This was done to identify specific areas in the cost estimation and procurement processes that need attention and to determine the probable causes of these differences.

The findings reveal that the Department of Defense has experienced approximately 10.8% cost growth in the procurement process after Milestone II, which is lower than might be expected. Studies done during the early 1980s report that the average total cost growth of weapon systems was between 20% and 30%. However, the time of those studies is relevant to the difference in findings. Three major changes have occurred in the last decade to lower weapon system cost growth. First, estimators have developed a large computerized cost data base to more accurately predict costs. Second, high technology systems, that were brand new in 1980, have been developed and produced so that they are now much easier to estimate. Lastly, the early studies resulted in a determined effort by the Department of Defense to control cost growth.

Mistakes made in the estimation of system costs make up 30.6% of the total cost growth of a system while decisions make up 69.4% of the total cost growth. Therefore decisions outweigh mistakes by a margin of 2.3:1.

A majority of the mistake cost growth is attributable to mistakes in estimating the cost of production. However, mistake cost growth averages only 3.3% and is not nearly as significant as controlling the cost growth due to decisions.

A majority of the decision cost growth is attributable to schedule slippage. Some of this schedule slippage can be attributed to decisions to change the design and performance requirements of the system, while the remaining amount is unexplained. Further study concentrating on the causes of schedule slippage needs to be done.

The low cost systems have a higher mistake cost growth when compared to high cost systems by a margin of 2.4:1. Two possible explanations exist for this effect. First, estimators do not take as much care in estimating the costs of low cost systems since they are not as visible on an oversight level. The second reason concerns the nature of high cost and low cost systems. A majority of high cost systems are large platforms which have a majority of their production cost resulting from large components or similar components that have been used before. This makes the estimation of the production costs of these large components fairly accurate. Therefore, the mistakes in estimating the smaller and relatively cheaper items would be masked in high cost systems by these high cost items. Therefore, the difference between the low cost and high cost system mistake cost growth is probably not as significant as it appears to be.

The significant difference between the cost growth of new missile systems and other weapon systems is that the mistake cost growth for new missile systems is significantly less than that of other systems, specifically in estimating the cost of production. This is due to the evolutionary nature of missile systems. The guidance, propulsion, and warhead systems of newer missiles is generally a modernization or modification of a previous system. This would tend to increase the accuracy of missile system estimates over other weapon systems. Previous studies show that missile systems have a much higher cost growth than do other systems. These studies included much older missile systems. The evolutionary process discussed above had not yet developed and therefore a higher cost growth could have resulted.

The Army and Navy have effectively equal cost growths. A majority of early 1980s studies reported that the Army had a significantly higher cost growth than the Navy. This was attributed to the modernization of the Army. This study concentrated on more recent weapons systems and did not find this to be the case. The most obvious explanation for this effect is that the Army has completed its modernization and is now proficient at controlling the costs of its weapon systems.

These results are promising in that it appears that over the last decade, the DoD has gained control over cost growth. It is still necessary to determine and correct the cause of schedule slippage, but, on the whole, the cost growth problem is being solved.

I. INTRODUCTION

A common perception among the public, in Congress, and even within the defense establishment is that weapons system cost growth results from poor managerial practices combined with an inability to accurately estimate weapons system costs. This oversimplification of a very complex problem is at the forefront of discussion now that reduced budgets, military downsizing, and decreased procurement are realities.

Many studies have shown that most of a weapons system's procurement cost growth occurs after it enters Engineering and Manufacturing Development (EMD) but prior to Full Scale Production [Ref. 1]. This cost growth will be magnified if the United States attempts to maintain its technological edge in the reduced budget environment by developing technology and then "shelving it" until needed. This will result in increased scrutiny by the Congress on cost growth and its control.

Most of the research on cost growth occurred prior to the 1980's military buildup. Some research focused on single system cost growth (e.g., just the F-14 [Ref. 2]). This was done to identify and change managerial and estimating problems within a particular weapons system already identified as having high cost growth. The remaining research used the Selected Acquisition Report (SAR) categories for a basis [Ref 3]. In the SAR, each cost variance is categorized as an estimating, economic, quantity, schedule, support or other change from the Milestone II baseline estimate. Unfortunately, these categories were not uniformly used across different systems to classify cost variances, making any cross-system analysis using these categories of limited validity. Furthermore, the criteria for classifying a cost variance into one of these SAR categories changed in the mid-1980's and as a result, comparisons across this time are not valid. Therefore, none of the relatively new high technology systems can be analyzed using a time series approach.

As a result of this lack of adequate data on current technology combined with tighter military budgets, new research on the factors affecting cost growth is required. It will be necessary to form new categorization criteria for cost variances in order to break the cost variances into a more useful structure. The objective of this research is not to predict or model particular systems, but to determine those factors that affect the cost growth of the Department of Defense as a whole. The quantitative analysis of this data is designed to yield descriptive information on those areas in the procurement process where cost growth is occurring. This information can be used by Program Managers and cost estimators to evaluate their cost methodology and refine their cost estimating techniques. This should ultimately yield lower procurement cost growth.

II. BACKGROUND

A. REVIEW OF THE ACQUISITION PROCESS

The purpose of this chapter is to provide a brief review of the weapons system acquisition process prior to a discussion of research methodology used and why data from specific points in the acquisition process was used.

The acquisition process is broken down into five phases with the transition between phases being marked by a milestone. Decision authorities determine at each milestone whether the results of the previous phase warrant continuation into the next acquisition phase. Department of Defense Instruction 5000.2 (current version dated February 1991) describes the process and discusses the objectives of each phase and milestone in the acquisition process. Systems within the acquisition process do not necessarily follow this exact process However, each system must ultimately gain approval at each milestone in this process.

1. Mission Need

Initially, a determination of mission need is decided upon, by various sources, based upon continuing assessments of the military requirements and capabilities.

2. Milestone 0, Concept Studies Approval

Decision authorities determine if a study of alternatives is warranted and determine the alternatives to be evaluated. If approval is granted, the system proceeds into Phase 0.

3. Phase 0, Concept Exploration and Definition

Various alternatives are evaluated. The most promising systems satisfying the mission requirements are evaluated to determine high risk areas and initial objectives for program cost, schedule, and performance.

4. **Milestone I, Concept Demonstration Approval**

Decision authorities determine if a new acquisition program is needed based on the results of Phase 0. A baseline for program cost, schedule, and performance is established. Approval at Milestone I authorizes the program to move into Phase I.

5. **Phase I, Demonstration and Validation**

Critical design and performance characteristics are thoroughly evaluated. Schedule, cost, and performance objectives are refined.

6. **Milestone II, Development Approval**

If the results of Phase I warrant continuation, a Developmental Baseline for cost, schedule and performance for the program is approved. This includes the Developmental Estimate (DE) which defines the objective total system cost. This estimate is the refined total cost from Milestone I. Milestone II approval authorizes program continuation into Phase II.

7. **Phase II, Engineering and Manufacturing Development**

The system enters full scale engineering development. A cost effective, producible design is developed to validate the production process. Tests are conducted to verify that system performance satisfies performance requirements.

8. **Milestone III, Production Approval**

A production baseline for cost, schedule and performance using the revised data from Phase II is established. The system now proceeds into Phase III.

9. **Phase III, Production and Deployment/Phase IV, Operations and Support**

An efficient production capability along with its associated support base is established to achieve operational capability satisfying the mission need. Once initial systems are fielded, system monitoring, support and problem correction continue throughout system lifetime.

10. **Milestone IV, Major Modification Approval**

Decision authorities determine if a major modification or change to the system is warranted and if so, how to implement this change in the most effective manner.

B. SELECTED ACQUISITION REPORT (SAR)

The data used is derived from the Selected Acquisition Report (SAR). Comprehensive instructions for the SAR are contained in Department of Defense Manual 5000.2M. The SAR is a comprehensive report designed to provide Defense Department officials with cost and management information on each major weapons system. The SARs are submitted to the Congress to allow the Armed Services Committees to monitor the Department's progress in meeting its procurement plans, and to provide an early warning of emerging cost problems.

The SARs are compilations of status reports from the Program Managers responsible for major defense acquisition programs. They provide each Program Manager's latest estimates of progress in achieving key goals with respect to performance, schedule and cost. The most recent estimates are recorded in then year dollars and in constant base year dollars, with the base year generally being the Milestone II year.

SARs are required by Department of Defense Manual 5000.2M to be submitted for programs that have been designated by the Secretary of Defense as major systems or are estimated to cost more than $200 million for research, development, test, and evaluation or more than $1 billion for procurement. Highly classified programs are excluded from this requirement. SARs are prepared on an exception basis for the first, second, and third quarter of each year, with a comprehensive report for the fourth quarter ending December 31. The cost data in the December SARs are expected to correspond to data in the President's annual budget submitted to the Congress in January.

1. SAR Categories

The SAR reports the Program Manager's most recent best cost estimate. The initial estimate listed in the SAR is the baseline estimate or developmental estimate (DE). The DE is generally made at Milestone II in the acquisition process. The SAR records all changes in terms of deviation from the previous cost estimate. These changes are defined as cost variances. The sum of all the cost variances and the DE is defined as the Current Estimate (CE).

Each cost variance listed in the SAR is categorized according to the cause of change. These categories are explicitly defined in Department of Defense Manual 5000.2M.

a. *Quantity Change*

A cost variance is classified as a quantity change if it is due to a change in the number of units of an end item of equipment.

b. *Schedule Change*

A cost variance is classified as a schedule change if it is due to a change in procurement or delivery schedule, completion date, or intermediate milestone for development or production.

c. *Engineering Change*

A cost variance is classified as an engineering change if it is due to an alteration in the physical or function characteristics of a system or item delivered, to be delivered, or under development, after establishment of such characteristics.

d. *Economic Change*

A cost variance is classified as an economic change if it is due to price level changes in the economy.

e. *Estimating Change*

A cost variance is classified as an estimating change if it is for correction of an error, refinement of a prior Current Estimate, or a change in program or cost estimating assumptions and techniques.

f. Support Change

A cost variance is classified as a support change if it is due to a change in cost, regardless of reason, associated with any work breakdown structure element not included in the flyaway, rollaway, or sailaway cost.

g. Other Change

A cost variance is classified in the other change category if it cannot be classified into one of the above categories.

III. ISSUES PERTAINING TO THE DATA

A. PROCUREMENT COSTS

Weapon system costs are broken down into two major cost categories, Research, Development, Testing and Evaluation (RDT&E) costs and procurement costs. This study will focus on only the procurement cost growth of major weapons systems. RDT&E cost growth is difficult to quantify because of constantly changing requirements and modifications in the initial design of the system. These changes, which occur prior to Milestone II, could greatly affect the RDT&E cost growth.

Also, the major focus of this research is to identify managerial and cost estimation problems within the Department of Defense after a system enters EMD. Analysis of RDT&E cost growth would be more beneficial in defining areas that need attention within the initial stages of concept exploration and definition.

B. NEW CATEGORICAL DEFINITIONS

The criteria for classifying cost variances into the SAR categories has changed over the years. This makes any cross system analysis of limited validity. Also, the SAR categories do not allow for easy identification of the root causes behind cost growth of a particular weapon system [Ref. 4]. For example, a cost variance in the support category does not show whether the cost variance was due to a decision to change the support requirements or if a mistake was made in initial estimate of the support costs. Therefore, the cost variances need to be reclassified into a new categorization format before any analysis of the reasons for cost growth can be done.

The new categorization system used is under development by the Department of Defense (DoD). The new categories used to classify cost variances must differentiate between decisions that are made that would knowingly increase weapon system cost (i.e., increased range or performance) and mistakes that underestimated or overestimated aspects in the process which, if estimated correctly, would not have resulted in cost growth. The new categories must also partition these broad categories into smaller subcategories to give insight into the most likely areas for cost growth to occur.

The new categories consist of two major categories defined as to whether the cost variance was due to a decision or a mistake. The cost variance is further classified into one of six subcategories according to the specific area that is related.

1. Decision Variance

A decision variance is a cost variance due to a decision external to a program's defined Milestone II baseline. Examples include changes in system capability and acquisition strategy changes (such as dual source procurement, multiyear procurement, etc.) not dictated by fact of life conditions. Decision variances are subcategorized by the type of change. These subcategories are:

a. Dcrv

A cost variance is classified in the Dcrv category if it results from a decision that changes the system requirements or results in a new variant of the system.

b. Dsmmi

A cost variance is classified in the Dsmmi category if it results from a decision that causes changes to the procurement schedule, shifts in the multiyear procurement rate or in different management initiatives.

c. Dils

A cost variance is classified in the Dils category if it results from a decision to change the Integrated Logistical Support (ILS) factors or changes in spares or support requirements.

d. Depf

A cost variance is classified in the Depf category if it results from changes to the external program factors (foreign military sales (FMS), labor strikes, etc).

e. Descl

A cost variance is classified in the Descl category if it results from a decision to change the escalation (inflationary) requirements.

f. Dother

This category is designed to account for minor or unforeseen decision variances that cannot be categorized into one of the above categories.

2. Mistake Variance

A mistake variance is a cost variance not attributable to post-Milestone II decisions. Examples include method errors, omissions, schedule slips attributable to technical problems, weight growth, and inadequately scoped engineering and software development efforts. An important point is that this category is considerably broader than estimating error: "mistakes" include many factors that are manifestly not considered to be related to "cost estimating" (e.g., weight growth). This category is intended to capture all the variance that the acquisition system as a whole should have anticipated, not just the cost estimator. Mistake variances are subcategorized by the type of change.

a. Mcep

A cost variance is classified in the Mcep category if it is due to a mistake in estimating the production costs of the system.

b. Mcede

A cost variance is classified in the Mcede category if it is due to a mistake in estimating the developmental and engineering costs of the system.

c. *Mils*

A cost variance is classified in the Mils category if it is due to a mistake in estimating ILS factors, spares or support requirements.

d. *Mssmf*

A cost variance is classified in the Mssmf category if it is due to schedule slips and or changes in the management factors that are not attributable to a decision.

e. *Mescl*

A cost variance is classified in the Mescl category if it is caused by a mistake in estimating the escalation requirements.

f. *Mother*

This category is designed to account for minor or unforeseen mistake variances that cannot be categorized into one of the above categories.

This new classification system will allow for a more detailed evaluation of the factors affecting cost growth. It will indicate the specific areas in which cost growth is occurring and where measures to control cost growth should be focused.

C. USING SAR DATA

Each service was tasked by the DoD to reconstruct the data into the new categories using historical SAR data.

1. Advantages of SAR Data

A majority of major weapons systems are required to have a SAR filed on them. This allows for a comprehensive analysis of cost growth within the Department of Defense. Most SARs are unclassified and are publicly available. This allows wide dissemination of data and results. This allows objective research outside the government establishment to review the progress on the control of cost growth. Failure to analyze classified systems should not significantly impact the results of a cost growth study since there are a limited number of these systems. Furthermore, subsequent analyses by the Office of the Secretary of Defense of all weapons systems when they become available, including classified systems, will alleviate this concern.

Each cost variance must be reported on the SAR along with the cause of the variance. This allows for a full accounting by the services of these variances. A minimal amount of cross referencing will be required by the services to obtain the root cause of the cost variance which is needed to accurately analyze cost growth [Ref 4].

These advantages make the use of SAR data a necessity once it is appropriately modified by the services into a more useful categorization of the variances.

2. Disadvantages of SAR Data

Since the old SAR categories were not consistently applied, obtaining the data in a consistent categorization will require the cooperation of the services to reclassify the data into the new categories. Each service will also need to reconstruct the actual cause of each variance. Service cooperation is available, although it will take two years to obtain all weapons systems covered by SAR reporting requirements.

The categorization of the cost variances is a judgment call. The decisions by individual services may generate associated errors that cannot be objectively described.

These disadvantages, while important, do not constitute a large problem. The errors imparted into the data should not be of a sufficiently large magnitude to nullify the findings. The additional time to categorize the cost variances should be offset by the time saved in using the SARs as described above.

D. MILESTONE II BASELINE

This baseline cost estimate is considered valid in the Department of Defense since this is where the Developmental Estimate (DE) originates. Prior to this point, numerous alternatives combined with unproven concepts would tend to introduce gross margins of error into any estimate.

A major problem when analyzing weapons system cost growth is that the DE baseline can change. The baseline is allowed to change if major modifications or changes to the weapon system are performed. This could suppress the actual cost growth of the system if the cost variances are compared to the new baseline. The reconstruction of the data into the new format by the services maintains the Milestone II baseline as its initial estimate and reports all cost variances from this point. This should allow for a focus on all forms of cost growth in the weapons system.

E. ESCALATION ADJUSTMENT

The data used is in constant base year dollars. The base year for analysis of cost growth of those systems that are beyond Milestone II is generally chosen as the year the project enters EMD. Using constant base year dollars is necessary when measuring program management effects since this allows for consistent comparisons to the base estimate [Ref 5]. If then year (budgetary) dollars were used, any analysis that combines the cost variances across time could not be performed since this would result in attempting to combine different year dollars which cannot be done. Therefore, for this analysis, constant base year dollars are required.

F. QUANTITY ADJUSTMENT

Quantity changes, whether a change in the total quantity procured or a change in the procurement rate, will greatly affect the total cost growth of a system. Milestone II cost estimates were based on the Milestone II quantity. Any subsequent change in quantity could not have been foreseen at Milestone II. Therefore, an adjustment to the cost variances needs to be made to account for these changes in quantity. This is defined as quantity normalization.

1. Quantity Related Cost Equation

Before developing the quantity normalization equation, it is necessary to understand the composition of the current estimate (CE) and how it relates to the Milestone II decision estimate (DE).

Two types of costs exist in the DE. One type is cost not related to quantity. These are costs that do not change with changes in the quantity to be procured or changes in the procurement rate. Examples of these costs include initial design engineering and tooling. The total nonquantity-related cost at the DE is defined as N.

The other type of cost in the DE is quantity related. The sum of the quantity-related costs at Milestone II is defined as R. These change with changes in quantity or changes in the procurement rate. Examples of these costs include material and labor. The total quantity-related cost at Milestone II is formed by the product of the Milestone II unit cost (U) times the Milestone II quantity to be procured (Q). By evaluating the reasons given in the SAR for each of the cost variances, any cost variance listed in the SAR can be classified as bei g either quantity related or not. Therefore, the Milestone II DE is written as:

$$\begin{aligned} DE &= N + R \\ &= N + UQ \end{aligned}$$

The total change in the nonquantity related costs from the decision estimate to the current estimate (ΔN) can be calculated by summing all of the cost variances that are not quantity related.

The total change in the quantity related costs from the decision estimate to the current estimate (ΔR) can be calculated by summing all of the cost variances that are quantity related.

The current estimate (CE) can be determined from the DE and the cost variances by:

$$CE = DE + \Delta N + \Delta R$$

A quantity related cost variance can be caused by a change in the quantity to be procured (ΔQ), a change in the unit cost of the item (ΔU), or both. Therefore, CE can be rewritten as:

$$CE = DE + \Delta N + \Delta R$$
$$= N + \Delta N + R + \Delta R$$
$$= N + \Delta N + (U + \Delta U)(Q + \Delta Q)$$
$$= N + \Delta N + UQ + Q\Delta U + U\Delta Q + \Delta U\Delta Q$$

By further analyzing the reasons for the cost variances listed in the SAR, those cost variances resulting from a change in quantity with no change in unit cost can be identified. The sum of these cost variances is defined as $U\Delta Q$. The remaining quantity related cost variances are due to changes in quantity with a corresponding change in unit cost or are due to a change in unit cost with no change in the quantity. The sum of these cost variances is defined as $\Delta U(Q + \Delta Q)$. Therefore, CE can be rewritten as:

$$CE = N + \Delta N + UQ + Q\Delta U + U\Delta Q + \Delta U\Delta Q$$
$$= (N + \Delta N) + UQ + \Delta U(Q + \Delta Q) + U\Delta Q$$

Define ΔP as the difference between the current estimate and the decision estimate:

$$\Delta P = CE - DE$$
$$= (N + \Delta N) + UQ + \Delta U(Q + \Delta Q) + U\Delta Q \quad - (N + UQ)$$
$$= \Delta N + \Delta U(Q + \Delta Q) + \Delta U\Delta Q$$

with ΔN, $\Delta U(Q + \Delta Q)$, and $U\Delta Q$ each being a determinable quantity.

2. Quantity Normalization Equation

The quantity normalization equation used in this research is currently under development by the Office of the Secretary of Defense.

The preferred method of quantity normalization varies widely [Refs. 4, 5]. Two types of effects due to quantity must be addressed. The first is that the final quantity is changed with no change in the procurement rate. This study deals with the total costs of the system based on the quantity determined at Milestone II and therefore requires that this type of quantity change not result in a cost variance. The second type of quantity effect is a change in the procurement rate with no change in the final quantity. Since contractors face both fixed and variable costs, a change in the procurement rate such as a schedule slippage will result in a higher unit cost since additional fixed costs will be incurred. This type of cost variance must be fully accounted for.

The data collected is classified as to whether or not it was quantity related. No adjustment for quantity is required if it is not quantity related. The quantity adjustment to the cost variance must be made to the base-year adjusted cost variance to remove any inflationary effects.

ΔP is not quantity normalized since a change in the quantity (ΔQ) with no change in the procurement rate (i.e., $\Delta U = 0$) will result in a change in ΔP.

The required form for a quantity normalized procurement cost C must remove any effect for a change in quantity without a change in procurement rate since this form of cost variance could not have been foreseen by the Milestone II estimators. However, C must fully account for procurement rate changes since these are attributable to decisions or mistakes that should have been foreseen at Milestone II. Therefore the proper form for C is:

$$C = (N + \Delta N) + (U + \Delta U)Q$$

This satisfies the requirements listed above, namely that changes in quantity with no change in procurement cost are ignored but that changes in procurement rate which affect the unit cost are completely accounted for.

The quantity normalized cost variance ΔC is the quantity normalized CE (C) minus the DE. This yields:

$$\Delta C = C - DE$$

$$= (N + \Delta N) + (U + \Delta U)Q - (N + UQ)$$

$$= \Delta N + Q\Delta U$$

The equation for determining ΔC can be obtained as follows:

$$\Delta C = \Delta N + Q\Delta U$$

$$= \Delta N + Q\Delta U(Q + \Delta Q)/(Q + \Delta Q)$$

The terms Q and ΔQ can be taken directly from the SAR. The remaining terms, ΔN and $\Delta U(Q + \Delta Q)$ can be determined by the method listed previously when determining ΔP. Therefore, ΔC is the quantity normalized procurement cost variance in base year dollars. ΔC will be used in the analysis as the quantity normalized cost variance to determine the cost growth of the weapon system.

IV. DATA

Data from nine weapon systems are currently available. In several years, data for all systems reported under the SAR guidelines will be collected and all of the data will be analyzed by the Office of the Secretary of Defense.

Only nine systems were chosen due to the limited time available for data collection for this study. The Department of Defense selected the first nine systems so that they reflect a representative sample of the systems in each service. They include ships, missiles and electronic systems. No aircraft systems were available, and it should be noted that the results of this analysis should not be applied to any analysis of aircraft systems. There are approximately equal numbers of Army and Navy systems. No Air Force systems were available.

The systems are at different times in their procurement lifetime and have a wide range of total costs to reflect the actual nature of the overall procurement process within the Department of Defense.

Four of the systems were reported by the Army. They were the ATACM missile, the MLRS rocket system, the SINCGARS electronic system and the MSE electronic system. The remaining five systems were reported by the Navy. These are the CH\MH-53 helicopter, the Trident II submarine, the DDG-51 surface ship, the HARM missile and the SM-2 missile.

The data for each weapon system was constructed from existing SAR data by the respective service. The data consists of all cost variances reported in constant base year dollars from the SAR since Milestone II along with the SAR categorization, the new categorization, and whether or not the cost variance is quantity related. The reported data also included the Milestone II RDT&E and procurement costs as well as any amplifying remarks necessary to further explain any cost variances.

A. COST GROWTH RATIO

The cost growth ratio (CGR) is defined as the ratio of the quantity and escalation adjusted cost variances and the Milestone II total system costs including RDT&E costs:

$$CGR = \Delta C/DE.$$

The total system cost is used so that the CGR represents the change in the total cost of the system as opposed to a percentage change in the procurement cost of the system. All cost variances for each system were converted to CGRs. The CGR is used in nearly all research on cost growth to show the magnitude of the change compared to the original estimate. For instance, a fifty million dollar change in a system that cost two hundred million dollars is much more significant than a fifty million dollar change in a ten billion dollar system since the first constitutes a relatively large change in the accuracy of the original estimate (CGR = 0.25), while the latter is well within any reasonable expectations for margin of estimating error (CGR = 0.005).

For each system, the CGRs associated with a particular category, using both the SAR and the new categorization systems, were aggregated to form the cost growth for a system classified by category. The CGRs that are associated with the mistake categories were aggregated to form the mistake cost growth and in a similar manner the decision categories were combined to form the decision cost growth.

The sum of the decision and mistake cost growths form the total cost growth of a system since Milestone II.

B. DOLLAR WEIGHTED AVERAGE

When systems are combined into sets for analysis of the effects of common factors, the dollar weighted average is used as the mean value instead of the arithmetic mean. This is done to account for the greater impact that cost growth of more expensive weapon systems has on budgetary considerations. The objective of this research is to determine what factors are causing cost growth within the entire Department of Defense rather than on a particular system. This type of analysis should aid in determining the impact of cost growth on the military's procurement budget. A strictly arithmetic average is not appropriate in a budgetary context since the effect of less expensive systems would skew the combined CGRs away from the expected cost growth in the procurement of all weapons systems.

The weapon systems will be divided into various sets in the analysis of their cost growth (e.g., Army and Navy systems). The dollar weighted average (DWA) for a set of weapon systems is determined by:

$$DWA = \Sigma_i w_i (CGR_i) \qquad i \in \{\text{all systems in the set}\}$$

where $w_i = TC_i / (\Sigma_i TC_i) \qquad \forall i \in \{\text{all systems in the set}\}$

$$\Sigma_i w_i = 1 \qquad i \in \{\text{all systems in the set}\}$$

TC_i = Milestone II total system cost of system i.

The TC_is for the weapon systems in the set must all be converted to the same year dollars. For this analysis, all Milestone II estimates were converted to 1993 constant dollars using the OSD/NAVCOMPT Guidance of March 1993 dated 26 March 1993.

C. SINCGARS SYSTEM ANOMALY AND TREATMENT

The Army's SINCGARS electronic system has a CGR of -0.777 for the seventh year since Milestone II. This results from a decision in that year for a large scale reduction in the system. This decision is not typical of most weapons systems. The data for the first six years is typical and will be used. The first six years since Milestone II had a total CGR of 0.105.

D. TOTAL DATA SET

Table 1 displays the Milestone II year, the Milestone II decision estimate (DE) in millions of base year dollars, and the number of years of data since Milestone II available. Each data series extends only through the final year reported by each service.

Table 2 displays the unweighted cost growth ratios for the decision categories and the total decision cost growth ratio for each system. It also displays the dollar weighted average of each category.

Table 3 displays the unweighted cost growth ratios for the mistake categories and the total mistake cost growth ratio for each system. It also displays the dollar weighted average of each category.

Table 4 displays the unweighted decision, mistake, and total cost growth ratios for each system and the dollar weighted average of each category.

TABLE 1. BASELINE SYSTEM DATA

System	Milestone II Year	DE (in Millions of Base Year Dollars)	Years of Data Used
ATACM	1990	1506.0	2
CH\MH-53	1979	510.0	12
DDG-51	1987	16723.8	4
HARM	1982	3274.3	10
MLRS	1984	2077.8	7
MSE	1989	3548.4	3
SINCGARS	1983	4145.0	6
SM-2	1984	6571.5	8
Trident	1986	14258.9	4

TABLE 2. UNWEIGHTED CGRS FOR DECISION CATEGORIES

	Derv	Dsmmi	Dils	Depf	Descl	Dother	Decision
ATACM	0	0.023	0	0.015	0	0	0.038
CH\MH-53	-0.009	0.018	-0.310	0	0	0	-0.301
DDG-51	0.041	0.100	0.009	0	0.006	0	0.156
HARM	-0.142	0.258	0.015	0.030	0	0	0.161
MLRS	0.079	0.014	0.035	-0.008	0	0	0.120
MSE	0	0.018	0	0	0	0	0.018
SINCGARS	0.156	0	-0.037	0	0	0	0.119
SM-2	0.016	0.072	0.010	-0.025	0	0	0.073
Trident	-0.022	0	0	0	0	0	-0.022
Average	0.015	0.061	-0.001	-0.001	0.002	0	0.075

TABLE 3. UNWEIGHTED CGRS FOR MISTAKE CATEGORIES

	Mcep	Mcede	Mils	Msmf	Mescl	Mother	Mistake
ATACM	0	0	-0.011	0	0.020	0	0.009
CH\MH-53	0.529	0	0.047	0	0	0	0.576
DDG-51	0.113	0	-0.005	0	0	0	0.108
HARM	0.037	0	0.022	-0.005	0.002	0	0.056
MLRS	-0.036	0	-0.006	0	0	-0.020	-0.062
MSE	0.082	-0.010	0	0.003	0	0	0.075
SINCGARS	-0.030	0	0.005	0.011	0	0	-0.014
SM-2	-0.033	0	-0.009	0	-0.014	0	-0.056
Trident	-0.039	-0.001	0	0	0.014	0.002	-0.024
Average	0.031	-0.001	-0.001	0.001	0.003	0	0.038

TABLE 4. UNWEIGHTED SYSTEM COST GROWTH RATIOS

	Decision	Mistake	Total
ATACM	0.038	0.009	0.047
CH\MH-53	-0.301	0.576	0.276
DDG-51	0.156	0.108	0.264
HARM	0.161	0.056	0.217
MLRS	0.120	-0.062	0.058
MSE	0.018	0.075	0.092
SINCGARS	0.119	-0.014	0.105
SM-2	0.073	-0.056	0.017
Trident	-0.022	-0.024	-0.046
Average	0.075	0.033	0.108

V. METHODOLOGY AND RESULTS

A. USEFULNESS OF NEW CATEGORIES

In order to more readily identify areas of cost growth, it is necessary to classify the cost variances into a more useable and more detailed categorization system. The new system should classify the cost growths into more categories than the SAR categorization method.

This system shows data counts, and it would be inappropriate to use analysis of variance (ANOVA) since the data is not normally distributed. However, a simple comparison of the number of categories needed under each system will suffice in this determination.

Table 5 displays the number of SAR categories as compared to the number of new categories used to classify each system's cost variances since Milestone II.

As can be seen from the table, all systems require a larger number of categories to classify the cost variances using the new system than using the SAR system. Therefore, those factors having the greatest impact on cost growth can be more readily identified and the underlying causes of each of the most significant contributors can be determined.

TABLE 5. NUMBER OF REQUIRED CATEGORIES

System	SAR Categories	New Categories
ATACM	3	4
CH\MH-53	4	5
DDG-51	4	6
HARM	4	8
MLRS	2	7
MSE	3	4
SINCGARS	4	5
SM-2	4	7
Trident II	2	5

B. STATISTICAL APPROACH

1. Regression And Time Series Models

A regression model of the cost growth ratio would appear to be useful when analyzing the cost growth of weapon systems. However, with the limited data available, combined with the large variation in CGRs, the only regression model that fits is the full or saturated model which does not provide any beneficial information. Also, since the objective of this research is not to predict the cost growth of a specific system but instead to describe the cost growth of the entire Department of Defense, a regression model would not be of use.

A time series approach modeling the cost growth versus time of weapon systems is also of little benefit. The uniqueness of an individual weapon system and the decisions that affect a particular system do not allow for general system models of cost growth for these weapon systems.

2. Data Groups

The weapon systems will be broken into sets to determine if a specific attribute of each set of systems has an impact on the cost growth of the set. The following groupings or sets of weapons systems will be used to analyze the data: low cost versus high cost systems, missile systems versus nonmissile systems, and Army versus Navy systems. An analysis of those categories where a majority of the cost growth occurs in each of these sets can be used to evaluate the causes of cost growth. The reasons for each of the groupings will be discussed in detail in each of the sections below.

3. Testing For Common Means

The assumption of normality of the cost growth ratios in order to test for common means using parametric tests would be difficult to make since the CGR cannot go below a value of -1.0. The appropriate nonparametric test for common means is the Wilcoxon Rank Sum Test which is equivalent to the Mann-Whitney U Test. The value of the Wilcoxon test statistic (W) will be given along with the associated level of significance (p value).

If the p value associated with the Wilcoxon test is not determinable as significant or not (i.e., between 0.1 and 0.15) and paired system data is being evaluated, the Friedman nonparametric test will be used to determine whether or not to accept the null hypothesis. The Friedman chi-squared value (X^2) will be given along with the associated level of significance (p value) when this test is conducted. [Ref 6]

a. *Dollar Weighting the Data*

The mistake, decision, and total CGRs of each element i in a set need to be transformed to account for the different total cost each system has. This allows for a larger weight to be placed on the CGR of the higher cost systems in the set and a lesser weight to be placed on the less expensive systems in the set. Each CGR will be adjusted using a dollar weighting factor. The dollar weighting factor (w_i) is determined for each element i of a set of weapon systems and is equivalent to the w_i defined in calculating the dollar weighted average. Before a test for common means is performed, the mistake, decision, and total CGRs of each element i in the set is multiplied by its dollar weighting factor w_i. The dollar weighted CGRs are then used for the common means tests.

C. DECISION VERSUS MISTAKE COST GROWTH

An analysis of the difference between decision cost growth and mistake cost growth of all of the systems is required to determine how accurate Milestone II estimates are and to identify those areas where improvements in our estimating techniques need to be made.

1. Hypothesis

The Wilcoxon Rank Sum Test is used to test the null hypothesis that the mean cost growth due to decisions is equal to the mean cost growth due to mistakes. The alternative hypothesis is that the mean cost growth for decisions is greater than the mean cost growth due to mistakes. The common means test is performed on the dollar weighted data for all nine weapon systems.

2. Data

Table 6 displays the dollar weighted decision, mistake and total cost growths for all the weapon systems.

TABLE 6. COST GROWTH RATIOS FOR EACH SYSTEM

System	Decision	Mistake	Total
ATACM	0.001	0.000	0.001
CH\MH-53	-0.004	0.008	0.004
DDG-51	0.048	0.033	0.081
HARM	0.011	0.004	0.015
MLRS	0.005	-0.003	0.002
MSE	0.001	0.004	0.006
SINCGARS	0.010	-0.001	0.009
SM-2	0.010	-0.007	0.002
Trident II	-0.006	-0.006	-0.012

3. Results of Decision Versus Mistake Cost Growth

The Wilcoxon rank sum test for common means for decision and mistake cost growth yields a test statistic value of W = 72 with a p value of 0.13. This may or may not be significant, so a Friedman test was performed and yields a test statistic value of X^2 = 2.778 with a p value of 0.096. This is significant and the null hypothesis of equal means is rejected. Therefore, the mean decision cost growth is greater than the mean mistake cost growth. The dollar weighted average (DWA) decision cost growth is 0.075 and the DWA mistake cost growth is 0.033.

4. Categorical Analysis

Table 7 displays the dollar weighted average CGRs of the decision and mistake categories. No statistical tests were performed to determine which categories contain the largest cost growth; only a visual inspection is required.

TABLE 7. AVERAGE CATEGORY CGRS FOR ALL SYSTEMS

Decision	Dcrv	Dsmmi	Dils	Depf	Descl	Dother
CGR	0.015	0.061	-0.001	-0.001	0.002	0
Mistake	Mcep	Mcedc	Mils	Mssmf	Mescl	Mother
CGR	0.031	-0.001	-0.001	0.001	0.003	0

The majority of decision cost growth occurs in the Dsmmi category and has a dollar weighted average value of 0.061. The majority of mistake cost growth occurs in the Mcep category and has a dollar weighted average value of 0.031.

D. LOW COST VERSUS HIGH COST SYSTEMS

A determination of the relationship between system cost and system cost growth is needed to determine if a difference exists between the cost growth of low cost systems and the cost growth of high cost systems. A low cost system is defined as any system whose total system cost estimated at Milestone II is less than three and a half billion dollars. The value of three and a half billion dollars is somewhat arbitrary, but this number was chosen to split the number of systems in each grouping approximately in half and to ensure that an approximately equal ratio of Army to Navy systems exist in each set to eliminate any possible service effects. The low cost systems are the ATACM, the CH\MH-53, the HARM and the MLRS. The systems in the high cost category are the DDG-51, the MSE, the SINCGARS, the SM-2 and the Trident II.

1. Hypothesis

The Wilcoxon Rank Sum Test is used to test the null hypothesis that the mean cost growth of low cost systems is equal to the mean cost growth of high cost systems. The alternative hypothesis is that the low cost systems have a higher mean cost growth than the high cost systems.

2. Data

Table 8 displays the dollar weighted cost growth ratios for the low cost weapon systems.

Table 9 displays the dollar weighted cost growth ratios for the high cost weapon systems.

TABLE 8. DOLLAR WEIGHTED CGRS FOR LOW COST SYSTEMS

System	Decision	Mistake	Total
ATACM	0.006	0.001	0.008
CH\MH-53	-0.029	0.055	0.026
HARM	0.075	0.026	0.102
MLRS	0.033	-0.017	0.016

TABLE 9. DOLLAR WEIGHTED CGRS FOR HIGH COST SYSTEMS

System	Decision	Mistake	Total
DDG-51	0.056	0.039	0.095
MSE	0.001	0.005	0.007
SINCGARS	0.012	-0.001	0.011
SM-2	0.011	-0.009	0.003
Trident II	-0.007	-0.008	-0.014

3. Comparison between High Cost and Low Cost Systems

a. *Total Cost Growth*

The Wilcoxon rank sum test for common means for total cost growth of low cost and high cost systems yields a test statistic value of W = 19 with a p value of 0.08. This is significant and the null hypothesis of equal means is rejected. Therefore, the mean total cost growth of low cost systems is greater than the mean total cost growth of high cost systems. The DWA total cost growth for low cost systems is 0.152 and the DWA total cost growth for high cost systems is 0.100.

b. *Decision Cost Growth Comparison*

The Wilcoxon rank sum test for common means for decision cost growth of low cost and high cost systems yields a test statistic value of W = 22 with a p value of 0.311. This is not significant and the null hypothesis of equal means is not rejected.

c. Mistake Cost Growth Comparison

The Wilcoxon rank sum test for common means for mistake cost growth of low cost and high cost systems yields a test statistic value of W = 21 with a p value of 0.35. This is not significant and the null hypothesis of equal means is not rejected.

The difference between the mistake cost growths, while not statistically different, is substantively different. The total cost growth of low cost systems is greater than that of high cost systems, and it can be observed that the difference between the mistake cost growths is the driving factor behind this difference. The DWA mistake cost growth for low cost systems is 0.066, while the DWA total cost growth for high cost systems is 0.027.

4. Low Cost Systems

a. Decision Versus Mistake Cost Growth

The Wilcoxon rank sum test for common means for decision cost growth and mistake cost growth of low cost systems yields a test statistic value of W = 17 with a p value of 0.38. This is not significant and the null hypothesis of equal means is not rejected.

b. Categorical Analysis

Table 10 displays the dollar weighted average CGRs of the decision and mistake categories for low cost systems. No statistical tests were performed to determine which categories contain the largest cost growth; only a visual inspection is required.

TABLE 10. AVERAGE CATEGORY CGRS FOR LOW COST SYSTEMS

Decision	Dcrv	Dsmmi	Dils	Depf	Descl	Dother
CGR	-0.046	0.130	-0.013	0.014	0	0
Mistake	Mcep	Mcede	Mils	Mssmf	Mescl	Mother
CGR	0.058	0	0.011	-0.002	0.004	-0.005

The majority of decision cost growth for low cost systems occurs in the Dsmmi category and has a dollar weighted average value of

0.130. The majority of mistake cost growth in low cost systems occurs in the Mcep category and has a dollar weighted average value = 0.058.

5. High Cost Systems

a. *Decision Versus Mistake Cost Growth*

The Wilcoxon rank sum test for common means for decision cost growth and mistake cost growth of high cost systems yields a test statistic value of W = 22 with a p value of 0.14. This may or may not be significant, so a Friedman test was performed and yields a test statistic value of $X^2 = 1.8$ with a p value of 0.18. This is not significant and the null hypothesis of equal means is not rejected.

The difference between the mistake and decision cost growths, while not statistically different, is substantively different when compared to the difference between the decision and mistake cost growths of low cost systems. The DWA mistake cost growth for high cost systems 0.027 and the DWA decision cost growth for high cost systems is 0.074.

b. *Categorical Analysis*

Table 11 displays the dollar weighted average CGRs of the decision and mistake categories for high cost systems. No statistical tests were performed to determine which categories contain the largest cost growth; only a visual inspection is required.

TABLE 11. AVERAGE CATEGORY CGRS FOR HIGH COST SYSTEMS

Decision	Dcrv	Dsmmi	Dils	Depf	Descl	Dother
CGR	0.026	0.048	0.001	-0.004	0.002	0
Mistake	Mcep	Mcede	Mils	Msmf	Mescl	Mother
CGR	0.026	-0.001	-0.003	0.001	0.002	0.001

The majority of decision cost growth for high cost systems occurs in the Dsmmi category and has a dollar weighted average value of 0.048. The majority of mistake cost growth for high cost systems occurs in the Mcep category and has a dollar weighted average value of 0.026.

K. MISSILE SYSTEMS VERSUS OTHER SYSTEMS

An analysis of the cost growth of missile systems compared to other weapons systems is beneficial since it will allow for identification of differences in the procurement and estimation processes of these systems that may need to be evaluated in further detail in future studies. The missile systems consist of the ATACM, the HARM and the SM-2. These two sets have approximately equal low cost to high cost ratios and Army to Navy system ratios. This should remove any effects that system cost would have on the data. The data was then dollar weighted within each set.

1. Hypothesis

The Wilcoxon Rank Sum Test is performed to test the null hypothesis that the mean cost growth of missile systems is equal to the mean cost growth of other weapon systems. The alternative hypothesis is that the missile systems have a lower mean cost growth than the other weapon systems.

2. Data

Table 12 displays the dollar weighted cost growths for missile systems.

Table 13 displays the dollar weighted cost growths for the nonmissile systems.

TABLE 12. DOLLAR WEIGHTED CGRS FOR MISSILE SYSTEMS

System	Decision	Mistake	Total
ATACM	0.004	0.001	0.005
HARM	0.050	0.018	0.068
SM-2	0.042	-0.032	0.010

TABLE 13. DOLLAR WEIGHTED CGRS FOR NONMISSILE SYSTEMS

System	Decision	Mistake	Total
CH\MH-53	-0.006	0.011	0.005
DDG-51	0.062	0.043	0.104
MSE	0.006	-0.003	0.003
SINCGARS	0.001	0.006	0.007
SM-2	0.013	-0.002	0.012
Trident II	-0.008	-0.008	-0.016

3. **Comparison between Missile and Nonmissile Systems**

a. ***Total Cost Growth***

The Wilcoxon rank sum test for common means for total cost growth of missile and nonmissile systems yields a test statistic value of W = 17.5 with a p value of 0.27. This is not significant and the null hypothesis of equal means is not rejected.

b. ***Decision Cost Growth Comparison***

The Wilcoxon rank sum test for common means for decision cost growth of missile and nonmissile systems yields a test statistic value of W = 19 with a p value of 0.16. This is not significant and the null hypothesis of equal means is not rejected.

c. ***Mistake Cost Growth Comparison***

The Wilcoxon rank sum test for common means for mistake cost growth of missile and nonmissile systems yields a test statistic value of W = 14 with a p value of 0.40. This is not significant and the null hypothesis of equal means is not rejected.

The difference between the mistake cost growths for missile and nonmissile systems, while not statistically different, is substantively different. It can be readily observed that the difference between the mistake cost growths is relevant when compared to the decision cost growths as is discussed below. The DWA mistake cost growth for missile systems is -0.014 and the DWA total cost growth for nonmissile systems is 0.046.

4. **Missile Systems**

a. ***Decision Versus Mistake Cost Growth***

The Wilcoxon rank sum test for common means for decision cost growth and mistake cost growth of missile systems yields a test statistic value of W = 7 with a p value of 0.076. This is significant and the null hypothesis of equal means is rejected. The DWA mistake cost growth for missile systems -0.014 and the DWA decision cost growth for missile systems is 0.097.

b. ***Categorical Analysis***

Table 14 displays the dollar weighted average CGRs of the decision and mistake categories for missile systems. No statistical tests were performed to determine which categories contain the largest cost growth; only a visual inspection is required.

TABLE 14. AVERAGE CATEGORY CGRS FOR MISSILE SYSTEMS

Decision	Dcrv	Dsmmi	Dils	Dcpf	Descl	Dother
CGR	-0.035	0.125	0.010	-0.003	0	0
Mistake	Mcep	Mcede	Mils	Mssmf	Mescl	Mother
CGR	-0.007	0	0.001	-0.002	-0 005	0

The majority of decision cost growth for missile systems occurs in the Dsmmi category and has a dollar weighted average value of 0.125. The majority of mistake cost growth for missile systems occurs in the Mcep category and has a dollar weighted average value of -0.007.

5. **Nonmissile Systems**

a. ***Decision Versus Mistake Cost Growth***

The Wilcoxon rank sum test for common means for decision cost growth and mistake cost growth of nonmissile systems yields a test statistic value of W = 38 with a p value of 0.43. This is not significant and the null hypothesis of equal means is not rejected.

b. ***Categorical Analysis***

Table 15 displays the dollar weighted average CGRs of the decision and mistake categories for nonmissile systems. No statistical tests were performed to determine which categories contain the largest cost growth; only a visual inspection is required.

TABLE 15. AVERAGE CATEGORY CGRS FOR NONMISSILE SYSTEMS

Decision	Derv	Dammi	Dils	Depf	Descl	Dother
CGR	0.030	0.042	-0.005	0	0.002	0
Mistake	Mcep	Mcede	Mils	Msamf	Mescl	Mother
CGR	0.042	-0.001	-0.001	0.001	0.005	0

The majority of decision cost growth for nonmissile systems occurs in two categories, the Dammi category and the Derv category. The Dammi category has a dollar weighted average value of 0.042. The Derv category has a dollar weighted average value of 0.030. The majority of mistake cost growth for non missile systems occurs in the Mcep category and has a dollar weighted average value of 0.042.

F. ARMY VERSUS NAVY SYSTEMS

A comparison of Navy cost growth versus Army cost growth is required to determine which service, if either, has a better estimation or decision making process.

1. Hypothesis

The Wilcoxon Rank Sum Test is performed to test the null hypothesis that the mean cost growth of Army systems is equal to the mean cost growth of Navy systems. The alternative hypothesis is that the means are not equal.

2. Data

Table 16 displays the dollar weighted cost growths for Army systems along with the dollar weighted average (DWA) of these systems.

Table 17 displays the dollar weighted cost growths for the Navy systems along with the dollar weighted average (DWA) of these systems.

TABLE 16. DOLLAR WEIGHTED CGRS FOR ARMY SYSTEMS

System	Decision	Mistake	Total
ATACM	0.004	0.001	0.005
MLRS	0.023	-0.012	0.011
MSE	0.005	0.021	0.026
SINCGARS	0.048	-0.006	0.043

TABLE 17. DOLLAR WEIGHTED CGRS FOR NAVY SYSTEMS

System	Decision	Mistake	Total
CH\MH-53	-0.006	0.011	0.005
DDG-51	0.060	0.042	0.102
HARM	0.014	0.005	0.020
SM-2	0.012	-0.009	0.003
Trident II	-0.007	-0.008	-0.016

3. Comparison between Army and Navy Systems

a. Total Cost Growth

The Wilcoxon rank sum test for common means for total cost growth of Army and Navy systems yields a test statistic value of W = 21.5 with a p value of 0.21. This is not significant and the null hypothesis of equal means is not rejected.

b. Decision Cost Growth Comparison

The Wilcoxon rank sum test for common means for decision cost growth of Army and Navy systems yields a test statistic value of W = 22 with a p value of 0.31. This is not significant and the null hypothesis of equal means is not rejected.

c. Mistake Cost Growth Comparison

The Wilcoxon rank sum test for common means for mistake cost growth of Army and Navy systems yields a test statistic value of W = 18 with a p value of 0.31. This is not significant and the null hypothesis of equal means is not rejected.

4. Army Systems

a. *Decision Versus Mistake Cost Growth*

The Wilcoxon rank sum test for common means for decision cost growth and mistake cost growth of Army systems yields a test statistic value of W = 12 with a p value of 0.045. This is significant and the null hypothesis of equal means is rejected. The DWA mistake cost growth for Army systems 0.004 and the DWA decision cost growth for Army systems is 0.081.

b. *Categorical Analysis*

Table 18 displays the dollar weighted average CGRs of the decision and mistake categories for Army systems. No statistical tests were performed to determine which categories contain the largest cost growth; only a visual inspection is required.

TABLE 18. AVERAGE CATEGORY CGRS FOR ARMY SYSTEMS

Decision	Dcrv	Dsmmi	Dils	Depf	Dscl	Dother
CGR	0.079	0.011	-0.008	0	0	0
Mistake	Mcep	Mcede	Mils	Msmf	Mscl	Mother
CGR	0.004	-0.003	0	0.005	0.002	-0.004

The majority of decision cost growth in Army systems occurs in the Dcrv category and has a dollar weighted average value of 0.079. The majority of mistake cost growth in Army systems occurs in two categories, the Mcep category and the Msmf category. The Mcep category has a dollar weighted average value of 0.004. The Msmf category has a dollar weighted average value of 0.005.

5. Navy Systems

a. *Decision Versus Mistake Cost Growth*

The Wilcoxon rank sum test for common means for decision cost growth and mistake cost growth of Navy systems yields a test statistic value of W = 23 with a p value of 0.18. This is not significant and the null hypothesis of equal means is not rejected.

b. Categorical Analysis

Table 19 displays the dollar weighted average CGRs of the decision and mistake categories for Navy systems. No statistical tests were performed to determine which categories contain the largest cost growth; only a visual inspection is required.

TABLE 19. AVERAGE CATEGORY CGRS FOR NAVY SYSTEMS

Decision	Dcrv	Dsmmi	Dils	Depf	Descl	Dother
CGR	-0.002	0.074	0.001	-0.001	0.002	0
Mistake	Mcep	Mcede	Mils	Mssmf	Mescl	Mother
CGR	0.038	0	-0.001	0	0.003	0.001

The majority of decision cost growth in Navy systems occurs in the Dsmmi category and has a dollar weighted average value of 0.074. The majority of mistake cost growth in Navy systems occurs in the Mcep category and has a dollar weighted average value of 0.038.

VI. CONCLUSIONS

A. NEW CATEGORIES

The new categorization systems breaks out the cost growth into more categories than the SAR system. This system is better at detecting sources of cost growth in a particular weapon system and enabling correction of that source. It also shows when mistakes or decisions are the major effect behind the cost growth of a system.

B. DOLLAR WEIGHTED AVERAGES

Using dollar weighted averages adjusts the findings to account for the greater effect more expensive weapon systems have on budgetary considerations. This allows for a more realistic interpretation of the cost growth and its effect on the defense budget. If an arithmetic average is used, the data is equally weighted, giving the cost growth of low cost systems an equal weight on the overall cost growth. This would tend to skew the results and not allow them to be applied directly to the entire military budget.

An example of this effect occurs when evaluating the decision and mistake cost growth ratios of all the weapon systems. If an arithmetic average is used, the average decision cost growth ratio is 0.040 and the average mistake cost growth ratio is 0.074. This is opposite to the findings using dollar weighted averages, where the decision cost growth ratio is 0.075 and the mistake cost growth ratio is 0.033. By using an arithmetic mean, it would lead one to conclude that 7.4% mistake cost growth is occurring in the defense budget, when in reality, only 3.3% is occurring. Therefore, dollar weighted averages provide a more realistic picture of cost growth.

C. SYSTEM COST GROWTH

1. Total Cost Growth

The total cost growth of a weapon system is much less than might be expected. It has a dollar weighted average value of 0.108.

A 1980 study reports that the average total cost growth of weapons systems is 25.9% [Ref. 3]. This is significantly higher than the 10.8% this analysis shows. However, the time of that study is relevant to the difference in findings. The development by estimators of a computerized large data base, which contains the production costs of a large number of components, assemblies, and subassemblies, allows for a more accurate estimate of the production costs of new systems. This is beneficial in estimating system costs which should bring cost growth down. Another cause is the high technologies that were brand new in 1980 and extremely difficult to estimate have been developed and produced so that now they are much easier to estimate. Lastly, the results of the 1980 study and others resulted in a determined effort by the Department of Defense to control cost growth. This has also had a positive impact in lowering the cost growth of weapons systems.

2. System Model

Eighty five percent of the total cost growth can be captured in Dsmmi and the Mcep categories. To control total cost growth, it is required that the cost growth in these two categories be focused upon. The possible causes of the cost growth in these categories will be discussed below.

3. Mistake and Decision Cost Growth Comparison

Mistakes make up 30.6% of the total cost growth of a system while decisions make up 69.4% of the total cost growth. Therefore decisions outweigh mistakes by a margin of 2.3:1.

One recent study reports that cost growth due to decisions outweighs cost growth due to mistakes by a margin of two to one [Ref. 7]. This analysis reaches a similar conclusion.

4. Mistake Cost Growth

A majority of the mistake cost growth occurs in the Mcep category. The Mcep category is used to classify cost variances attributable to mistakes in estimating the cost of production. While it may be noted that this implies that the Department of Defense needs to concentrate its efforts on becoming better at estimating the production costs of a weapon system, the mistake cost growth for a system is only 3.3% and is not nearly as significant as controlling the cost growth due to decisions.

5. Decision Cost Growth

A majority of the decision cost growth occurs in the Dsmmi category. The Dsmmi category is used to classify cost variances attributable to a decision to change the procurement schedule, shifts in the multiyear procurement rate or in different management initiatives. A detailed analysis of the data indicates that a majority of the Dsmmi cost growth is due to schedule slippage. Some of this schedule slippage can be attributed to decisions to change the design and performance requirements of the system. These changes are classified into the Dcrv category and has a dollar weighted value of 0.015. This may or may not account for all of the schedule slippage, however, the data does not provide sufficient evidence to support or deny this possible explanation. Further study concentrating on the causes of schedule slippage needs to be done.

D. SYSTEM COST COMPARISON

The driving factor between the difference between low cost system cost growth and high cost system cost growth is the difference in the mistake cost growth.

The low cost systems have a higher mistake cost growth by a margin of 2.4:1. Both high and low cost systems have a majority of their mistake cost growth occurring in the Mcep category. This is not surprising since this result has already been determined above.

However, low cost systems have over twice as much cost growth in the Mcep category than do high cost systems. This indicates that estimators are not nearly as adept at estimating the production costs of low cost systems as high cost systems.

One possible explanation for this is that estimators do not take as much care in estimating the costs of low cost systems. Low cost systems are not nearly as visible on a Congressional oversight level or on an internal level, and therefore the care taken to accurately estimate the production cost of a system may not be nearly as high as for that of the more expensive systems.

Another explanation concerns the nature of high cost to low cost systems [Ref. 1]. A majority of high cost systems are large platforms which have a majority of their production cost resulting from large components. These large components, such as hull construction or propulsion plants, have been used before or a similar component has been used before. This makes the estimation of the production costs of these large components fairly accurate. The mistakes in estimating the smaller and relatively cheaper items would be masked in the overall cost growth of the system even if they were of equal dollar value to the errors in the low cost systems.

Therefore, the difference between the low cost and high cost system mistake cost growth is probably not as significant as it appears to be.

E. MISSILE SYSTEMS

The significant difference between the cost growth of missile systems as compared to other weapon systems is that the mistake cost growth for missile systems is significantly less than that of other systems, specifically in estimating the cost of production. The most likely explanation is similar to the discussion above concerning the cost of a system. Missiles are evolutionary in nature. The guidance system of newer missiles is generally a modernization or modification of a previous guidance system. The same can be said for propulsion system and warhead type. This would tend to increase the accuracy of missile systems over other types of systems.

One report on cost growth states that missile systems have a much higher cost growth than do other systems [Ref. 1]. This article, prepared in 1982, included much older missile systems. The evolutionary process discussed above had not yet developed and therefore a higher cost growth could have resulted. A comparison of the cost growth of older missile systems to newer ones would be required to validate this assertion.

F. SERVICE COMPARISON

The Army and Navy have effectively equivalent cost growths. The only difference is that part of the Army's mistake cost growth results from mistakes in the estimation process that resulted in schedule slips. The reasons behind this are not clear and need to be addressed in the future.

A majority of early 1980s studies reported that the Army had a significantly higher cost growth than the Navy [Refs. 1, 3]. This was attributed to the modernization of the Army. This study concentrated on more recent weapons systems and did not find this to be the case. The most obvious explanation for this effect is that the Army has completed its modernization and is now proficient at controlling the costs of its weapon systems.

VII. RECOMMENDATIONS

A. NEW CATEGORIES

The new categorization system should be used to classify cost variances in the SAR system. This would allow for a more detailed accounting of the cost variances and allow for identification of the exact areas in which cost growth is occurring.

B. TOTAL COST GROWTH

The total cost growth as been significantly lowered over the past ten years. This is significant and promising. The Department of Defense should continue its current oversight and decision process to ensure that future cost growth is maintained at acceptable levels.

C. DECISION COST GROWTH

Decision cost growth is the driving force behind the total cost growth of weapon systems. This is driven by decisions that result in schedule slippage in the procurement process. This type of cost growth must be minimized. The most likely solution is to ensure at Milestone II that all decisions that can be made that could result in schedule slippage are made and finalized.

D. MISTAKE COST GROWTH

The mistake cost growth is well within any reasonable limits. The driving factor for this type of growth is mistakes in estimating the production costs of a weapon system. This amounts to only 3.3% cost growth and is well within any reasonable margin of error that could be placed on this type of estimation.

E. ARMY COST GROWTH

The Army mistake cost growth, while similar in magnitude to the Navy's, is partially driven by schedule slippage. The Army must evaluate the factors that are causing this problem and correct them. One possible solution is to compare the Army's estimation process with the Navy's and to attempt to isolate the key differences that result in this type of cost growth.

F. FUTURE STUDIES

All of the results and conclusions of this study are tentative since they are based on nine weapon systems. This is the initial analysis of a three year study by the DoD and the results and conclusions of the study using all of the SAR reportable weapon systems may differ from this report.

A continuation of this study, once data for more weapons systems has been obtained, should be done to compare Air Force systems with those of the Army and Navy. Also, a comparison of aircraft and ship cost growth would be beneficial.

A study of RDT&E cost growth is necessary to evaluate the decision and estimation process of this aspect of weapon system acquisition.

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