SOME EMPIRICAL EVIDENCE ON THE NON-NORMALITY OF COST VARIANCES ON DEFENSE CONTRACTS

THESIS

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Robert J. Conley IV

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Abstract

This study tested the hypothesis that defense cost variances reported on the *Cost Performance Report* are normally distributed. The DOD requires that all defense cost variances which breech a pre-specified threshold be investigated. The present variance investigation model has been criticized because it can prompt frivolous investigations. In theory, statistical models could reduce the number of frivolous investigations, but they are not used because they require too much information about the cost variance, including its distributional form. Often such models assume a normal distribution, but researchers have shown that the models do not work properly if the assumption is fallacious. Two prior studies have investigated the normality of cost variances with mixed results, and neither investigated defense cost variances. Here, fifty series of cost variances from two defense contracts were extracted from *Cost Performance Reports* and evaluated using four popular tests of normality (Bowman-Shenton, Shapiro-Wilks, Kolmogorov-Smirnov, and Chi-square). The results show that the vast majority of the series of cost variances were not normally distributed. These results were insensitive to the normality test used and to the effects of inflation. The statistical variance investigation models may still be used, but normality should not be assumed.

SOME EMPIRICAL EVIDENCE ON THE NON-NORMALITY OF COST VARIANCES ON DEFENSE CONTRACTS

I. Introduction

The Issue

Since the end of the Cold War, pressure for improved cost efficiency on defense projects has been enormous. The Department of Defense (DOD) has responded by reducing its forces and promoting policies such as "fee-for-service" to make defense organizations more cost efficient. The DOD has also examined its defense acquisition procedures in order to streamline the acquisition process and take advantage of innovative and cost-efficient practices in industry, such as just-in-time production and activity-based costing.

One area that has tremendous potential for improved cost efficiencies is the control of cost growth and the elimination of cost overruns on defense projects. For example, based on a review of over one hundred major weapon systems since the mid 1960s, Drezner *et al.* (10:xiii) report that the average cost growth has fluctuated around 20 percent. Similarly, based on an analysis of hundreds of defense contracts since the 1960s, Christensen (3:30) reports that the average cost overrun on defense contracts is about 18 percent. These findings are particularly disappointing because these cost problems have continued despite numerous acquisition initiatives and policies since the 1960s designed to control them (Drezner *et al.* 1993, 10:29).

One of these policies requires that defense contractors comply with DOD Cost/Schedule Control Systems Criteria (C/SCSC), also known as "the criteria." Simply put, the criteria are internal controls which require the development and use of performance budgets to manage a defense project. Although the criteria have been widely supported as a sound project management tool, they have been over-implemented by the military services and are now being revised to reduce the administrative cost that over-implementation has created.

One area addressed by the criteria that has been over-implemented involves an excessive analysis of cost variances. The criteria require the defense contractor to analyze "significant variances," and specify that a significant variance is one that breeches a pre-determined threshold, expressed as either a percentage, a dollar amount, or as a combination of the two. (8:3-17). For example, a cost variance may be defined as significant if it exceeds 10 percent of the budget, or exceeds $10,000, or exceeds 10% and $10,000. When a breech occurs, the contractor is required to investigate, report the cause, and implement a corrective action plan if possible. Although the use of simple thresholds to determine when to investigate a cost variance is simple, it can become an administrative burden when the threshold is applied mechanically to all levels of work on the contract. Unfortunately, this has been the experience on defense contracts, and contractors have sought relief from such requirements for many years.

The academic literature describes several statistical cost variance investigation models which are reported to be superior to the simple variance investigation model described above (Kaplan, 1975, 20). Assuming a knowledge of the distributional properties of a cost variance, the statistical models use probability theory to signal an investigation only when the marginal benefit of correcting the problem exceeds the marginal cost of the investigation. Thus, the use of these models on defense contracts has the potential to reduce the number of frivolous defense cost variance investigations that the simple cost variance investigation model now requires. However, based on a review of defense contracts managed by the Air Force, Hoang and Quick (1993, 15:vii) report that the statistical models are rarely used. This finding is consistent with reports that statistical cost variance investigation models are rarely used in the civilian sector (Koehler, 1968, 22).

The Research Problem

One reason suggested for not using the statistical models involves the requirement that the distributional properties of the cost variance be known in advance (Boer, 1984, 1; Gribbin and Lau, 1991, 13). For example, these models are often described using the assumption that the cost variance is normally distributed. However, Gribbin has recently shown that if this assumption is erroneous, then the variance investigation signal can be suboptimal (Gribbin, 1989, 12).

In a recent study of cost variances at a medium size manufacturing plant, Gribbin and Lau report that cost variances experienced there were not always normal (Gribbin and Lau, 1991, 13). The only other study of the distributional properties of cost variances reported similar results (Jacobs and Lorek, 1980, 17). Thus, Gribbin and Lau caution current and potential users of the statistical cost variance investigation models that the assumption of normality is not always appropriate, and recommend that their research be replicated in other settings.

Given the increasing importance of cost efficiency in defense, and the widely recognized problem with the current defense cost variance investigation model, this study replicates the research of Gribbin and Lau using data from completed and on-going defense contracts. Specifically, it investigates the normality of cost variances reported on two defense contracts.

Hypothesis Statement

An appropriate hypothesis in null form is:

Ho: Defense cost variances are normally distributed.

If the hypothesis is supported, the use of statistical cost variance investigation models which require the assumption of normally distributed cost variances should be encouraged on defense contracts. If not supported, then the statistical models may still be beneficial, but only with non-normal distributions that more closely fit defense cost variances.

Conclusion

The increased emphasis on cost efficiency in defense, and the wide-spread dissatisfaction with the present variance investigation model used on defense contracts, have prompted this study. Further, based on their analysis of nondefense cost variances, Gribbin and Lau (13) conclude that the indiscriminate use of the normality assumption in statistical cost variance investigation models is inappropriate, and recommend more empirical research into the distributional properties of cost variances. This study replicates Gribbin and Lau's (13) study using defense cost variances.

The remaining chapters review the relevant literature (Chapter II), describe the methodology (Chapter III), report the results of the hypothesis test (Chapter IV), and summarize the project and its implications (Chapter V).

II. Literature Review

Introduction

As indicated in Chapter I, statistical cost variance investigation models are considered superior to the present model commonly used on defense contracts. Because the statistical models are based on probability theory and compare marginal benefits to marginal costs before prompting an investigation, the use of these models would likely reduce both the number of frivolous variance investigations and the cost of managing a defense contract.

However, the statistical models often assume that cost variances are distributed normally (1:48, 51; 18:24; 23:140; 25:66-78; 26:728), which may not be the case. If the cost variances are not normal, then an investigation signal from a statistical model which assumes normality may still prompt a frivolous investigation:

> *Gribbin has shown recently that if the cost variances are indeed non-normal, then assuming normality instead of modeling the non-normality correctly can lead to significantly inferior cost variance investigation decisions.* (Gribbin and Lau, 1991, 13:88)

Thus, this study tests the null hypothesis that cost variances reported on defense contracts are normally distributed. In this chapter, the relevant academic literature which proposes various statistical cost variance models is summarized. Although these models appear to be improvements over the simple model, surveys indicate that they are rarely used in industry (Laudeman and Schaeberle, 1983, 24; Gaumnitz and Kollaritsch, 1988

11). Therefore, this chapter also reviews various reasons given for not using the models. One of these, of course, is the possible fallacious assumption of normality. The final section of this chapter reviews the only two published studies which have tested the normality assumption.

Cost Variance Investigation Decision Models

The academic literature describes several statistical cost variance investigation models which are reported to be superior to the simple variance investigation model. Kaplan (20:311-337) surveyed the accounting, statistics, and management science literature dealing with these models, and developed a taxonomy that organizes the models along dimensions which form the following table.

Table 1. A Taxonomy of Variance Investigation Models (Kaplan, 1975, 20)

	Costs and Benefits of Investigation Not Considered	*Costs and Benefits of Investigation Considered*
Single-Period	Zannetos (1964), Juers (1967) Koehler (1968), Luh (1968), Probst (1971), Buzby (1974)	Duncan (1956) Bierman, Fouraker, and Jaedicke (1961)
Multi-Period	Cumulative-Sum Chart as in Page (1954) Also Barnard (1959), Chernoff and Zacks (1964)	Duvall (1967), Kaplan (1969) Dyckman (1969), Bather (1963)

One dimension classifies the models by the number of observations they require. The other dimension classifies the models by whether or not the costs and benefits of the investigation are considered. Thus, the table places variance investigation models into four categories, where each category includes examples of variance investigation models proposed by researchers. Because Kaplan (1975, 20) describes these examples in detail, they will not be repeated. A brief description of these categories and their relationship to the normality assumption follows.

Single-period Models with No Cost-benefit Comparison. This type of model is the most common, where current cost variances which breech a pre-determined threshold are investigated. In some cases, a control chart approach is used, where the cost variance is assumed to be a random variable with a normal probability distribution, and the threshold is defined as a set number of standard deviations from the expected value of the cost variance.

On defense contracts, thresholds are usually formally specified as a simple percentage, a dollar amount, or both (8:3-17) on the *Contractor Data Requirements Listing* (CDRL). In addition, thresholds can be revised by contractor and government management during the life of the contract. Hoang and Quick (15) report that modeling the cost variance as a random variable is almost never done (15:57), and in some cases thresholds are simply copied from the CDRLs of prior contracts (15:62).

Multi-period Models with No Cost-benefit Comparison. One way to improve the single-period model is to include previous observations. The expectation is that by examining the trend of variances, a significant problem may be detected sooner, especially when no individual variance by itself may exceed a threshold. Kaplan (19:151-153) reports that the "cumulative sum procedure" is the most common model of this kind, where variances are often assumed to be normally distributed (19:151-153). Furthermore, defense policy does not prevent the use of this type of model, but Hoang and Quick (15) report that its use is rare.

Models with Cost-benefit Comparisons. Regardless of the periods included, signaling an investigation only when the expected benefit exceeds the expected cost is an improvement over the basic model, because the control chart approach does not formally include costs and benefits. Clearly, these models require a lot of information, including estimates of the cost of the investigation, the benefit of correcting an out-of-control process, the cost of correcting the out-of-control process, and the probability that the process is out-of-control. In addition, the assumption that the cost variance is normally distributed is commonly made in the literature which describes this class of models (e.g., Kaplan, 1982, 19:337-338).

Assessment. Each of these categories of models has their strengths and weaknesses. The basic model, which is used on defense contracts, is the easiest to implement and requires much less information than the other models. However, if the information is available, the models which include multiple periods and a cost-benefit comparison are clearly superior by reducing the amount and cost of frivolous investigations. The main problem with the more elaborate models is the additional information required to use them. But the defense policy which requires a cost variance investigation does not prohibit the use of the more elaborate models.

Normality Studies

As indicated in the preceding section, the assumption of normality is frequently included in descriptions of the statistical cost variance investigation models. After completing his survey of the cost variance investigation model literature, Kaplan (20) concludes that

> *The final judgment on the appropriateness of formal statistical and mathematical models for cost variance analysis must be based on empirical studies. To date, little such evidence is available.* (20:148)

The validity of the normality assumption is an empirical question. As indicated in Table 2, only two reported studies have explored this question. Each of these will now be described.

Table 2. Cost Variance Normality Studies

Researchers (Year)	*Variances (amount)*	*Normality tests used*	*Results at* $\alpha = .05$
Jacobs & Lorek (1980)	Material and utilities usage (11 daily , 9 weekly) from a grain processing firm	Skewness, Kurtosis, Kolmogorov-Smirnov	None of the daily and 7 of 9 weekly variances tested normal.
Gribbin & Lau (1991)	Direct labor efficiency in dollars and percent (32 to 43 months in each of 14 production departments)	Bowman-Shenton Shapiro-Wilk	7 of 14 of the dollar and 1 of the 14 percentage variances tested normal.

Jacobs and Loreck. Jacobs and Loreck (17) were the first to investigate the normality of cost variances. In their study of usage variances experienced on several processes at a grain processing firm, 11 series of daily variances and 9 series of weekly variances were tested for normality using the Kolmogorov-Smirnov test and moment tests (skewness and kurtosis). These tests and other normality tests will be described in Chapter III. A usage variance is the difference between a budgeted and actual quantity used in a process. Usually this difference is multiplied by the standard price per unit. In this case, the authors reported that price data were not available to them. Also, it is not clear how many variances were included in a series and if the samples were random. Given these limitations, the normality hypothesis was rejected for all of the daily variances, and accepted for 7 of the 9 weekly variances at the .05 significance level. Thus, the authors concluded that usage variances may not always be normally distributed.

Gribbin and Lau. Gribbin and Lau (13) investigated the normality of direct labor efficiency variances experienced at a medium sized manufacturing plant. Thirty-three to 42 weeks of direct labor efficiency variances were collected from each of 14 production departments. The authors did not describe their collection method. Thus, their sample of variances may not have been randomly selected.

Because variance thresholds can be in dollars or in percentages, the authors computed the variances both ways. A direct labor efficiency variance expressed in dollars is the difference between the planned and actual number of hours required, multiplied by a standard wage rate. The direct labor efficiency variance can then be converted into a percentage by dividing it by the actual direct labor cost.

Using the Bowman-Shenton and Shapiro-Wilk normality tests, Gribbon and Lau tested the normalilty of the variances at the .05 significance level, and had mixed results: seven of the 14 direct labor dollar variances were normal, and only 1 of the 14 direct labor percentage variances were normal.

Assessment. The results of both studies indicate that cost variances are not always normal. Neither result appears to be based on a random sample of cost variances, and neither result was based on defense cost variances. Thus, there appears to be ample room for this study, which tests the normality of defense cost variances. Indeed, this study was partially prompted by the advice of Gribbin and Lau for more empirical research to validate their non-normality conclusions (13:97).

Conclusion

This chapter has reviewed the literature pertaining to cost variance investigation models, and described the only two reported empirical tests of the normality assumption. The statistical models show considerable promise to reduce the number of frivolous cost variance investigations. However, these models have not been widely adopted in industry, perhaps because the information requirement is quite large relative to the information required by the simple model.

Many of the statistical models require information about the distribution of the cost variance. Often, the models assume that the distribution is normal. Yet the only two empirical tests of this assumption show that cost variances are sometimes not normally distributed. The following chapter will describe the procedures used to test the normality assumption on defense cost variances.

III. Methodology

Introduction

This study tests the hypothesis that defense cost variances are normally distributed. A defense cost variance is defined as the difference between the Budgeted Cost of Work Performed (BCWP) and the Actual Cost of Work Performed (ACWP):

$$\text{Cost variance} = \text{BCWP} - \text{ACWP} \qquad (1)$$

ACWP is "costs actually incurred and recorded in accomplishing the work performed within a given time period." (8:2-1). BCWP is "the sum of budgets for completed work packages and completed portions of open work packages" and coincides to the same time period as ACWP (8:2-2).

The rationale for the hypothesis was described in Chapter I, and the relevant literature involving the statistical cost variance investigation models and prior studies similar to this one were reviewed in Chapter II. This chapter focuses on the specific methodology used to test this hypothesis by describing the statistical normality tests, the sample data, and the procedures used to collect the sample data.

Normality Tests

There are many tests of normality. In a comprehensive review, D'Agostino and Stephens concluded that no single test is optimal for every possible situation (6). Four tests were used in this study: Bowman-Shenton (simultaneously uses the skewness and kurtosis moments), Shapiro-Wilk, Chi-square, and Kolmogorov-Smirnov. As described in Chapter II, Jacob and Lorek evaluated cost variance normality using "moment tests," which involve separate measures of skewness and kurtosis, and the Kolmogorov-Smirnov test. In a more recent study, Gribbin and Lau used two tests. The first was the Bowman-Shenton test, an "omnibus moment test" which combines skewness and kurtosis. The second was the Shapiro-Wilk W test, a regression test of normality recommended by D'Agostino and Stephens (6). Finally, the Chi-square test was used largely because of its availability in statistical software packages.

Skewness. Skewness is a measure of a distribution's deviation from symmetry. The normal distribution is symmetrical, with the mean, median, and mode the same. A distribution that stretches toward one tail or the other is termed "skewed." When the tail stretches to the left, toward smaller values, it is negatively skewed where the distribution's mean < median < mode. When the tail stretches toward the right, toward larger values, it is positively skewed where mean > median > mode.

The equation for skewness of a sample is (6:279, 375) :

$$\sqrt{b_1} = [\Sigma (x_i - \hat{u})^3] / [\Sigma (x_i - \hat{u})^2]^{3/2} \qquad (2)$$

where b_1 is the skewness of a sample, x_i is a random variable or observation for $i = 1$ to n, and $\hat{u}$ is the sample mean. If a distribution is symmetric about its mean, as is the normal distribution, its skewness is zero. Thus, a non-zero value for $\sqrt{b_1}$ indicates that the distribution is not normal.

Kurtosis. Kurtosis is a measure of a distribution's peakedness (or flatness). Distributions where dollar variances cluster heavily or pile up in the center (along with more observations than normal in the extreme tails) are peaked or "leptokurtic." Flat distributions with dollar variances more evenly distributed and tails fatter than a normal distribution are called "platykurtic." Intermediate or "mesokurtic" distributions are neither too peaked nor too flat.

The equation for the kurtosis of a sample is (6:279, 375):

$$b_2 = [\Sigma(x_i - \hat{u})^4] / [\Sigma(x_i - \hat{u})^2]^2 \tag{3}$$

where b_2 is the kurtosis of a sample, x_i is a random variable or observation for $i = 1$ to n, and $\hat{u}$ is the sample mean. The value of kurtosis for a normal distribution is 3 (6:375). Values of b_2 not equal to 3 indicate non-normality. In distributions with tails thicker than tails in the normal distribution, $b_2 > 3$. Similarly, when the tails are thinner than tails in a normal distribution $b_2 < 3$.

Bowman-Shenton Test. The Bowman-Shenton test consists of computing skewness ($\sqrt{b_1}$) and kurtosis (b_2) using equations (2) and (3), and plotting the couplet ($\sqrt{b_1}$, b_2) on a contour chart drawn for a given level of significance. D'Agostino and Stephens indicate that the simple moment tests for normality can give conflicting signals because skewness ($\sqrt{b_1}$) and kurtosis (b_2) are not independent variables, and consider the "omnibus test" developed by Bowman and Shenton to be more powerful (6:283). If the plotted point is external to the contour corresponding to the sample size, the null hypothesis of normality is rejected. Both 90% and 95% contour charts are provided by

D'Agostino and Stephens (6:282), and will not be duplicated. Here, a significance level of .05 (α = .05) was selected for all of the normality tests, and the 95% contour chart was used for this test.

Shapiro-Wilk Test. The Shapiro-Wilk W test is a regression test of normality. For a description of the regression procedures, see D'Agostino and Stephens (6:393-394). The W test statistic is computed as

$$W = (\Sigma a_i x_i)^2 / \Sigma (x_i - \hat{u})^2 \tag{4}$$

where a_i are optimal weights, x_i is the random variable or observation for i = 1 to n, and $\hat{u}$ is the sample mean. The a_i values were derived by Shapiro and Wilks using weighted least squares regression analysis, and are available in tables (e.g., 6:209 and 28:604).

The W statistic is interpreted similar to the coefficient of determination, R^2. The upper limit is one, and the closer the W statistic is to one, the closer the distribution fits a normal distribution. In this case, the larger the W statistic, the closer the distribution of cost variances is to normality.

The computed W test statistic is compared with critical W values in a table provided by several authors (4:468-469; 6:212; 28:605). If the computed W test statistic is less than the critical value given in the lower tail of the table, the null hypothesis of normality is rejected. For example, for a sample size of 48, the critical value is 0.947 at the .05 level of significance. If the W test statistic is less than 0.947, the null hypothesis is rejected.

Kolmogorov-Smirnov Test. The Kolmogorov-Smirnov test for goodness-of-fit (4:346-349; 5:650-651; 21:712-713) compares an observed sample distribution, $F_o(X)$, with a theoretical distribution, $F_T(X)$. The theoretical distribution represents the expectation of normality under the null hypothesis. The test determines the greatest vertical distance between the observed and theoretical distributions, and defines this value as maximum deviation (D).

Using a table of critical values for D, the test determines whether such a large divergence is likely. Conover cautions that when the sample size is larger than 40, the critical value is not exact, but can be approximated by a formula given in the footnotes to his table (4:462). Here, the expected sample size is 48. Using his formula, the critical value is 0.192 at a significance level of 0.05. Thus, if the Kolmogorov-Smirnov test statistic exceeds 0.192, the null hypothesis of normality is rejected.

Chi-square Goodness-of-Fit Test. The chi-square goodness-of-fit test compares the observed frequencies (F_o) of a particular occurrence with the expected frequencies (F_e) of the assumed distribution to determine if the expected distribution fits the data. The computation for the test statistic (X^2) is the sum of the observed minus expected frequencies squared, divided by the expected frequency (5:447; 21:680):

$$X^2 = \Sigma \left[(F_o - F_e)^2 / F_e \right] \quad (5)$$

The chi-square statistic is based on the size of the difference for each category in the frequency distribution. If the observed frequencies are very close to the expected frequencies, then the chi-square statistic will be close to zero. As the observed frequencies reflect greater differences from the expected frequencies, the value of the chi-square statistic becomes larger.

The level of significance and the degrees of freedom determine the critical value for the chi-square test statistic. The degrees of freedom are equal to the number of categories, minus the number of parameters used in the estimate, minus one. The subtraction of one is necessary because the last category entered is not free to vary. If the test statistic exceeds the critical value, the null hypothesis is rejected.

Software. The normality tests were accomplished with a micro-computer and three software packages available at AFIT: *Excel, Statgraphics*, and *Statistix*. *Excel* (27) was used to compute the descriptive statistics (mean, median, mode, skewness, and kurtosis) for each sample of cost variances, and to perform the Bowman-Shenton test. *Statgraphics* (29) was used for the Kolmogorov-Smirnov and the Chi-square tests. *Statistix* (30) was used for the Shapiro-Wilk test.

The Data

The Cost Performance Report. Data for the normality tests were obtained from microfiche copies of *Cost Performance Reports* stored in the cost library supporting the Aeronautical Systems Center (ASC) of Air Force Material Command located at Wright-Patterson Air Force Base. Defense contractors prepare the *Cost Performance Report* (CPR) each month and send it to the system program office that manages the project.

The CPR summarizes the cost, schedule, and technical status of the defense project using a standardized breakdown of the work on the project, termed a "Work Breakdown Structure" (WBS). The WBS is a product-oriented description of all work required to complete the project, and is often viewed as a family-tree, with successive layers of detail termed "levels" (9).

Since 1967, CPRs on virtually all significant defense contracts managed by ASC have been sent to the program offices at ASC and eventually to the cost library for storage on microfiche. The CPR typically contains monthly and cumulative cost, budget, and variance data for every WBS element down to level three, although the contractor performs work at much more detailed levels.

Validity. To ensure the validity of the data on the CPR, the DOD requires that the contractor comply with the *DOD Cost/Schedule Control Systems Criteria* (C/SCSC), or "criteria" for short. The criteria are internal controls intended to ensure that the contractor's management control systems provide reliable and timely data useful for managing the defense contract (2, 7, 8, 9, 14; 16:669-670). Government review teams from the program office and government surveillance teams at the contractor's factory monitor the contractor's compliance to the criteria. If the contractor is compliant, the government assumes that the data on the CPR are reliable. The criteria have been required since 1967, and most defense contractors have been criteria-compliant for many years.

The Collection Procedure. For this study, about 4 years of monthly cost variances were extracted from 50 WBS elements on two research and development contracts, termed A and B. The identity of each contract will not be revealed. Forty-eight months of consecutive cost variances were considered necessary to properly replicate the number of sequential cost variances collected by Gribbin and Lau (13). Due to severe time constraints on the researcher, only two contracts with the necessary 4 years of consecutive cost variances were selected. Contract A contained 13 WBS elements and Contract B contained 37 WBS elements with 4 years of consecutive cost variances. Thus, data from 50 WBS elements, each with about 4 years of consecutive cost variances, were manually extracted from the microfiche and input into an *Excel* spreadsheet for analysis.

Inflation Adjustment. Cost data on CPRs are in then-year dollars. It was not clear if the cost variances needed to be adjusted to constant dollars. Neither of the two previous normality studies (13, 17) indicated that the cost variances were adjusted for inflation before the normality tests were performed. Further, the literature describing the cost variance investigation models does not address this issue.

To be prudent, the normality tests were performed on the cost variances in then-year dollars and in constant dollars. The base years for contracts A and B were 1991 and 1974, respectively. Weighted inflation indices corresponding to these base years were available from an internet site managed by the Assistant Secretary of the Air Force, Financial Management & Comptoller (SAF/FM) in Washington D.C. Once down-loaded and entered into *Excel*, the cost variance data were converted into constant dollars.

Conclusion

This chapter has described the procedures for testing the null hypothesis that defense cost variances are distributed normally. Based largely on what previous researchers have used on comparable studies, four tests were selected and briefly described. Among these are the Bowman-Shenton and the Shapiro-Wilk tests, which are considered by D'Agostino and Stephens (6) to be the most powerful goodness-of-fit tests for normality. The only two known normality studies reported in the literature were also reviewed. This study is a replication of the most recent, performed by Gribbin and Lau (13). Finally, the data, the data collection procedures, and the inflation adjustment procedures were described. The next chapter reports the results of the normality tests.

IV. Results

Introduction

This chapter describes the results of testing the null hypothesis that cost variances on defense contracts are distributed normally. Fifty series of monthly cost variances experienced on two defense contracts (Contract A and Contract B) were evaluated using four tests of normality (Bowman-Shenton, Shapiro-Wilk, Kolmogorov-Smirnov, and Chi-square). The rationale for the hypothesis was provided in Chapter I. The relevant literature was reviewed in Chapter II. The normality tests, data, and data collection procedures were described in Chapter III. Here, several tables and figures are used to summarize the results.

Four tables summarize the results of the normality tests. Tables 3 and 4 pertain to defense contracts A and B, respectively, with the cost variances reported in nominal dollars. Tables 5 and 6 are similar, except the cost variances were adjusted to constant dollars before applying the normality tests.

Each table is formatted the same way to facilitate comparison across contracts. The first four columns list the work breakdown structure (WBS) element number, the WBS level, the WBS element name, and the final Budget at Completion (BAC) of that WBS element for each series of cost variances. The next four columns contain descriptive statistics pertaining to the cost variances, and include the mean, standard deviation,

Table 3. Results of Normality Tests on Contract A (48 months, Nominal Dollars)

Work Breakdown Structure				*Cost Variance Statistics ($000)*				*Normality Test Statistics (* = normal at α =.05)*				
WBS Element	*WBS Level*	*WBS Element Name*	*Final BAC ($000)*	*Mean*	*Std Dev*	*Median*	*Mode*	*Bowman-Shenton Skewness* $\sqrt{b_1}$	*Bowman-Shenton Kurtosis* b_2	*Shapiro-Wilk W=.947*	*Kolmo.-Smirnov KS=.192*	*Chi-Square (df)*
1	1	System	184,796	(979.8)	1,592.2	(508.5)	NA	(4.00)	18.75	0.521	0.275	37(2)
2	2	Air Vehicle	147,069	(601.5)	1,517.4	(214.0)	(157.0)	(4.22)	20.07	0.473	0.313	63(4)
3	3	Air Frame Mod	24,115	(74.8)	125.6	(43.0)	(38.0)	(1.89)	4.74	0.812	0.202	19(4)
4	3	Communication	2,996	(8.8)	34.3	0.0	0.0	(4.50)	24.02	0.396	0.366	117(3)
5	3	Nav/guidance	984	(3.9)	25.5	0.0	0.0	(6.91)	47.82	0.129	0.472	167(3)
6	3	Elec/Op sensors	44,967	(125.8)	812.6	(9.0)	(2.0)	(5.13)	32.50	0.348	0.407	108(2)
7	3	Fire Control System	24,022	(52.5)	251.4	0.0	0.0	(6.26)	41.43	0.249	0.400	113(2)
8	3	Control & Display	7,866	(33.1)	124.2	0.0	0.0	(4.70)	26.34	0.454	0.334	82(3)
9	3	System Sofware	12,578	(127.8)	168.6	(115.0)	(127.0)	(2.04)	10.33	0.780	0.177*	15(3)
10	3	Misc. Proc. Equip.	4,176	(4.4)	28.3	0.0	0.0	(3.24)	13.02	0.387	0.464	177(4)
11	3	EW Def. System	2,667	(0.1)	24.1	0.0	0.0	3.34	18.75	0.567	0.357	67(3)
12	3	Armament	22,698	(177.1)	1,273.1	0.0	0.0	(6.89)	47.60	0.144	0.480	156(3)
13	2	Training	127	(0.3)	0.9	0.0	0.0	(0.529)	5.55	0.623	0.400	NA

Table 4. Results of Normality Tests on Contract B (47 months, Nominal Dollars)

Work Breakdown Structure				*Cost Variance Statistics ($000)*				*Normality Test Statistics (* = normal at α =.05)*				
WBS Element	*WBS Level*	*WBS Element Name*	*Final BAC ($000)*	*Mean*	*Std Dev*	*Median*	*Mode*	*Bowman-Shenton Skewness* $\sqrt{b_1}$	*Bowman-Shenton Kurtosis* b_2	*Shapiro-Wilk W=.946*	*Kolmo.-Smirnov KS=.194*	*Chi-Square (df)*
1	1	System	152,150	(624.6)	1,019.6	(300.0)	(541.0)	(1.84)	3.67	0.808	0.221	11(3)
2	2	Air Vehicle	72,436	(478.9)	903.5	(111.0)	(60.0)	(2.27)	6.37	0.752	0.245	28(4)
3	3	Air Frame	69,338	(298.5)	970.4	(109.0)	(79.0)	(1.47)	6.48	0.778	0.242	47(3)
4	4	Integr. & Assembly	6,345	(46.9)	94.5	(7.0)	(1.0)	(3.29)	14.53	0.652	0.223	29(3)
5	4	Basic Structure	51,226	(388.8)	918.0	(60.0)	(407.0)	(1.81)	5.69	0.767	0.290	54(3)
6	4	Vehicle Power	5,785	(21.2)	137.2	(3.0)	(1.0)	(0.84)	4.40	0.809	0.221	24(4)
7	4	Env. Control System	465	(3.4)	36.6	(1.0)	0.0	0.40	10.09	0.678	0.239	47(2)
8	4	Flt. Control System	2,823	2.8	107.1	(1.0)	0.0	0.24	6.48	0.727	0.267	50(2)
9	4	Crew Station	1,332	(6.0)	45.8	(3.0)	0.0	(0.60)*	4.13*	0.818	0.223	22(3)
10	4	Engine Installation	1,363	(69.4)	484.2	(0.0)	0.0	(6.72)	45.70	0.174	0.458	134(3)
11	3	Communications	249	5.0	53.2	(0.0)	0.0	1.45	14.14	0.328	0.419	133(3)
12	3	Nav. guidance	398	3.8	45.8	(0.0)	0.0	(0.61)	11.45	0.579	0.335	79(2)
13	3	Fire Control	2,451	(26.2)	126.1	(6.0)	0.0	(0.72)*	2.44*	0.931	0.135*	22(3)
14	2	Training	434	1.0	2.9	0.0	0.0	0.76*	2.63*	0.840	0.260	37(4)
15	3	Equipment	276	0.3	2.00	0.0	0.0	0.38*	2.28*	0.827	0.296	43(3)
16	3	Services	158	0.5	1.8	0.0	0.0	(0.78)	5.73	0.764	0.295	41(3)
17	3	Peculiar Spt. Equip.	7,207	(25.9)	158.7	(23.0)	13.0	1.68	18.56	0.541	0.268	59(2)
18	3	Org. Intermediate	7,062	(23.5)	156.9	(20.0)	(10.0)	1.73	19.52	0.517	0.273	55(2)
19	3	Depot	146	(0.0)	3.1	0.0	0.0	(0.76)*	2.47*	0.911	0.189*	23(4)

Continued on next page.

Table 4. Results of Normality Tests on Contract B (47 months, Nominal Dollars) - Continued -

Work Breakdown Structure				*Cost Variance Statistics ($000)*				*Normality Test Statistics (* = normal at α =.05)*				
WBS Element	*WBS Level*	*WBS Element Name*	*Final BAC ($000)*	*Mean*	*Std Dev*	*Median*	*Mode*	*Bowman-Shenton Skewness $\sqrt{b1}$*	*Kurtosis b2*	*Shapiro-Wilk W=.946*	*Kolmo.-Smirnov KS=.194*	*Chi-Square (df)*
20	2	System Test & Eval	51,392	(109.1)	315.7	(17.0)	NA	(1.28)	2.54	0.908	0.144*	6(3)*
21	3	Mock-ups	2,632	(18.8)	67.7	(6.0)	(4.0)	(0.85)*	2.99*	0.819	0.243	34(4)
22	3	Wind Tunnel test	404	(3.6)	22.7	0.0	0.0	(3.18)	22.40	0.439	0.318	76(2)
23	3	Static Articles test	2,492	(8.2)	45.0	(1.0)	(1.0)	(0.56)	1.81	0.884	0.217	50(3)
24	3	Fatique Articles test	5,236	(20.4)	87.4	(16.0)	(8.0)	0.25	1.27	0.957*	0.135*	15(3)
25	3	Egress tests	1,035	(0.2)	28.2	0.0	0.0	(0.53)	13.60	0.568	0.307	52(2)
26	3	Prototype tests	10,135	(13.4)	106.2	(1.0)	0.0	1.14	7.10	0.741	0.255	62(3)
27	3	DT&E and IOT&E	24,090	(21.1)	208.5	(16.0)	NA	(1.00)	4.12	0.886	0.166*	11(3)
28	3	Other system tests	5,368	(25.6)	45.2	(8.0)	(5.0)	(1.66)	2.56	0.803	0.247	24(4)
29	2	System prog. mngt.	15,515	(16.6)	75.9	2.0	3.0	(1.16)	2.37	0.870	0.216	10(4)
30	3	System engin. mngt.	4,097	(2.3)	19.9	0.0	0.0	(0.97)	3.59	0.863	0.187*	13(3)
31	3	ILS support	2,891	(2.3)	18.7	0.0	0.0	0.60	1.73	0.893	0.165*	35(3)
32	3	Prog. mngt. element	8,528	(16.9)	63.9	3.0	(51.0)	(1.51)	3.02	0.852	0.216	24(3)
33	2	Data	5,166	9.9	61.0	3.0	26.0	1.14	5.55	0.866	0.154*	11(3)
34	3	Tech orders/ manuals	2,060	5.0	16.3	0.0	0.0	1.12	0.66	0.895	0.174*	10(4)
35	3	Engine data	1,534	(8.2)	59.5	(3.0)	(20.0)	1.71	8.66	0.793	0.200	23(3)
36	3	Management	670	3.5	11.4	1.0	0.0	3.84	19.64	0.611	0.252	29(3)
37	3	Other provisioning	901	6.7	11.3	3.0	0.0	0.31	(0.27)	0.942	0.181*	17(4)

Table 5. Results of Normality Tests on Contract A (48 months, Constant Dollars)

Work Breakdown Structure				*Cost Variance Statistics ($000)*				*Normality Test Statistics (* = normal at α =.05)*				
WBS Element	*WBS Level*	*WBS Element Name*	*Final BAC ($000)*	*Mean*	*Std Dev*	*Median*	*Mode*	*Bowman-Shenton Skewness* $\sqrt{b_1}$	*Kurtosis* b_2	*Shapiro-Wilk W=.947*	*Kolmo.-Smirnov KS=.192*	*Chi-Square (df)*
1	1	System	168,918	-927.1	1501.9	-489.1	NA	-3.9	17.8	0.565	0.283	86(3)
2	2	Air Vehicle	134,432	-571	1430.9	-204.3	-190.7	-4.1	19.2	0.515	0.309	77(3)
3	3	Air Frame Mod	22,043	-71.3	121.5	-40.4	NA	-2.0	5.0	0.818	0.205	25(2)
4	3	Communication	2,739	-8.3	32.2	0.0	0.0	-4.4	23.3	0.452	0.363	109(2)
5	3	Nav/guidance	899	-3.8	25	0.0	0.0	-6.9	47.8	0.166	0.473	162(3)
6	3	Elec/Op sensors	41,103	-122.3	792.9	-8.4	-1.8	-5.2	32.8	0.402	0.409	99(2)
7	3	Fire Control System	21,958	-49.1	234.1	0.0	0.0	-6.2	41.2	0.297	0.400	144(3)
8	3	Control & Display	7,190	-31.3	116.3	0.0	0.0	-4.6	25.5	0.506	0.330	60(3)
9	3	System Sofware	11,497	-122.1	162.3	-107.7	NA	-2.2	11.1	0.816	0.169*	15(3)
10	3	Misc. Proc. Equip.	3,817	-4.1	26.3	0.0	0.0	-3.3	13.1	0.422	0.464	165(4)
11	3	EW Def. System	2,438	-0.2	22.5	0.0	0.0	3.1	17.4	0.633	0.356	60(3)
12	3	Armament	20,748	-165	1184.3	0.0	0.0	-6.9	47.6	0.184	0.480	168(4)
13	2	Training	116	-0.2	0.9	0.0	0.0	-0.6	5.3	0.667	0.401	87(3)

Table 6. Results of Normality Tests on Contract B (47 months, Constant Dollars)

Work Breakdown Structure				*Cost Variance Statistics ($000)*				*Normality Test Statistics (* = normal at α =.05)*				
WBS Element	*WBS Level*	*WBS Element Name*	*Final BAC ($000)*	*Mean*	*Std Dev*	*Median*	*Mode*	*Bowman-Shenton Skewness* $\sqrt{b_1}$	*Kurtosis* b_2	*Shapiro-Wilk W=.946*	*Kolmo.-Smirnov KS=.194*	*Chi-Square (df)*
1	1	System	117,038	(575.2)	935.4	(255.3)	NA	(1.78)	3.05	0.801	0.238	27(4)
2	2	Air Vehicle	55,720	(442.9)	828.6	(90.5)	NA	(2.17)	5.79	0.772	0.246	42(4)
3	3	Air Frame	53,337	(284.9)	889.8	(83.8)	(60.8)	(1.43)	5.62	0.817	0.250	41(3)
4	4	Integr. & Assembly	4,881	(42.7)	85.5	(5.4)	(2.3)	(3.13)	13.08	0.692	0.237	59(3)
5	4	Basic Structure	39,405	(368.3)	846.7	(48.9)	(17.9)	(1.71)	4.67	0.798	0.292	72(4)
6	4	Vehicle Power	4,450	(17.2)	125.0	(2.3)	(1.5)	(0.61)	4.35	0.836	0.237	30(3)
7	4	Env. Control System	358	(2.7)	30.9	(0.8)	0.0	0.49	8.85	0.760	0.244	33(2)
8	4	Flt. Control System	2,172	4.1	97.4	(0.8)	0.0	0.49	6.83	0.763	0.217	30(3)
9	4	Crew Station	1,025	(5.0)	42.9	(2.3)	0.0	0.00*	4.80*	0.831	0.232	23(3)
10	4	Engine Installation	1,048	(55.8)	395.4	0.0	0.0	(6.69)	45.40	0.224	0.454	135(3)
11	3	Communications	192	4.9	48.9	0.0	0.0	1.74	14.57	0.378	0.442	119(3)
12	3	Nav. guidance	306	3.9	41.4	0.0	0.0	(0.36)	11.41	0.633	0.331	63(2)
13	3	Fire Control	1,885	(22.4)	109.0	(4.6)	0.0	(0.55)	2.01	0.958*	0.405	13(4)
14	2	Training	334	0.9	2.7	0.0	0.0	1.00	2.84	0.854	0.257	31(4)
15	3	Equipment	212	0.2	1.8	0.0	0.0	0.31*	2.26*	0.840	0.294	70(3)
16	3	Services	122	0.5	1.6	0.0	0.0	(0.33)*	4.33*	0.822	0.302	57(2)
17	3	Peculiar Spt. Equip.	5,544	(22.2)	124.0	(20.4)	12.6	1.64	17.40	0.648	0.257	44(2)
18	3	Org. Intermediate	5,432	(20.7)	122.7	(16.3)	(1.0)	1.69	18.21	0.631	0.266	43(2)
19	3	Depot	112	0.0	2.7	0.0	0.0	(0.64)	1.88	0.931	0.175*	13(4)

Continued on next page.

Table 6. Results of Normality Tests on Contract B (47 months, Constant Dollars) - Continued -

Work Breakdown Structure				*Cost Variance Statistics ($000)*				*Normality Test Statistics (* = normal at α =.05)*				
WBS Element	*WBS Level*	*WBS Element Name*	*Final BAC ($000)*	*Mean*	*Std Dev*	*Median*	*Mode*	*Bowman-Shenton Skewness* $\sqrt{b1}$	*Kurtosis* $b2$	*Shapiro-Wilk W=.946*	*Kolmo.-Smirnov KS=.194*	*Chi-Square (df)*
20	2	System Test & Eval	39,532	(99.2)	280.1	(13.1)	NA	(1.38)	2.64	0.900	0.160*	10(4)
21	3	Mock-ups	2,025	(17.3)	61.9	(4.6)	(4.6)	(0.99)	3.20	0.838	0.245	33(3)
22	3	Wind Tunnel test	311	(3.3)	20.7	0.0	0.0	(4.22)	27.79	0.459	0.322	77(2)
23	3	Static Articles test	1,917	(7.8)	42.8	(0.8)	(0.8)	(0.60)*	2.13*	0.883	0.228	33(4)
24	3	Fatique Articles test	4,028	(17.8)	76.3	(15.5)	NA	0.23	1.03	0.965*	0.336	8(4)*
25	3	Egress tests	796	(0.1)	27.2	0.0	0.0	(0.52)	13.96	0.627	0.321	49(1)
26	3	Prototype tests	7,796	(12.7)	98.2	(0.8)	0.0	0.91	6.10	0.786	0.254	53(3)
27	3	DT&E and IOT&E	24,090	(17.4)	178.9	(12.3)	NA	(1.12)	4.76	0.908	0.174*	14(3)
28	3	Other system tests	4,129	(23.7)	43.2	(6.5)	0.0	(1.82)	3.02	0.774	0.264	65(3)
29	2	System prog. mngt.	11,935	(17.4)	71.7	1.8	6.2	(1.32)	2.62	0.861	0.232	13(4)
30	3	System engin. mngt.	3,152	(2.5)	18.2	0.0	0.0	(1.05)	3.50	0.872	0.201	18(4)
31	3	ILS support	2,224	2.1	17.1	0.0	0.0	0.58	1.58	0.894	0.178*	28(4)
32	3	Prog. mngt. element	6,560	(17.1)	60.7	2.3	36.3	(1.64)	3.34	0.845	0.231	30(4)
33	2	Data	3,974	9.4	51.0	2.3	2.3	1.09	4.79	0.911	0.140*	11(3)
34	3	Tech orders/ manuals	1,585	4.1	13.7	0.0	0.0	1.06	0.52	0.899	0.171*	13(3)
35	3	Engine data	1,180	(6.4)	49.2	(2.4)	(1.5)	1.68	8.05	0.846	0.196	23(3)
36	3	Management	515	3.1	10.1	0.8	0.0	3.83	19.40	0.650	0.252	40(3)
37	3	Other provisioning	693	6.2	10.3	2.4	0.0	0.35	(0.39)	0.929	0.196	16(4)

median, and mode. The remaining columns contain the statistics resulting from the four normality tests.

In addition to these tables, four figures pertaining to the Bowman-Shenton normality test are provided. In the Bowman-Shenton test, measures of the distribution's shape (skewness and kurtosis) are plotted on a contour chart drawn for a specific level of statistical significance. For this study, the level of significance was five percent ($\alpha = .05$) for each normality test, including the Bowman-Shenton test. When the couplet of skewness ($\sqrt{b_1}$) and kurtosis (b_2) lies within the contour corresponding to the sample size, the distribution of cost variances is normal.

A description of the results of the normality tests follows, first for Contract A, and then for Contract B. The chapter concludes by comparing the results of this study with results reported on the two prior studies.

Contract A

As shown in Tables 3 and 5, the null hypothesis was generally rejected for each of the thirteen series of monthly cost variances on Contract A evaluated in nominal and constant dollars, respectively. Each series was for 48 months (January 1991 to December 1994). Ten of the series were at WBS level 3, two were at level 2, and the last was at the total contract level. The final Budget at Completion (BAC) for the series ranged from $127 thousand (nominal dollars) for WBS Element 13 to $184.8 million (nominal dollars) for WBS Element 1.

In general, these results were insensitive to the normality test used and to inflation. The four normality tests were usually in agreement, and when the null hypothesis of normality was rejected with the variances in nominal dollars, it was also rejected with the variances in constant dollars. The only exception was WBS Element 9 (System Software), which passed the Kolmogorov-Smirnov test in nominal dollars and in constant dollars (but failed the other three normality tests).

All but one of the moment couplets for the Bowman-Shenton test were off the 95% contour chart. The series for WBS Element 13 (Training) was on the chart in nominal and in constant dollars, but because it was outside the contour line corresponding to a sample size of 48, the series was not normally distributed (Tables 3 and 5; Figures 1 and 3).

None of the Shapiro-Wilk test statistics were above the critical value of 0.947. In general, converting a series from nominal to constant dollars increased the Shapiro-Wilk test statistic, moving the series closer to normality, but never enough to exceed the critical value at the .05 level of significance.

The Chi-square test statistic did not indicate that any of the series were normally distributed. However, the statistic was found to be very sensitive to the software package that was used. When computing the statistic on the same series using several statistical software packages, different Chi-square statistics were reported. An analysis

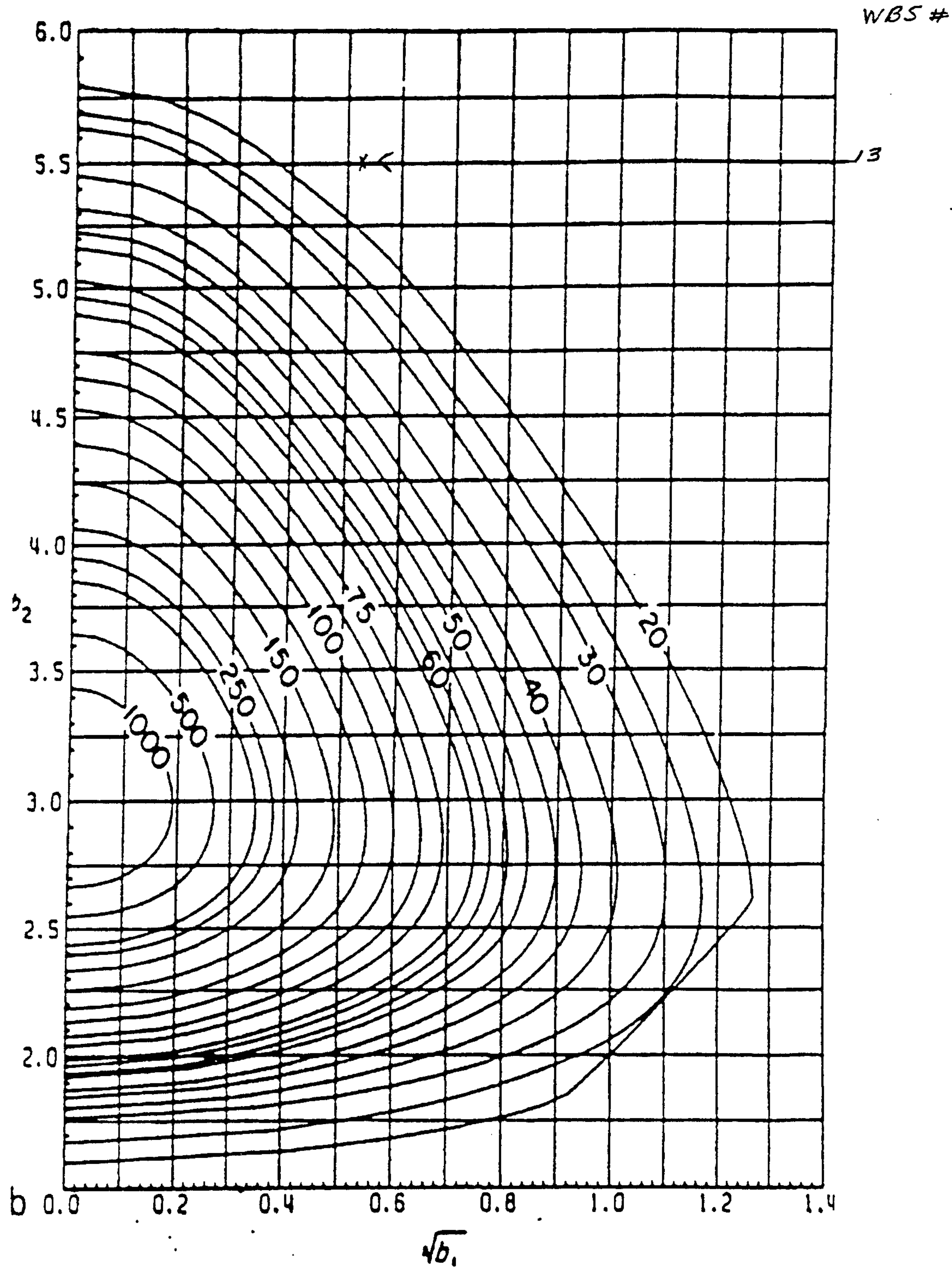

Figure 1. 95% Contour Chart for Contract A
Then Year Dollars
Source: D'Agostino and Stephens (1986, p. 282), with permission of the authors and the publisher, Marcel Dekker, Inc.

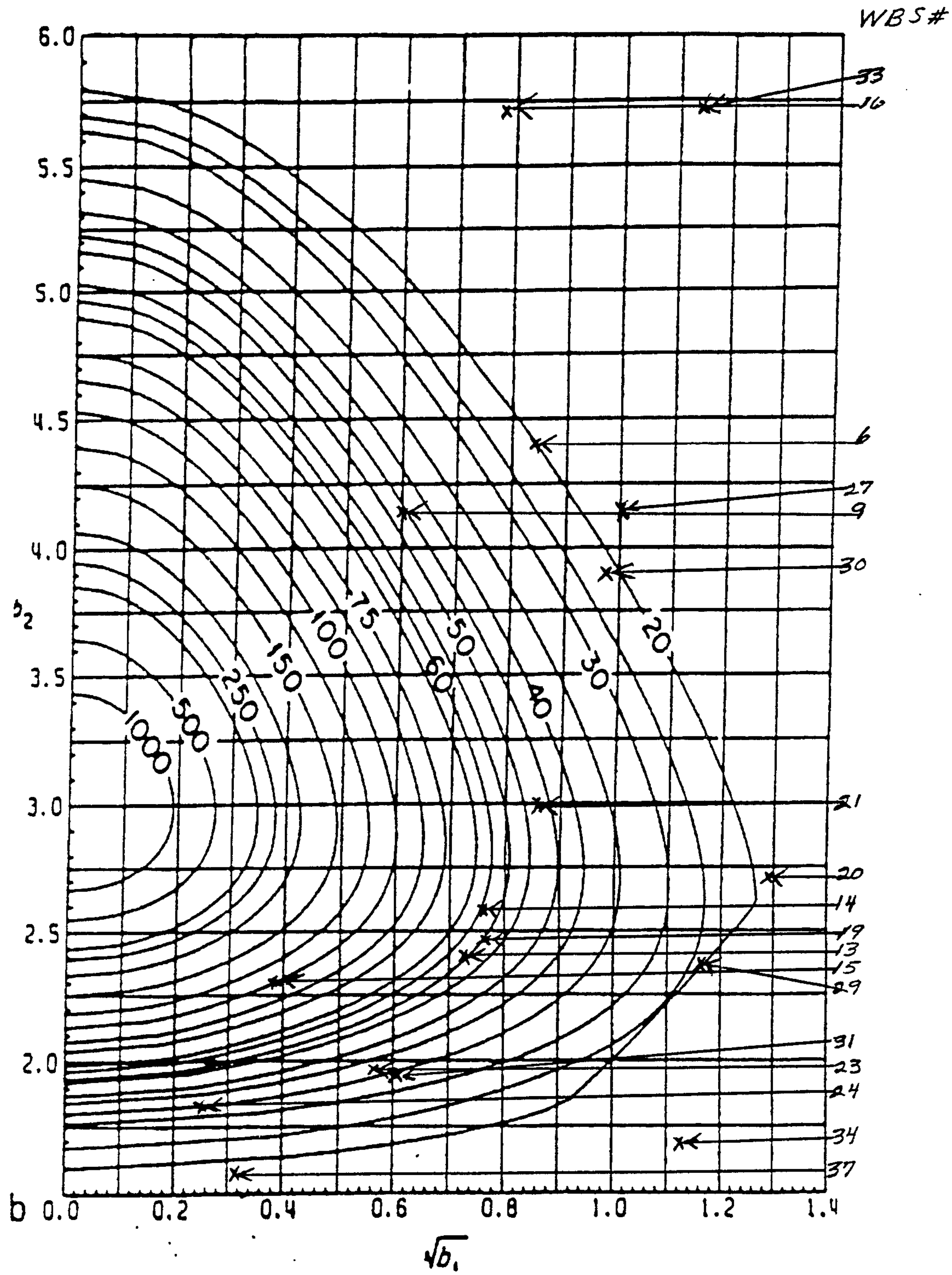

Figure 2. 95% Contour Chart for Contract B
Then Year Dollars
Source: D'Agostino and Stephens (1986, p. 282), with permission of the authors and the publisher, Marcel Dekker, Inc.

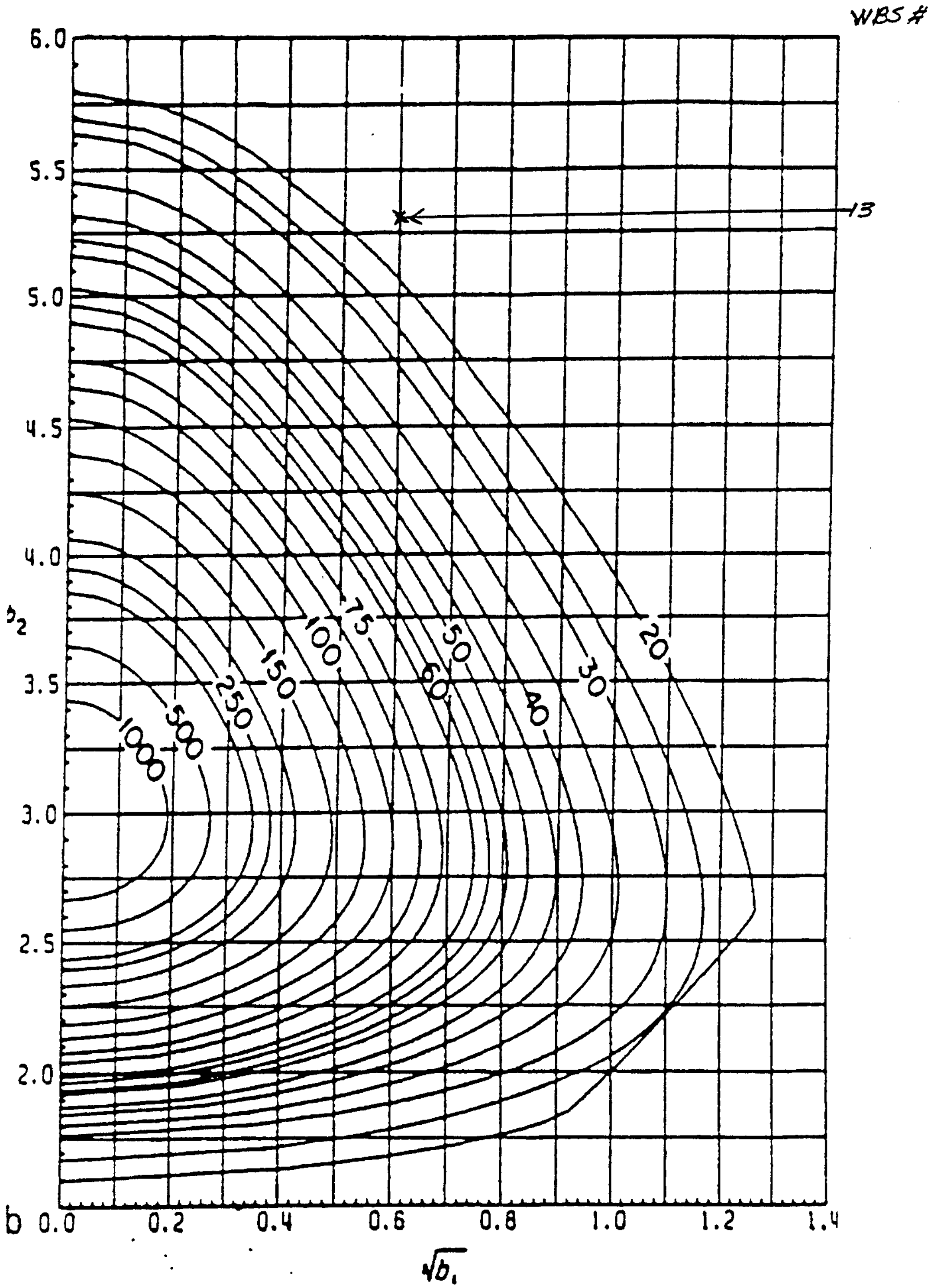

Figure 3. 95% Contour Chart for Contract A
Constant Year Dollars
Source: D'Agostino and Stephens (1986, p. 282), with permission of the authors and the publisher, Marcel Dekker, Inc.

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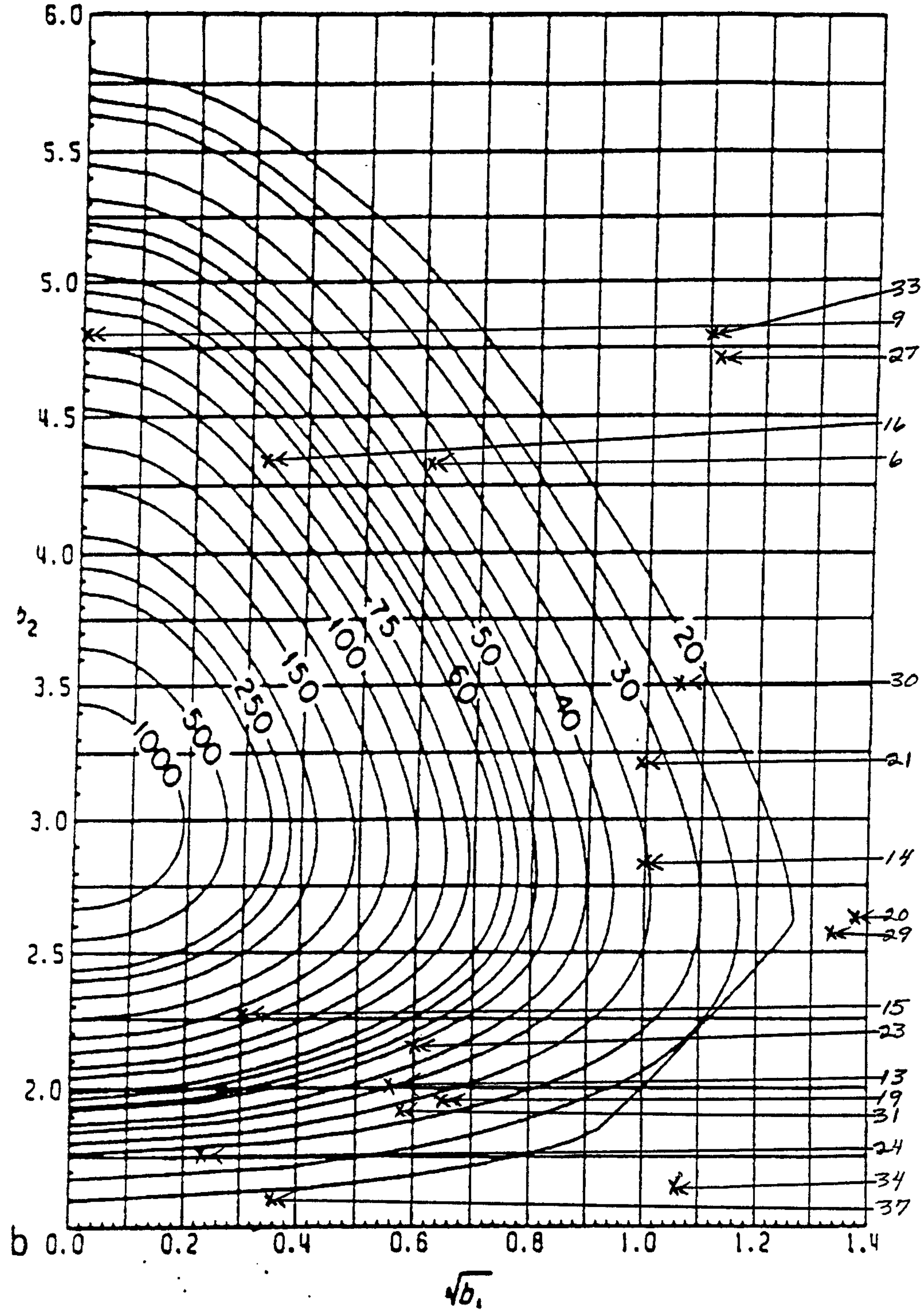

Figure 4. 95% Contour Chart for Contract B
Constant Year Dollars
Source: D'Agostino and Stephens (1986, p. 282), with permission of the authors and the publisher, Marcel Dekker, Inc.

showed that each package determined a different number of cells or groups in which to place the data. Apparently, each package used a different and undocumented algorithm to determine the number of cells. For consistency, a single package (*Statgraphics for DOS*) was chosen for all of the Chi-square tests. But it was clear from this analysis that of the four normality tests used here, the Chi-square test is the least appropriate.

Contract B

As shown in Tables 4 and 6, the null hypothesis was generally rejected for the 37 series of monthly cost variances on Contract B evaluated in nominal and constant dollars, respectively. Each series was 47 months (January 1977 to December 1991, with one month deleted because of missing data). Seven of the series were at WBS level 4, twenty-four were at level 3, five were at level 2, and the last was at the total contract level. The final BAC for the series ranged from $146 thousand (nominal dollars) for WBS Element 19 to $152.2 million (nominal dollars) for WBS Element 1.

As with Contract A, these results were generally insensitive to the normality test used and to inflation. But there were some exceptions. For example, in nominal dollars, six series (WBS elements 9, 13, 14, 15, 19 and 21) were found to have normal distributions based on the Bowman-Shenton test, and non-normal distributions based on the Shapiro-Wilk test. As shown in Table 4 and Figure 2, these WBS elements were within the appropriate contour line on the 95% contour chart. In constant dollars, four series (WBS elements 9, 15, 16 and 23) were found to have normal distributions based on the Bowman-Shenton test (Table 6 and Figure 4), but only two series (WBS elements 13 and 24) were normal based on the Shapiro-Wilk test.

The Kolmogorov-Smirnov test found more series normal than the other tests. In nominal dollars, ten series (WBS elements 13, 19, 20, 24, 27, 30, 31, 33, 34, 37) tested normal. This test was also the most sensitive to inflation. In constant dollars, six series (WBS elements 19, 20, 27, 31, 33, 34) were normal.

Like the Shapiro-Wilk test, the Chi-square test found few series to be normally distributed. In nominal dollars, only one series (WBS Element 20, System Test and Evaluation) was normally distributed. In constant dollars, only one series (WBS Element 24, Fatigue Articles Test) was normally distributed.

Comparison to Prior Studies

Table 7 compares the results of Jacobs and Lorek (1980, 17) and Gribbin and Lau (1991, 13) with the results of this study. Because neither of the prior studies referred to any adjustment for inflation, it is assumed that no adjustment was made. To be comparable, the results of this study are presented based on the analysis of cost variances in nominal dollars.

Jacobs and Lorek. The results reported by Jacobs and Lorek are the most different from the results of this study. For Jacobs and Lorek, 78 percent (7 of 9) of the weekly series had normal distributions based on the Kolmogorov-Smirnov test. Here, only 22 percent (11 of 50) of the series were normal using the same test (Table 3 and 4 for nominal dollars). This difference may be due to differences in the type and frequency of the variances tested. As shown in Table 7, the variances tested by Jacobs and Lorek were not in dollars and were not monthly.

In addition to these differences, the majority of the defense cost variances were much more aggregated at WBS level 3 than the variances tested by Jacobs and Lorek. As defense cost variances are aggregated from levels where work is performed (usually much lower than WBS level 4) to the CPR reporting levels (WBS 1,2,3, and 4), there may be some loss of normality.

Table 7. A Comparison of Cost Variance Normality Studies

Researchers (year)	*Variances (amount)*	*Normality tests used*	*Results at $\alpha = .05$*
Jacobs and Lorek (1980)	Material and utilities usage (11 daily, 9 weekly) from a grain processing firm	Skewness, Kurtosis, Kolmogorov-Smirnov	None of the daily, and 7 of 9 weekly series tested normal.
Gribbin and Lau (1991)	Direct labor efficiency in dollars and percent (32 to 43 months in each of 14 production departments)	Bowman-Shenton, Shapiro-Wilk	7 of 14 dollar series and 1 of 14 percentage series tested normal.
Conley (1996)	Cost variances on R&D defense Contract A (48 months in each of 13 WBS elements)	Bowman-Shenton Shapiro-Wilk Kolmogorov-Smirnov Chi-square	0 series tested normal 0 series tested normal 1 series tested normal 0 series tested normal
	Cost variances on R&D defense Contract B (47 months in each of 37 WBS elements)	Bowman-Shenton Shapiro-Wilk Kolmogorov-Smirnov Chi-square	6 series tested normal 1 series tested normal 10 series tested normal 1 series tested normal

This is apparent even at the reporting levels. For example, consider the Crew Station, identified in Table 4 as WBS element 9. Based on the Bowman-Shenton test, the Crew Station was the only level 4 element to be normally distributed. The other level 4 elements were not normally distributed. The parent element for the Crew

Station and the other level 4 elements is the Air Frame at level 3, and its series is not normally distributed. Apparently, as many non-normal series are combined with few normal series, the distribution of the combined series may not be normally distributed.

Gribbin and Lau. With the possible exception of the level of aggregation, the methodology used by Gribbin and Lau is comparable. Both studies examined monthly cost variances in dollars, and two of the normality tests were the same. In addition, the results are generally consistent, in that both studies found a significant number of series to be non-normal. As shown in Table 7, Gribbin and Lau report 50 percent (7 of 14) of the dollar series to be non-normal. Here, most of the series were non-normal. For example, using the Shapiro-Wilk test, 98 percent (49 of 50) of the series were non-normal, and using the Bowman-Shenton test, 88 percent (44 of 50) of the series were non-normal.

As before, a major difference between Gribbin and Lau and this study pertains to the level of aggregation. The series examined by Gribbin and Lau are direct labor efficiency variances. The series examined here are cost variances, defined as BCWP minus ACWP (Equation 1, Chapter III). All costs may be included in these numbers, including direct labor, direct material, and indirect costs. In general, the *Cost Performance Report* will not distinguish between such categories at WBS levels 3 or 4. Such detail would only be available at much lower levels in the WBS, and is generally not provided to the government unless specifically requested. Thus, cost variances which may be normally distributed at the more detailed levels in the WBS may lose this characteristic as they are aggregated and eventually reported on the CPR.

These results appear to conflict with the Central Limit Theorem in statistics, which infers that as cost variances are aggregated from lower-level WBS elements into higher-levels in the WBS, the total should become increasingly normal. Clearly, that is not the case here.

One possible explanation is a lack of independence among the lower level elements. To test this possibility, the cost variances in WBS elements within the Air Frame on Contract B were tested for correlation using the nonparametric Spearman rank correlation test (5:505-509; 29). (The alternative parametric Pearson Product Moment Correlation test (5:481-488; 29) was not used because most of the cost variances at WBS level 4 were not normal.). The results of this test are presented in Table 8.

Table 8. Spearman Rank Correlations Between WBS Level 4 Elements

	WBS element	*4*	*5*	*6*	*7*	*8*	*9*	*10*
4	Integration and Assembly	1						
5	Basic Structure	0.2796 0.0579	1					
6	Vehicle Power	-0.1179 0.4241	-0.0984 0.5047	1				
7	Environmental Control System	0.2831 0.0549	0.0162 0.9125	-0.0326 0.8249	1			
8	Flight Control System	0.1021 0.4884	-0.3486 0.0181*	0.4112 0.0053*	0.0496 0.7365	1		
9	Crew Station	0.4583 0.0019*	0.0696 0.6370	-0.1513 0.3049	0.4333 0.0033*	0.1308 0.3750	1	
10	Engine Installation	0.0057 0.9690	-0.2412 0.1019	0.2446 0.0971	0.2261 0.1251	0.4334 0.0033*	0.1607 0.2759	1

The first number in each row of the table is the Spearman rank correlation coefficient for the WBS elements within the Air Frame. The correlation coefficients range between -1 and +1, and measure the association between the WBS elements. The second number in each row is the statistical significance (p-value) of the estimated correlations. Here, a p-value below 0.05 indicates significant non-zero correlation, and the null hypothesis of independence is rejected.

As shown in the table, several of the WBS elements at level 4 are significantly correlated. Most of the significant positive correlations seem plausible; the one negative correlation may not be plausible. For example, the Crew Station is significantly correlated with the Environmental Control System. It seems reasonable that cost variances involving the Crew Station could be dependent on cost variances involving the Environmental Control System because the WBS elements are functionally related.

The significant negative correlation between the Flight Control System and the Basic Structure is less plausible, but explaining the relationship is not the purpose of this analysis. Here, the purpose is to discover a lack of independence among the level 4 cost variances within the Air Frame at WBS level 3. The lack of independence may explain why the Central Limit Theorem does hold in this case. Specifically, as cost variances are aggregated up the WBS, they do not become normal because at least some of the WBS elements are not independent.

Conclusion

This chapter has described the results of testing the null hypothesis that cost variances on defense contracts are distributed normally. With few exceptions, the null hypothesis of normality was rejected at the .05 level of significance. This result was generally insensitive to the normality test used and to inflation adjustments.

Prior studies have also shown that cost variances are not always distributed normally. Here, the percentage of cost variances found non-normal was significantly larger than percentages reported by others. This difference may be due to the level of aggregation and the lack of independence among lower-level WBS elements. The cost variances tested here were at a much higher level of aggregation (WBS levels 4 and above) than the variances tested previously.

The next chapter will summarize this study, discuss its implications, and propose areas for further research.

V. Conclusion

Introduction

This study was prompted by increasing defense requirements to reduce costs and find more efficient ways of doing business. Over the years, there have been many DOD initiatives to economize, including the application of DOD Cost/Schedule Control Systems Criteria or "the criteria" on major defense contracts. Recently, however, the criteria have been criticized as being a non-value added cost to defense contracts. In particular, one of the requirements under the criteria, cost variance analysis, has been criticized as an administrative burden to defense contractors which results in frivolous and costly variance investigations and reports.

Although cost variance analysis is a widely used management control practice, it can be over-implemented. In theory, cost variances should be investigated only when benefits from identifying and correcting the variance exceed the cost of the investigation. To this end, a number of statistical cost variance investigation models have been described in the literature. In practice, the statistical models are rarely used on defense contracts or elsewhere. Instead, a simple investigation model is used where a variance is investigated when it breeches a pre-specified threshold. Although the simple model is easy to use, it can prompt a frivolous investigation.

One reason suggested in the literature for not using the statistical models is that the models require too much advance information about the cost variance, including its distributional form. The literature describing these models commonly assumes that the cost variance is distributed normally, for example. But the models may not work properly if this assumption is fallacious:

> *Gribbin has shown recently that if the cost variances are indeed non-normal, then assuming normality instead of modeling the non-normality correctly can lead to significantly inferior cost variance investigation decisions.* (Gribbin and Lau, 13:88)

Given the criticism over the present cost variance model used on defense contracts, and the potential benefit from adopting a statistical cost variance investigation model, this study tested the null hypothesis that defense cost variances are distributed normally. If the hypothesis is accepted, then using the statistical models described in the literature should be encouraged. If the hypothesis is not accepted, then the models may still be used, but only with additional information about the distributional form of defense cost variances.

Chapter II described the statistical cost variance investigation models which have been proposed in the academic literature. In addition, two prior studies which have tested the normality assumption were reviewed. Neither of these studies focused on defense cost variances, and each had mixed results. Some series of cost variances were normal; others were not. This study replicated these studies on defense contracts.

Chapter III described the methodology related to testing the hypothesis. Fifty series of cost variances from two defense contracts were collected and tested for normality. The sensitivity of the results to the specific normality test used and to the effects of inflation were analyzed.

As described in Chapter IV, the results show that the vast majority of defense cost variances tested were not distributed normally. In general, this was true regardless of the normality test used and whether or not the variances were adjusted for inflation. The implication of this finding and suggestions for further research will now be described.

Implications and Further Research

The results show that most of the cost variances on the *Cost Performance Report* (CPR) for two defense contracts were not normally distributed. This implies that government program offices cannot safely assume normality when using a statistical cost variance investigation model. To do so may result in a signal to investigate when an investigation would not be beneficial, or in a signal to not investigate when an investigation would be beneficial.

A non-normal distribution may be more appropriate for statistical cost variance investigation models used at the government program offices. In many cases, the literature describing these models assumes normality because it's convenient. Most of the models could use non-normal distributions.

The wording of this conclusion is careful and deliberate. Limitations associated with the conclusion affect its generalizability. One pertains to the level aggregation; the other pertains to random sampling. The limitations also suggest areas for further research.

Level of Aggregation. The results of prior studies were mixed, with some series of cost variances normal, and other series not normal. Here, almost all of the series were not normal. The major difference between this study and the others pertains to the level of aggregation of the cost variances. In the prior studies, the variances were measured where the work is accomplished. Cost variances at the working level typically include direct costs only, and can often be separated into material and labor components.

In this study, the cost variances were measured at the reporting level, which corresponds to levels 1 through 4 on the Work Breakdown Structure (WBS) used to define and organize work on a defense contract. At these summary reporting levels, the variances can include hundreds of lower-level WBS elements, and often combine direct materials, direct labor, and various kinds of indirect costs.

It seems reasonable that as cost variances are aggregated up the WBS from the working level to the reporting level, a normally distributed cost variance at the working level could loose this characteristic, expecially if the WBS elements at the working level are not independent. In fact, this was found to be the case as the defense cost variances were aggregated from WBS level 4 to higher levels on the CPR. Thus, the conclusion that defense cost variances on the CPR are not be normal does not extend to lower levels in the WBS. The normality of defense cost variances at the working level is an empirical question.

<u>Nonrandom Sampling</u>. Neither the prior studies nor this one employed statistical random sampling to identify the cost variance series for testing. On this study, a random sample was not practical given the time constraints and the tedious task of retrieving the cost data from microfiche. It was simply not feasible to select a random sample of contracts with an adequate number of monthly cost variances. Thus, it cannot be inferred

from these results that cost variances on other defense contracts are non-normal. This too, remains an empirical question.

Conclusion

The results show that defense cost variances reported on the *Cost Performance Report* are not always normally distributed. Using statistical cost variance investigation models to signal variance analysis is still feasible, but without the assumption that the cost variances are distributed normally. Other non-normal distributions should be explored. Thus, this study may be extended to identify alternative, non-normal distributions which more closely fit cost variances on CPRs. Once identified, a demonstration of the statistical model which uses the non-normal distribution would be useful to those contemplating the application of the model in a government program office. Additionally, the distributional properties of defense cost variances below the reporting level is not known. Once known, the statistical models again promise the potential to reduce the number of frivolous investigations conducted by the defense contractor.

Appendix: Cost Variance Data

This Appendix contains cost variance data extracted from monthly *Cost Performance Reports* on two defense contracts, identified as Contract A and Contract B. The identity of the contracts is not revealed to ensure anonymity. Tables 9 and 10 each contain the Work Breakdown Structure (WBS) element number, the monthly date of the *Cost Performance Report*, the weighted inflation index, the monthly cost variance (CV), and the Budget at Completion (BAC), for Contracts A and B, respectively. Because the WBS names and levels corresponding to the WBS element numbers are provided in Tables 3 through 6 in Chapter IV, they are not repeated here.

Table 9. Contract A (Nominal $000)

WBS NUMBER:		1		2		3		4		5		6	
Date	Index	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC
01-Jan-91	1.023	-1577	163090	-759	129451	-435	23684	40	2995	-5	984	-27	29508
01-Feb-91	1.023	-2503	163090	-1622	129319	-547	23551	-23	2995	0	984	-814	29508
01-Mar-91	1.023	-1606	162491	-1217	129319	3	23551	-77	2995	-177	984	-654	29508
01-Apr-91	1.023	-476	162550	-238	129426	88	23543	16	2995	0	984	-41	29508
01-May-91	1.023	172	162647	760	146153	-197	23652	-40	2995	-1	984	1410	45865
01-Jun-91	1.023	-751	179483	-503	146003	-106	23652	4	2995	0	984	-29	45865
01-Jul-91	1.023	-510	179423	-223	146093	-109	23652	0	2995	0	984	-20	45865
01-Aug-91	1.023	-616	179431	-339	146093	-175	23652	0	2995	-1	984	-18	45865
01-Sep-91	1.023	-1240	179431	-701	146093	-51	23652	-14	2995	0	984	321	45865
01-Oct-91	1.023	-757	179411	-354	146097	-185	23652	0	2995	0	984	-22	45865
01-Nov-91	1.023	-5625	179324	-5318	146097	-91	23652	-6	2995	1	984	-5148	45865
01-Dec-91	1.023	-428	179324	-182	146097	76	23652	0	2995	0	984	-4	45865
01-Jan-92	1.053	-432	179324	-147	146097	99	23652	-8	2995	0	984	-3	45865
01-Feb-92	1.053	-743	179324	-406	146097	-386	23652	0	2995	0	984	-24	45865
01-Mar-92	1.053	-2000	178435	-1491	145199	-117	23652	-5	2995	0	984	-1181	44967
01-Apr-92	1.053	-523	178434	-242	145198	-54	23652	0	2995	-3	984	-27	44967
01-May-92	1.053	-375	178377	-157	145198	-42	23652	-13	2995	3	984	-25	44967
01-Jun-92	1.053	-780	179207	-436	145977	-179	23697	-5	2995	0	984	40	45701
01-Jul-92	1.053	-336	179207	-171	145977	-38	23697	-2	2995	0	984	-23	45701
01-Aug-92	1.053	-300	179207	-55	145977	-1	23697	-1	2995	0	984	33	45701
01-Sep-92	1.053	815	180486	535	146267	110	23837	0	2995	0	984	753	45701
01-Oct-92	1.053	-499	180486	-95	146267	-22	23837	0	2995	0	984	-1	45701
01-Nov-92	1.053	-359	180490	-121	146267	-29	23837	0	2995	0	984	1	45701
01-Dec-92	1.053	-507	180549	-348	146325	-16	23836	0	2995	0	984	-305	45701
01-Jan-93	1.075	-182	180549	-60	146326	-9	23837	0	2995	0	984	-6	45701
01-Feb-93	1.075	-1250	180956	-924	146440	-35	23877	0	2995	0	984	-9	45701
01-Mar-93	1.075	-345	185566	-205	147681	-38	24115	0	2995	0	984	-173	45701
01-Apr-93	1.075	-142	185566	-19	147681	-27	24115	0	2995	0	984	14	45701
01-May-93	1.075	-370	185566	-237	147681	-22	24115	0	2995	0	984	0	45701
01-Jun-93	1.075	-9519	185007	-8827	147798	27	24111	-2	2995	0	984	-32	45701
01-Jul-93	1.075	-210	185007	32	147798	5	24111	0	2995	0	984	-9	45701
01-Aug-93	1.075	-626	185007	-106	147798	-19	24111	0	2995	0	984	-5	45701
01-Sep-93	1.075	-1068	184724	-551	147798	-117	24111	0	2995	0	984	-17	45701
01-Oct-93	1.075	-438	184736	-118	147803	-44	24115	0	2996	0	984	-18	45701
01-Nov-93	1.075	-575	184736	-205	147803	-63	24115	0	2996	0	984	-1	45701
01-Dec-93	1.075	-3297	184736	-2704	147803	-266	24115	-206	2996	0	984	-17	45701
01-Jan-94	1.094	-862	184002	-247	147069	-85	24115	0	2996	0	984	-3	44967
01-Feb-94	1.094	-879	184280	-256	147069	-66	24115	0	2996	-3	984	-2	44967
01-Mar-94	1.094	-1320	184280	-638	147069	-111	24115	-1	2996	0	984	33	44967
01-Apr-94	1.094	-313	184796	160	147069	-58	24115	0	2996	0	984	80	44967
01-May-94	1.094	-972	184796	-509	147069	-72	24115	0	2996	0	984	-61	44967
01-Jun-94	1.094	62	184796	466	147069	-14	24115	0	2996	0	984	-23	44967
01-Jul-94	1.094	-479	184796	-177	147069	-38	24115	0	2996	0	984	-5	44967
01-Aug-94	1.094	-850	184796	-157	147069	-45	24115	0	2996	0	984	-12	44967
01-Sep-94	1.094	-288	184796	165	147069	-15	24115	-79	2996	0	984	39	44967
01-Oct-94	1.094	-353	184796	-53	147069	-11	24115	0	2996	0	984	0	44967
01-Nov-94	1.094	-422	184796	-141	147069	-109	24115	0	2996	0	984	-2	44967
01-Dec-94	1.094	-374	184796	268	147069	47	24115	0	2996	0	984	-2	44967

Table 9. Contract A (Nominal $000) - continued -

7		8		9		10		11		12		13	
CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC
-43	24022	49	7864	-475	10947	0	4236	40	2697	97	22514	0	120
1	24022	-23	7864	-215	10948	-1	4236	0	2697	0	22514	-1	120
-1	24022	8	7864	-186	10948	1	4236	-20	2697	-114	22514	-1	121
-311	24022	6	7865	-110	10948	0	4236	0	2691	114	22634	0	121
-39	24022	-237	7865	-156	11189	0	4236	20	2710	0	22635	-2	123
-20	24022	-101	7865	-202	11189	0	4236	-4	2710	-45	22635	0	123
0	24022	-154	7865	-201	11189	0	4176	-47	2710	0	22635	0	123
0	24022	0	7865	-144	11189	0	4176	0	2710	-1	22635	0	123
40	24022	16	7865	-919	11189	0	4178	-5	2710	-89	22635	0	123
0	24022	-33	7865	-114	11189	0	4178	0	2710	0	22639	-1	123
0	24022	81	7865	-127	11189	0	4176	-31	2710	1	22639	0	123
-13	24022	0	7865	-239	11189	0	4176	-1	2710	-1	22639	1	123
1	24022	-55	7865	-181	11189	0	4176	0	2710	0	22639	0	123
-14	24022	18	7865	0	11189	0	4176	0	2710	0	22639	0	123
0	24022	-4	7865	-214	11189	0	4176	32	2710	-2	22639	0	123
-37	24022	-9	7865	-112	11231	0	4176	0	2667	0	22639	0	123
20	24022	0	7865	-100	11231	0	4176	0	2667	0	22639	0	123
0	24022	-57	7865	-238	11231	0	4176	3	2667	0	22639	0	127
0	24022	0	7865	-108	11231	0	4176	0	2667	0	22639	0	127
0	24022	0	7865	-86	11231	0	4176	0	2667	0	22639	-1	127
-2	24022	-187	7865	-127	11381	0	4176	-18	2667	0	22639	0	127
0	24022	-1	7865	-71	11381	0	4176	0	2667	0	22639	-3	127
0	24022	0	7865	-93	11381	0	4176	0	2667	0	22639	-1	127
0	24022	35	7865	-39	11381	0	4176	-23	2667	0	22698	-1	127
0	24022	-15	7865	-65	11381	0	4176	0	2667	35	22698	-2	127
0	24022	-765	7865	-127	11455	0	4176	0	2667	12	22698	-3	127
0	24022	0	7866	13	12457	0	4176	-17	2667	10	22698	0	127
0	24022	0	7866	-6	12457	0	4176	0	2667	0	22698	0	127
-50	24022	-197	7866	32	12457	0	4176	0	2667	0	22698	0	127
19	24022	2	7866	18	12578	-60	4176	-2	2667	-8797	22698	0	127
0	24022	-13	7866	49	12578	0	4176	0	2667	0	22698	0	127
0	24022	9	7866	-91	12578	0	4176	0	2667	0	22698	0	127
0	24022	-4	7866	-116	12578	-129	4176	-16	2667	-152	22698	3	127
0	24022	11	7866	-67	12578	0	4176	0	2667	0	22698	0	127
0	24022	-23	7866	-118	12578	0	4176	0	2667	0	22698	0	127
-1700	24022	-3	7866	-178	12578	-118	4176	-41	2667	-175	22698	0	127
0	24022	0	7866	-159	12578	0	4176	0	2667	0	22698	0	127
0	24022	0	7866	-185	12578	0	4176	0	2667	0	22698	0	127
-149	24022	4	7866	-328	12578	-4	4176	-18	2667	-64	22698	0	127
0	24022	0	7866	138	12578	0	4176	0	2667	0	22698	0	127
0	24022	-30	7866	-346	12578	0	4176	0	2667	0	22698	0	127
149	24022	74	7866	-116	12578	9	4176	131	2667	256	22698	0	127
0	24022	0	7866	-133	12578	0	4176	0	2667	-1	22698	0	127
0	24022	0	7866	-100	12578	0	4176	0	2667	0	22698	0	127
-173	24022	-26	7866	300	12578	46	4176	13	2667	60	22698	0	127
0	24022	0	7866	-42	12578	0	4176	0	2667	0	22698	0	127
-20	24022	0	7866	-10	12578	0	4176	0	2667	0	22698	0	127
-176	24022	36	7866	-39	12578	47	4176	1	2667	354	22698	0	127

Table 10. Contract B (Nominal $000)

WBS NUMBER:		1		2		3		4		5		6	
Date	Index	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC
01-Jan-74	1.03	-442	121026	-419	66194	-432	63149	-5	5889	-407	46386	19	5408
01-Feb-74	1.03	-263	121866	-279	66544	-232	63499	-95	6142	-134	46483	27	5408
01-Mar-74	1.03	-1736	124132	-1601	68194	-1617	65149	-100	6225	-1450	47668	-130	5408
01-Apr-74	1.03	-1562	124302	-1075	68737	-812	65692	18	6272	-756	47925	-53	5567
01-May-74	1.03	-562	126155	-769	70334	-900	67347	6	6263	-926	49725	-6	5432
01-Jun-74	1.03	-2966	120958	-2857	65134	-2773	62202	-124	6121	-2585	45114	-84	5475
01-Jul-74	1.03	-1934	121189	-1519	65291	-1457	62359	9	6043	-1700	45336	4	5471
01-Aug-74	1.03	-1076	121689	-1099	65699	-1353	62767	-243	6106	-1285	45678	162	5470
01-Sep-74	1.03	-1778	121996	-1308	66119	-1387	63186	-114	6178	-1659	46009	279	5488
01-Oct-74	1.03	-1011	122498	-286	66754	-669	63845	-150	6171	-1596	46660	353	5488
01-Nov-74	1.03	-2049	123092	-1036	67163	-970	64253	17	6193	-1180	47002	-4	5491
01-Jan-75	1.13	-1596	124091	-1706	67309	1814	64400	-83	6246	-1450	47040	-110	5507
01-Feb-75	1.13	-3540	124652	-2167	68154	2019	65244	-45	6454	-799	47701	-485	5502
01-Mar-75	1.13	-65	125067	284	68051	357	65142	-70	6359	327	47680	148	5516
01-Apr-75	1.13	-4270	126124	-4305	68289	-4268	65380	-530	6170	-4155	48051	137	5526
01-May-75	1.13	-707	127072	-702	68693	-602	65783	-93	6200	-543	48134	64	5742
01-Jun-75	1.13	72	128307	140	69500	222	66590	-200	6239	1056	48889	-287	5743
01-Jul-75	1.13	-541	126881	-835	69252	-647	66392	-124	6221	-407	48742	20	5730
01-Aug-75	1.13	191	127648	633	69524	1062	66624	-96	6221	1536	48756	-188	5736
01-Sep-75	1.13	52	127839	-60	69696	-207	66797	51	6366	34	48772	-422	5736
01-Oct-75	1.13	-724	127906	10	69706	-71	66806	-41	6367	48	48777	14	5742
01-Nov-75	1.13	443	127960	760	69708	442	66809	31	6367	279	48777	24	5742
01-Dec-75	1.13	129	129035	-276	69753	-252	66853	-42	6388	-53	48784	-136	5746
01-Jan-76	1.227	57	129302	37	69907	43	67008	-40	6386	39	48961	5	5745
01-Feb-76	1.227	-405	129503	-175	69974	-173	67075	-42	6407	-87	48962	-35	5785
01-Mar-76	1.227	-517	130427	-428	70099	-195	67169	-46	6414	-39	49004	-59	5809
01-Apr-76	1.227	60	130567	214	70197	-57	67268	-15	6414	-22	49060	-4	5809
01-May-76	1.227	-397	130583	-84	70273	-73	67344	12	6436	-13	49076	-30	5851
01-Jun-76	1.227	-300	131736	-431	70440	30	67510	26	6436	-3	49242	8	5851
01-Jul-76	1.227	-281	134587	-111	70504	-121	67574	-47	6436	-22	49306	-68	5851
01-Aug-76	1.227	-594	133527	-102	70498	-111	67568	-1	6403	-58	49361	-10	5826
01-Sep-76	1.227	-435	132915	-430	70428	-175	67499	-10	6327	-61	49496	-75	5733
01-Oct-76	1.227	-205	137183	-36	70783	-137	67686	10	6343	-71	49593	-61	5785
01-Nov-76	1.227	357	137244	-135	70791	-75	67695	-2	6343	-60	49602	-1	5785
01-Dec-76	1.227	-184	138070	-61	70880	15	67784	-1	6343	20	49691	32	5785
01-Jan-77	1.3	-119	138469	-11	71002	-26	67906	0	6343	26	49799	-29	5785
01-Feb-77	1.3	-40	138490	-15	71002	-19	67924	3	6343	-3	49817	-15	5785
01-Mar-77	1.3	-256	141652	-60	71041	4	67945	-7	6343	21	49838	-9	5785
01-Apr-77	1.3	355	143181	20	71014	38	67918	-3	6343	53	49811	-2	5785
01-May-77	1.3	44	142654	-10	71102	-69	68005	-14	6343	-52	49898	6	5785
01-Jun-77	1.3	-267	143883	-110	71800	-109	68009	-3	6343	-104	49902	-3	5785
01-Jul-77	1.3	74	145168	-62	72052	-43	68956	6	6343	-15	50846	14	5785
01-Aug-77	1.3	605	145966	-78	72283	-79	69187	-5	6343	-69	51076	-2	5785
01-Sep-77	1.3	-541	146233	64	72367	190	69269	-3	6343	199	51158	0	5785
01-Oct-77	1.3	-740	147083	45	72372	-79	69273	4	6345	-72	51161	-3	5785
01-Nov-77	1.3	387	151890	44	72423	50	69325	-1	6345	38	51213	-1	5785
01-Dec-77	1.3	-78	152150	-121	72436	-122	69338	-4	6345	-113	51226	-1	5785

Table 10. Contract B (Nominal $000) - continued -

7		8		9		10		11		12		13		14		15	
CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC
-10	163090	-8	2659	-15	924	-4	1403	0	367	0	337	13	2341	4	412	0	256
-9	163090	4	2659	-21	924	-4	1403	0	367	0	337	-47	2341	4	412	-5	256
-2	162491	-17	2746	94	1219	-13	1403	0	367	0	337	16	2341	4	412	2	256
-5	162550	7	2746	-5	1300	-17	1403	0	367	0	337	-263	2341	1	412	0	256
-11	162647	14	2746	-9	1300	29	1403	0	367	0	337	132	2282	-1	426	-2	264
13	179483	1	2543	-7	1206	15	1318	0	357	0	313	-85	2263	10	426	5	264
22	179423	38	2543	31	1224	110	1318	7	357	21	313	-89	2263	0	427	-1	264
-20	179431	25	2543	-7	1227	13	1318	2	357	5	313	245	2263	1	427	3	264
32	179431	208	2543	-154	1226	23	1318	7	357	22	313	51	2263	-4	427	-3	264
78	179411	365	2558	137	1226	142	1316	226	249	152	398	4	2263	8	427	4	264
8	179324	53	2558	93	1227	44	1347	2	249	27	398	-93	2263	1	427	-3	264
-29	179324	-107	2569	-34	1256	-2	1347	3	249	15	398	89	2263	4	431	2	269
-15	179324	-387	2569	-2	1256	-264	1337	0	249	13	398	-161	2263	5	431	2	269
-3	178435	-38	2569	-13	1256	4	1337	-1	249	0	398	-72	2263	1	431	0	269
-58	178434	295	2534	-90	1308	133	1350	-2	249	-40	398	4	2263	0	431	1	269
-11	178377	13	2630	-12	1286	-20	1350	0	249	0	398	-98	2263	1	441	0	278
-15	179207	-161	2630	-63	1297	-105	1350	-1	249	39	398	-121	2263	1	441	1	278
-17	179207	-18	2631	-113	1268	11	1344	-3	249	-3	398	-182	2213	-4	434	-4	278
-12	179207	-127	2808	-54	1285	2	1363	-200	249	-200	398	-29	2253	4	434	4	278
19	180486	51	2808	7	1291	54	1367	0	249	-25	398	172	2253	1	434	0	279
-44	180486	13	2808	-19	1291	-43	1367	-1	249	-1	398	84	2253	3	434	1	279
-9	180490	106	2808	9	1291	3	1370	200	249	143	398	-27	2253	8	434	6	279
10	180549	-8	2808	-6	1293	-17	1370	0	249	59	398	-84	2253	0	434	0	278
147	180549	-151	2808	48	1293	-3	1351	0	249	-54	398	49	2253	-7	426	0	270
5	180956	-1	2809	-7	1294	-9	1352	0	249	-2	398	0	2253	-1	426	0	270
-143	185566	113	2811	-15	1311	-6	1355	0	249	0	398	-234	2283	0	426	0	270
-1	185566	-10	2811	0	1350	-9	1355	0	249	31	398	240	2283	-1	428	0	270
-4	185566	-38	2811	7	1350	-14	1355	0	249	0	249	-12	2283	2	428	0	270
0	185007	14	2811	1	1350	-11	1355	-3	249	0	398	-458	2283	0	428	0	270
-4	185007	0	2811	31	1350	0	1355	0	249	0	249	11	2283	0	428	0	270
0	185007	-10	2811	-32	1347	-3	1355	-2	249	0	398	11	2283	-1	432	-1	274
1	184724	-21	2811	-4	1312	0	1355	0	249	0	398	-255	2283	1	432	0	274
3	184736	-20	2823	2	1314	0	1363	0	249	0	398	100	2449	0	432	0	274
0	184736	0	2823	-12	1314	0	1363	0	249	0	398	-61	2449	0	432	0	274
0	184736	-6	2823	-31	1314	-3297	1363	0	249	-24	398	-52	2449	0	434	0	276
0	465	-22	2823	0	1328	0	1363	0	249	0	398	14	2449	0	434	0	276
-6	465	0	2823	1	1328	0	1363	0	249	1	398	4	2449	-1	434	-1	276
0	465	0	2823	0	1328	0	1363	0	249	0	398	-64	2449	1	434	1	276
0	465	-9	2823	-2	1328	0	1363	0	249	0	398	-18	2449	0	434	0	276
-1	465	-3	2823	-3	1328	0	1363	0	249	0	398	58	2449	0	434	0	276
0	465	0	2823	0	1328	0	1363	0	249	0	398	0	2449	0	434	0	276
0	465	-18	2823	-27	1332	-3	1363	0	249	0	398	-19	2449	0	434	0	276
-1	465	-3	2823	0	1332	0	1363	0	249	0	398	0	2449	0	434	0	276
0	465	-6	2823	0	1332	0	1363	0	249	0	398	-125	2451	0	434	0	276
-8	465	0	2823	0	1332	0	1363	0	249	0	398	125	2451	0	434	0	276
0	465	0	2823	14	1332	0	1363	0	249	0	398	-6	2451	0	434	0	276
-60	465	-1	2823	0	1332	0	1363	0	249	0	398	0	2451	0	434	0	276

Table 10. Contract B (Nominal $000) - continued -

16		17		18		19		20		21		22		23	
CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC
2	156	13	1749	12	1263	0	486	29	33537	-4	1658	0	269	-19	2997
1	156	-23	1748	-21	1263	-1	486	59	33942	-23	1658	-1	269	49	2997
2	156	13	1766	11	1281	2	486	10	34261	-28	1686	-4	269	-25	3000
-1	156	8	1766	7	1281	1	486	-244	33190	7	1686	6	269	-87	2662
0	162	-3	1767	-1	1281	-1	486	261	34066	59	1782	4	269	74	2664
5	162	-3	1788	-78	1298	-2	490	-71	33759	51	1980	-7	269	111	2663
1	162	-20	2088	-10	1598	0	490	-290	33461	-37	2001	-1	269	-121	2671
-2	162	59	2088	59	1598	1	490	48	33501	19	2001	-3	269	32	2682
1	162	-5	2066	-1	1575	-5	490	-345	33240	-152	2001	-129	2508	-129	2508
4	162	-5	2064	-10	1573	4	490	-715	33271	-218	2001	1	269	-106	2520
3	162	-119	2064	-113	1573	-5	490	-676	33456	-133	2116	0	269	-65	2521
3	162	-69	2064	-74	1573	5	490	57	34394	-130	2116	0	269	1	2533
3	162	-113	2053	-108	1705	-6	348	-1247	34409	-20	2116	0	269	-12	2533
0	162	16	2075	10	1727	6	348	-489	34866	-56	2108	0	269	0	2509
-1	162	-156	2681	-153	2334	-4	348	229	35117	-205	2193	1	269	-77	2433
0	162	-43	2684	-41	2337	-1	348	51	35598	175	2215	0	269	7	2433
1	163	-52	2729	-59	2381	6	348	-10	35829	-19	2254	0	269	-29	2433
0	156	94	2760	95	2412	0	348	-67	35081	9	2240	0	268	27	2432
0	156	-84	2781	-84	2433	0	346	-364	35081	-24	2240	0	268	-53	2432
4	156	44	2781	45	2434	-1	348	22	35077	-21	2241	0	268	-4	2428
2	156	-158	2781	-159	2434	0	348	-691	35083	-62	2141	0	268	-42	2434
3	156	-23	2781	-22	2434	-1	348	-458	35113	20	2243	0	268	59	2457
0	156	-52	2814	-54	2433	3	381	314	36078	8	2243	0	268	3	2459
-7	156	-39	2814	-36	2433	-3	381	-9	36233	-30	2243	0	268	-34	2458
0	156	-44	2814	-42	2433	-2	381	-231	36366	-139	2249	0	268	37	2458
0	156	-53	2951	-58	2570	5	381	-6	36748	92	2249	0	268	-7	2458
-1	158	-50	2952	-52	2570	2	382	166	36806	-10	2249	0	268	-1	2458
2	158	-12	2952	-7	2570	-4	382	-337	36820	-15	2256	0	268	-5	2458
0	158	-25	3049	-16	2618	-11	431	181	37493	32	2346	0	268	32	2549
0	270	-2	3049	-5	2618	3	431	-177	40209	-9	2346	0	268	-9	2549
0	158	-50	3049	-49	2618	0	431	-326	39376	-4	2330	0	268	-6	2468
0	158	-101	2779	-103	2635	3	145	187	39197	18	2316	0	268	20	2468
0	158	-55	6322	-57	6177	3	145	-121	39444	2	2321	0	268	-5	2475
0	158	-18	6322	-20	6177	0	145	257	39502	-8	2321	0	268	-4	2478
0	158	-46	6348	-46	6203	0	145	-48	40218	-2	2321	0	424	1	2488
0	158	15	6349	16	6203	1	146	-51	40494	1	2322	-6	424	4	2488
0	158	-7	6340	-10	6194	2	146	-17	40501	8	2322	-3	424	-1	2489
0	158	-27	6349	-26	6203	-1	146	-176	43348	-13	2322	-1	430	-1	2489
0	158	7	6553	8	6407	-1	146	320	44700	-2	2475	2	430	-2	2490
0	158	5	6575	4	6429	0	146	60	44052	7	2548	-12	430	-1	2490
0	158	-47	6616	-47	6471	0	146	-122	44541	-1	2548	-33	430	1	2490
0	158	35	6626	35	6480	0	146	97	45610	2	2570	-16	430	2	2492
0	158	780	6644	781	6498	0	146	-100	46102	-19	2570	68	430	1	2492
0	158	-630	6676	-630	6531	0	146	19	46219	6	2570	-14	430	-2	2492
0	158	-196	6676	-19	6531	0	146	-504	47045	-3	2570	-30	424	0	2493
0	158	-17	7195	-17	7050	0	146	382	51203	-6	2570	16	404	0	2492
0	158	41	7207	40	7062	0	146	17	51392	-6	2632	-7	404	-1	2492

Table 10. Contract B (Nominal $000) - continued -

24		25		26		27		28		29		30		31	
CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC
-8	2898	-29	355	-61	8857	149	12511	0	3993	-50	14333	-7	3591	10	3144
0	2898	-16	535	48	9019	50	12559	26	4007	-65	14420	15	3678	0	3144
-47	2898	-6	838	171	8949	12	12559	-66	4061	-216	14496	-56	3734	-10	3144
-86	2895	21	847	124	8991	112	12600	-96	3941	-239	14494	3	3734	2	3144
-16	2956	-126	894	114	9292	134	12256	19	3954	-79	14558	-1	3731	-25	3202
74	2956	-7	996	-66	9310	-60	11628	-111	3958	-46	14826	-20	3745	42	3201
-24	2963	35	1020	-74	8983	72	11647	-138	3998	-115	14852	-1	3854	10	3121
141	2965	32	1019	-198	8953	32	11670	-8	3911	-118	14887	-20	3888	31	3121
101	2854	114	1019	-247	9008	43	11670	-70	3911	-135	14895	-14	3893	-23	3122
-112	2866	35	1021	-170	9013	24	11670	-172	3911	-55	14914	-45	3893	12	3127
-101	2866	-9	1021	-204	9006	-17	11744	-147	3913	-221	14987	-26	3893	-27	3127
-149	2876	-6	1021	440	9856	-80	11727	-18	3996	88	14984	-24	3906	9	3128
-119	2882	-1	1025	-236	9856	-797	11736	-49	3996	2	14685	9	3956	-33	2777
-121	2882	-2	1021	-153	10858	-105	11206	-55	4013	3	14725	-6	3990	23	2783
-13	3175	-1	1021	-7	10858	513	11180	14	3984	-29	14729	-70	3956	36	2783
-8	3187	4	1025	9	10856	-99	11546	-31	4065	-6	14759	47	3956	-34	2791
-42	3213	3	1025	25	10858	110	11700	-61	4077	42	14894	-12	3954	12	2928
-45	3213	-2	1002	-24	10135	-22	11736	-9	4055	36	14948	4	3961	-2	2934
-18	3213	-49	1002	-27	10135	-137	11736	-57	4055	45	14959	-12	3961	-3	2934
56	3211	-6	1003	-21	10134	27	11739	-9	4055	-27	14981	-1	3983	-35	2935
-240	3301	-1	1003	-4	10134	-323	11739	-16	4055	78	15033	1	3985	38	2935
-94	3211	-1	1003	32	10134	-474	11743	-3	4055	159	15033	40	3985	60	2935
153	4127	1	1032	-5	10134	154	11759	2	4055	56	15053	22	3990	22	2948
111	4233	4	1032	0	10134	-52	11810	-8	4055	49	15019	6	3990	-2	2946
-192	4358	6	1032	-5	10134	62	11813	-1	4054	-10	15020	6	3990	-7	2946
-45	4398	6	1032	0	10134	-48	12154	-5	4054	-46	15300	-8	3993	-4	2949
-100	4409	2	1034	-4	10134	-42	12199	-8	4054	24	15303	-1	3998	-3	2958
-151	4409	-4	1034	0	10134	-149	12207	-12	4054	-8	15279	-6	4001	-6	2944
233	4642	-2	1034	-3	10134	-108	12351	-6	4169	5	15476	0	4012	1	2955
-55	4712	-1	1034	-2	10134	-88	14997	-12	4168	26	15506	13	4013	-1	2962
-16	4470	0	1034	-2	10134	-297	14551	-2	4121	7	15383	-5	4164	6	2823
48	4476	0	1034	14	10134	56	14478	31	4023	42	15404	19	4167	0	2823
9	4476	2	1035	-12	10135	-109	14708	-5	4026	36	15430	12	4167	-1	2845
4	4487	0	1035	0	10135	261	14752	0	4026	13	4167	13	4167	0	2845
-22	4853	0	1035	-1	10135	-23	14822	-2	4140	-55	15391	2	4145	-5	2844
-2	4983	0	1035	0	10135	-16	14893	-29	4213	8	15391	0	4145	7	2844
56	4983	0	1035	-82	10135	11	14895	-7	4216	-3	15395	13	4145	4	2844
-28	5118	0	1035	0	10135	-133	17586	-1	4232	3	15472	0	4145	0	2844
1	5147	0	1035	1	10135	321	18715	0	4272	3	15472	-2	4145	0	2844
-14	5147	-2	1035	0	10135	89	17976	-5	4289	-6	15483	0	4145	0	2844
-30	5147	-1	1035	0	10135	-61	18168	-5	4587	7	15484	-1	4145	0	2844
15	5149	-1	1035	0	10135	107	19159	-16	4640	9	15427	4	4081	-1	2847
-55	5200	0	1035	0	10135	-70	19217	-22	5023	8	15484	0	4087	3	2883
27	5231	0	1035	0	10135	-7	19027	8	5298	7	15498	1	4090	2	2889
-22	5231	0	1035	0	10135	-410	19859	-7	5298	-4	15513	-1	4097	-1	2889
-4	5232	1	1035	-1	10135	305	24002	30	5332	-4	15515	0	4097	-1	2891
-10	5236	0	1035	0	10135	91	24090	-62	5368	-1	15515	0	4097	1	2891

Table 10. Contract B (Nominal $000) - continued -

32		33		34		35		36		37	
CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC	CV	BAC
-51	7598	-16	4800	0	1924	-20	1375	-2	591	5	911
-81	7598	37	4800	0	1924	21	1375	2	591	16	911
-150	7618	56	5003	4	1924	38	1577	-8	591	19	911
-244	7616	-11	5003	-4	1934	-18	1557	1	591	10	911
-55	7625	26	5004	9	1951	-20	1557	21	591	15	905
-65	7879	5	5024	1	1951	0	1613	-2	555	6	905
-123	7877	9	5070	-7	1940	-8	1670	-1	555	25	905
-130	7878	31	5088	8	1940	11	1670	-5	555	17	922
-100	7880	15	5249	-7	2098	7	1680	-3	552	18	918
-22	7894	44	5070	17	2130	9	1457	-4	552	23	930
-166	7966	1	4995	-13	2056	-15	1457	2	552	25	930
105	7951	32	4908	-13	1966	15	1457	5	555	23	930
24	7951	-18	4920	-1	1966	-44	1457	18	558	11	939
-14	7951	118	4920	20	1966	37	1457	66	558	-5	939
5	7990	-8	4876	-10	1966	-33	1440	3	558	32	912
-18	8012	-10	4897	-11	1988	-20	1440	4	558	18	911
41	8012	-47	4914	-17	1988	-98	1457	7	558	27	911
35	8053	116	4406	3	1479	92	1457	5	559	15	910
58	8064	-39	4870	-7	1931	-50	1469	7	559	11	910
9	8063	67	4870	-13	1931	85	1469	7	560	-13	910
41	8114	35	4870	0	1931	7	1469	6	560	24	910
57	8114	-1	4891	36	1931	-33	1469	14	581	-20	910
13	8114	86	4903	38	1944	22	1468	19	580	8	910
44	8084	26	4903	35	1944	-7	1468	0	580	0	910
-7	8084	55	4903	53	1944	9	1468	-7	580	-1	910
-35	8359	17	4903	28	1944	-11	1468	0	580	0	910
28	8347	39	4881	37	1909	-3	1469	6	592	-2	911
4	8333	41	4831	20	1909	10	1469	4	592	0	861
5	8509	-30	4850	20	1928	-49	1469	0	592	-1	861
11	8530	-17	4891	-4	1931	-13	1485	0	592	0	883
8	8396	-120	4789	-15	1825	-101	1487	-7	592	3	886
22	8414	-133	4675	-4	1843	-132	1354	0	592	3	887
26	8418	-32	4772	-5	1843	-27	1452	0	592	0	887
-15	8400	257	4785	2	1855	261	1452	-9	592	3	887
-51	8402	25	4799	6	1855	13	1452	15	613	-9	879
0	8402	-78	4799	-4	1855	-76	1452	3	613	0	879
-18	8405	2	4800	0	1856	2	1453	-1	613	-1	879
3	8482	3	5008	13	2002	-6	1473	1	630	-4	902
6	8482	4	5008	7	2002	-2	1473	-1	630	1	902
-7	8494	-3	5008	-4	2003	-99	1473	1	630	-2	902
7	8494	3	5008	0	2003	-1	1473	-1	630	1	902
7	8499	-5	5019	-3	2003	-2	1483	-1	631	0	902
4	8514	-5	5019	-3	2003	0	1483	-2	631	3	902
6	8519	-1	5039	-9	2009	5	1496	-2	631	10	901
-3	8527	-81	5043	28	2013	-110	1497	1	632	0	901
-5	8527	-18	5120	11	2057	-30	1530	2	632	0	901
-1	8528	-14	5166	-7	2060	-2	1534	1	670	0	901

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Vita

Captain Robert J. Conley was born 27 May 1951 in Boston, Massachusetts. He graduated from Charles Wright Academy in Tacoma, Washington, 1970. He served as a Geodetic Surveyor for the Air Force from 1971-1973. Following his tour of duty during the Vietnam era he served in the Portland Air National Guard as a command and control specialist from 1973-1978 while also acquiring a Bachelor of Science degree in Business Administration (graduating from Portland State University in 1978). He then served in the Wyoming Air National Guard (1978-1987) in various capacities (accounting and finance, administrative, disaster preparedness) and finally acquired a commission through the Academy of Military Science. He transferred to the Arizona Air National Guard, serving as Cost Analysis Officer and Accounting and Finance Officer. During his assignment with the Arizona Air National Guard he accomplished special assignments for the Air Force assisting budget exercises while assigned to SAF/FMB, Pentagon (1988-1990). He was then assigned as Budget Officer to Davis-Monthan AFB where he became the Chief, Financial Management for Davis-Monthan AFB and 12th Air Force simultaneously (1990-1993). He was serving as Financial Manager, Los Angeles AFB, Global Positioning System from 1993 to 1995 when he entered the School of Logistics and Acquisition Management, Air Force Institute of Technology, in May 1995.

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13. ABSTRACT (*Maximum 200 Words)*
This study tested the hypothesis that defense cost variances reported on the *Cost Performance Report* are normally distributed. The DOD requires that all defense cost variances which breech a pre-specified threshold be investigated. The present variance investigation model has been criticized because it can prompt frivolous investigations. In theory, statistical models could reduce the number of frivolous investigations, but they are not used because they require too much information about the cost variance, including its distributional form. Often such models assume a normal distribution, but researchers have shown that the models do not work properly if the assumption is fallacious. Two prior studies have investigated the normality of cost variances with mixed results, and neither investigated defense cost variances. Here, fifty series of cost variances from two defense contracts were extracted from *Cost Performance Reports* and evaluated using four popular tests of normality (Bowman-Shenton, Shapiro-Wilks, Kolmogorov-Smirnov, and Chi-square). The results show that the vast majority of the series of cost variances were not normally distributed. These results were insensitive to the normality test used and to the effects of inflation. The statistical variance investigation models may still be used, but normality should not be assumed.

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