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(6) FORECASTING DEPOT OVERHAUL COSTS OF TACTICAL MISSILE GUIDANCE AND CONTROL SUBSYSTEMS.

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Donald F./Norville, GS-09

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Recently, increased emphasis has been placed on designing systems for supportability due to the significance of support costs on the total life cycle cost of the system. One of the most important contributors to tactical missile support costs is the cost of depot overhaul of guidance and control subsystems (GCS). Despite its importance, depot overhaul costs are not currently forecast by the operations and support cost model used by Warner Robins Air Logistics Center, the system manager for tactical missiles, Instead, the model requires an externally derived estimate of this cost as input data. However, accurate estimating techniques have not been developed to forecast the cost of tactical missile GCS depot overhaul during system development. The authors, using the technique of multiple linear regression (MLR), identified several physical characteristics of a GCS which are important determinants of depot overhaul cost. These important determinants were then used to develop a cost estimating relationship model for forecasting GCS depot overhaul cost during tactical missile system development.

LSSR 9-78A

# FORECASTING DEPOT OVERHAUL COSTS
# OF TACTICAL MISSILE GUIDANCE
# AND CONTROL SUBSYSTEMS

A Thesis

Presented to the Faculty of the School of Systems and Logistics
of the Air Force Institute of Technology
Air University
In Partial Fulfillment of the Requirements for the
Degree of Master of Science in Logistics Management

By

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June 1978

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This thesis, written by

Captain Joel D. Eichenberger

and

Mr. Donald F. Norville

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

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT
(ACQUISITION LOGISTICS MAJOR)

or

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT (PROCUREMENT MAJOR)

DATE: 14 June 1978

Leslie J Zambo

COMMITTEE CHAIRMAN

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## Chapter 1

## INTRODUCTION

The development of new air launched tactical guided missiles is a continuing process within the U.S. Air Force. Recently, increased emphasis has been placed on designing systems for support due to the significant impact of support costs on the total life cycle cost (LCC) of a system. For example, Warner Robins Air Logistics Center (WR-ALC) has estimated the annual operation and support (O&S) costs for the AIM-7F and AIM-9L missile systems to be $6.92 million and $4.53 million, respectively, for quantities of 10,000 each.

A large portion of these O&S costs were comprised of depot overhaul costs. For the AIM-7F and AIM-9L, annual depot overhaul costs were estimated to be $5.45 million and $3.28 million, respectively, or approximately 80 percent and 73 percent of total annual O&S costs (13). Of these depot overhaul costs, the single most important factor is the depot overhaul of guidance and control subsystems (GCS) (14), the "brains" of a guided missile, which may account for as much as 80 percent of missile acquisition cost (1:5). The portions of the WR-ALC annual O&S cost models for the AIM-7F and AIM-9L which compute total annual GCS depot overhaul costs (DC) are as follows:

$$AIM\text{-}7F \quad DC = (.067Q - .000061F + FZ)OHC$$

$$AIM\text{-}9L \quad DC = (.036Q - .00003F + FZ)OHC$$

The variables contained in these equations are identified in Table 1.1, O&S Cost Estimate Data, along with the values used by WR-ALC in determining the estimates of total annual O&S costs. Using these values in the above equations, the resultant estimates for total annual GCS depot overhaul costs are $5.43 million for the AIM-7F and $3.25 million for the AIM-9L.

Table 1.1

O&S Cost Estimate Data

| Variables | AIM-7F | AIM-9L |
|---|---|---|
| Missile Inventory (Q) | 10,000 | 10,000 |
| Annual Flying Hours per Missile on Aircraft (F) | 1,000 | 20,000 |
| Failure Rate per Flying Hour (Z) | .00870 | .01942 |
| GCS Depot Overhaul Unit Cost (OHC) | $8,000 | $4,353 |

When compared with the previous cost estimates for total annual missile depot overhaul ($5.45 and 3.28 million), it can be seen that virtually all of the depot overhaul costs for these missiles are associated with the overhaul of the GCS. Additionally, sensitivity analyses of total annual O&S cost relative to changes in GCS depot overhaul unit cost

(OHC) indicated that a 10 percent change in OHC resulted in a 7.8 percent change in total annual O&S cost for the AIM-7F and a 7.2 percent change in total annual O&S cost for the AIM-9L.

Despite the importance of GCS depot overhaul unit cost, the WR-ALC O&S cost model does not have the capability to forecast this cost. Instead, this model, as well as other current LCC models for tactical missiles, requires an externally derived estimate of this cost as input data. There is, however, no known validated method for deriving this estimate prior to actual depot overhaul (14; 16).

## Statement of the Problem

Accurate estimating techniques have not been developed to forecast the cost of tactical missile guidance and control subsystems depot overhaul during system development.

## Objectives

The first objective of this research was to identify the most important variables for determining the cost of tactical missile GCS depot overhaul.

The second objective was to use the variables to develop a cost estimating relationship model which could be used during tactical missile system development for forecasting GCS depot overhaul cost.

Research Questions

1. What variables are important in determining the cost of tactical missile GCS depot overhaul?

2. What cost estimating relationships would be useful in forecasting GCS depot overhaul cost during tactical missile system development?

## Chapter 2

## BACKGROUND AND JUSTIFICATION

### Background

The trend in federal spending over the past several years, as depicted in Figure 2.1, shows the decreasing share of resources being allocated to the Department of Defense (DOD). DOD's share of the federal spending has decreased

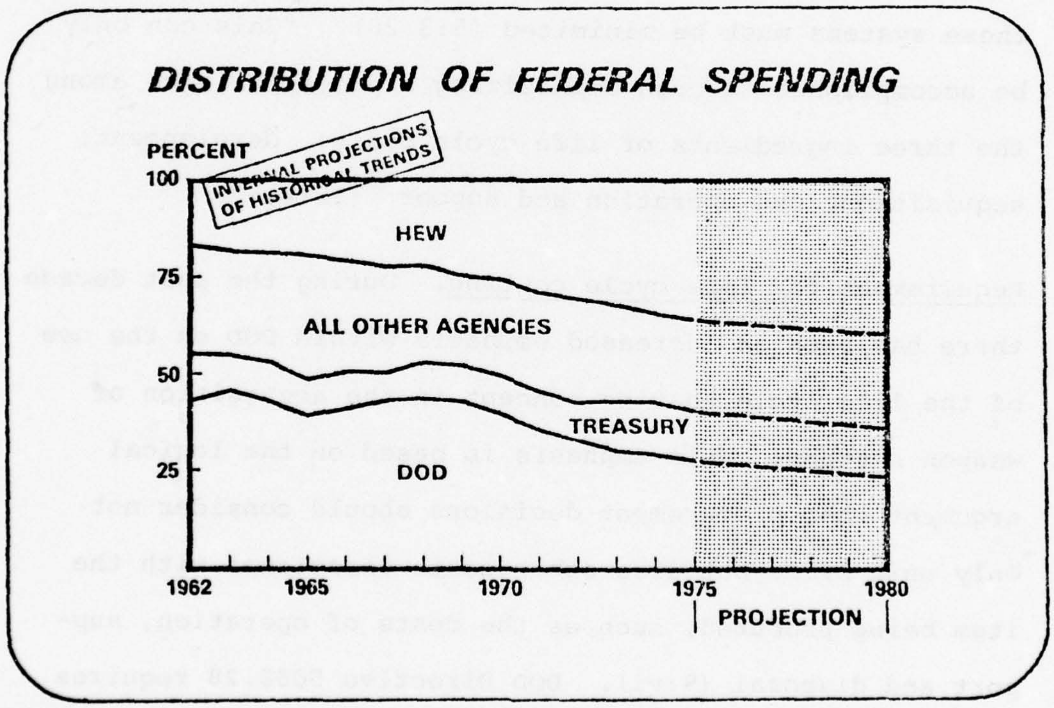


Figure 2.1

Distribution of Federal Spending

Source: (2:p.1-20)

from approximately 45 percent in 1962 to a projected 25 percent in 1980 (2:p.1-20). This decrease in total DOD spending has been compounded by rapidly rising manpower costs and the growing sophistication and complexity of weapon systems. Although high-level attention primarily focuses on research and development (R&D) and acquisition costs, the greatest costs over the life of a system are normally associated with operation and support (O&S) (11:4).

Clearly, then, if the United States is to obtain the weapon systems and related support equipment necessary to maintain a credible defense posture in light of limited resources, the operation and support costs associated with these systems must be minimized (5:3.28). "This can only be accomplished through emphasizing a proper balance among the three ingredients of life cycle costs: development, acquisition, and operation and support [12:4]."

Requirement for life cycle costing. During the past decade there has been an increased emphasis within DOD on the use of the life cycle costing concept in the acquisition of weapon systems. This emphasis is based on the logical argument that procurement decisions should consider not only unit price but also other costs associated with the item being procured, such as the costs of operation, support and disposal (9:vi). DOD Directive 5000.28 requires the establishment of life cycle cost objectives for weapon system acquisition programs. Tradeoffs between system capability, cost and schedules must be evaluated to provide the lowest overall life cycle cost within schedule and performance requirements (20:3).

Current laws and procurement regulations provide the general framework in which the life cycle costing concept can be applied.

> Title 10, USC, Section 2305(C) states: "Award shall be made . . . to the responsible bidder whose bid . . . will be the most advantageous to the United States, price and other factors considered." Furthermore, ASPR 3-801.1 states: "It is the policy of the Department of Defense to procure supplies from responsible sources at fair and reasonable prices calculated to result in the lowest ultimate overall cost to the Government." In addition, Comptroller General decision B-151177, dated 17 June 1963, held that award of contracts may be based on total cost considerations as long as the factors to be considered are stated with sufficient clarity [9:1].

Life cycle cost models. The integration of life cycle cost objectives into program management decision making requires the development of tools which the acquisition team can use to determine initial estimates of total life cycle costs, including operation and support costs. Tools are also needed to enable them to determine appropriate tradeoffs among acquisition cost, performance, scheduling and O&S costs (12:4).

The primary tool is the cost model, which can be defined as a systematic sequence of mathematical relationships formulating a cost methodology which utilizes inputs in the form of equipment descriptions, organization, procedures and other variables to determine outputs in the form of cost estimates (22:p.3-1). Cost models facilitate handling large-scale, complex systems by providing for "creative manipulation in order to test new ideas concerning system components and/or relationships [7:392]."

Included in the general category of cost models are life cycle cost models. These can be distinguished from other types of cost models in that they project subsequent operation and support costs resulting from contemplated design decisions (22:p.3-2). To be effective, these models should meet the primary requirements of completeness, sensitivity, validity and availability of input data. To be complete, they must consider all cost elements relative to the decision issue at hand. They must also be sensitive to changes in design or program variables so that differences in the costs of alternatives will be apparent. Although models can only approximate the real-life situation, they must be validated to be of practical use in decision making. Finally, in developing LCC models, one must recognize any limitations that exist with regard to obtaining accurate input data (6:24-25).

Several deficiencies have been identified in existing models. Many are insensitive to performance and design variables such as material type, dimensions, accuracy, speed and range, making the evaluation of design alternatives very difficult. Since many models are general in nature, they tend to be overly complex because of numerous and poorly defined variables. Some frequently require input data which may not be available in the required time frame or which may not meet required accuracy (3:8-10). Others may be subject to statistical errors where statistically determined cost estimating relationships are used (19:1). These deficiencies must be considered when LCC models are used as a basis for program decisions.

In addition to deficiencies in the models themselves, problems exist in the implementation of life cycle cost techniques. "Much effort remains before O&S costs can be measured in a manner suitable for practical applications in acquisition and logistics management [11:4]." Figure 2.2 compares this problem to an iceberg in which the majority of costs are submerged, making them less apparent (2:p.1-36). In the past, program managers have focused their attention on the more visible procurement and R&D costs while neglecting the less discernible O&S costs (21:2).

This "iceberg" effect can be attributed to many factors. Current techniques for predicting and verifying O&S costs are inadequate (9:viii). They usually address only a portion of total O&S costs in that they deal with logistics variables without considering performance variables. The validity of model outputs is often suspect due to poor quality and insufficient input data, especially during testing. Additional difficulties may arise when the various nomenclatures used within different data systems are considered (4:11).

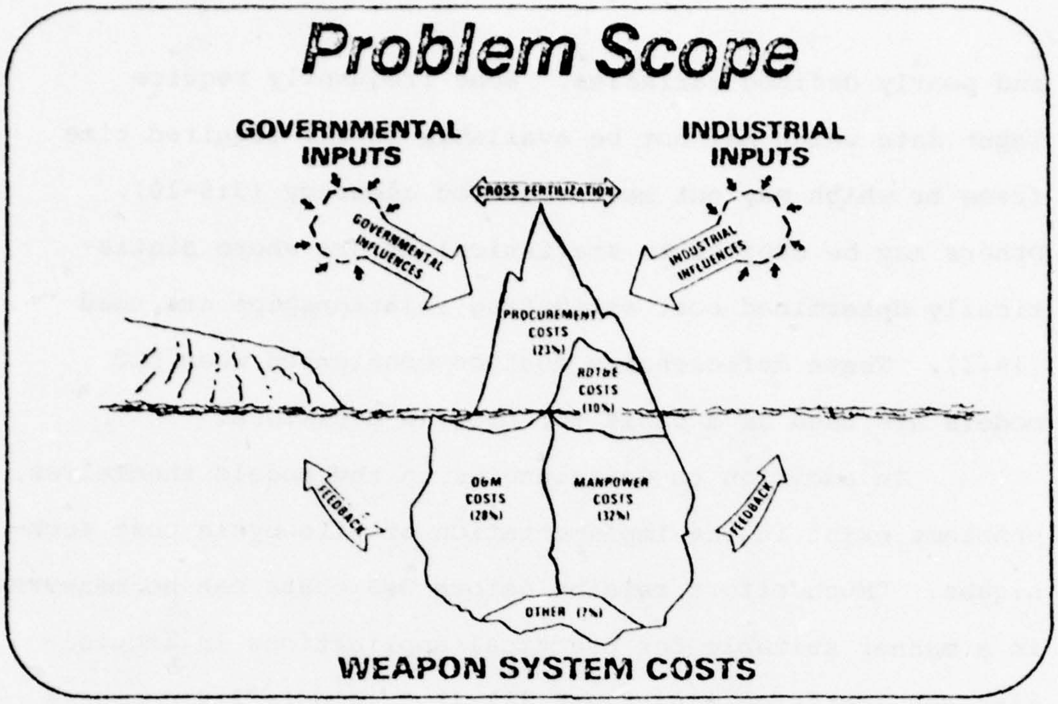


Figure 2.2

Problem Scope

Source: (2:p.1-36)

Summary. Due to the current budget crunch within DOD, increased emphasis has been placed on the concept of life cycle costing. DOD Directive 5000.28 requires the establishment of LCC objectives for weapon system acquisition programs. In order to meet these objectives, LCC models must be developed and applied. For these models to be effective, they should meet the primary requirements of completeness, sensitivity, validity and availability of input data. Many of the existing models, however, are deficient in one or more of these areas. Problems also exist in the implementation of LCC techniques.

## Justification

The Air Force Acquisition Logistics Division of the Air Force Logistics Command (AFLC) is in the process of developing a LCC model for the proposed Advanced Medium Range Air-to-Air Missile (AMRAAM). A by-product of this effort will be a general model applicable to all tactical missiles. As the basis for this effort, Ogden Air Logistics Center (OO-ALC) and Warner Robins Air Logistics Center (WR-ALC) have provided the LCC models applicable to the tactical missiles for which they are system managers (16). These models exhibit many of the deficiencies in LCC models discussed previously. Of particular concern is the weakness in accurately estimating the depot overhaul cost of guidance and control subsystems, which comprises a major portion of operation and support costs (14). For example, a recent cost estimate for the Low Cost Lightweight Missile (LCLM) attributed approximately 45 percent of total annual O&S costs to GCS depot overhaul (13:1). These existing models do not predict GCS depot overhaul costs but rather require an estimate of these costs as input data (16). In the past, the estimate was calculated simply as a percentage of missile acquisition cost; however, this estimating technique has never been validated (14).

Since existing models are dependent upon the accuracy of the externally estimated overhaul cost, a valid and reliable cost estimating technique is required (14). AFLC/MAX, which is responsible for maintenance planning within AFLC, depends upon the Cost Analysis Division, AFLC/ACRC, for information concerning depot overhaul costs (17). AFLC/ACRC, in turn, relies upon the ALC having item management responsibility for a particular subsystem for specific depot overhaul cost estimates (8). As previously stated, WR-ALC, the item manager for the majority of tactical missile guidance and control subsystems, does not possess a reliable method for forecasting the depot overhaul cost of these subsystems during system development. A cost estimating relationship model would provide a useful tool for forecasting tactical missile GCS depot overhaul cost (14).

## Chapter 3

## METHODOLOGY

The objectives of this research were twofold--to identify the most important variables for determining the cost of tactical missile GCS depot overhaul and to use these variables to develop a cost estimating relationship model for forecasting GCS depot overhaul cost. Both of these objectives were met by using the technique of multiple linear regression (MLR) since it serves two primary functions. First, MLR provides a statistical technique for analyzing relationships between a single dependent variable and one or more independent variables (15:321). Second, it provides means for developing a mathematical model which can be used to forecast the value of the dependent variable based on its relationships with one or more independent or predictor variables (18:391). Standard computer subprograms were used to facilitate these analyses and to provide the information required for evaluating their results.

### Data Acquisition Plan

A prerequisite to performing a linear regression analysis is the acquisition of data. Since this research was concerned with obtaining a predictive capability during system development, acquired data had to be of the type which could be identified and obtained prior to system deployment.

Population. The population from which a sample of missiles was drawn consisted of all present and future anti-radiation, infrared and semi-active radar tactical missile guidance and control subsystems (GCS) managed by WR-ALC. Missiles of these types currently in the Air Force inventory are the AGM-45A/B[1] Shrike, AGM-78C/D Standard ARM, AIM-9B/E/J/J-1[2] Sidewinder, AIM-7E2/3&F4/5/6/7 Sparrow, and AIM-4D-8/9&F/G Falcon (23:1). Others in development or production include the AMRAAM, LCLM, AGM-88 HARM, and AIM-9L Sidewinder (14). The population included only the GCS associated with the above missile types since the model was developed for WR-ALC use.

Sample. The sample data used to construct the cost model consisted of the GCS for the AGM-45, AIM-7, and AIM-9 series missiles which had been depot overhauled between fiscal years 1974 and 1977. The AGM-78 series missiles were excluded from the sample because no depot overhaul data was recorded for this time period. The AIM-4 series missiles were excluded from the sample since they are in the process of being phased out and are repaired under a maintenance concept

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[1]AGM - Air-to-Ground Missile.

[2]AIM - Air Intercept Missile.

which is not consistent with that of other tactical missiles within the population. The specified time frame was selected to facilitate data collection and to provide sufficient data to achieve a representative sample.

Data description. The data collected in the sample were depot overhaul costs, acquisition costs and numerical data on selected physical characteristics. Depot overhaul costs included the costs to overhaul either within the Air Force at WR-ALC or OO-ALC or under contract with the Navy or commercial contractors. All in-house and commercial overhaul costs were obtained from the AFLC HO36B, DOD Cost and Production Report. The Navy overhaul costs were obtained from the WR-ALC tactical missile production manager and the HO36B report, which included interservicing (Navy) depot overhaul costs beginning with the FY7T report. It was assumed that these reported costs were accurate and that errors, if any, were random. Since these costs are actual dollar amounts, they are ratio-level data. All costs were adjusted to constant FY 1977 dollars using a combined index developed in Appendix A.

Acquisition costs included the latest purchase price for each GCS in the sample, adjusted to constant FY 1977 dollars in accordance with the DOD Industry Purchases Index found in Table A.1, page 59. These costs were obtained from the WR-ALC tactical missile system manager and are also ratio-level data. Again, these costs were assumed to be accurate.

Numerical data on selected physical characteristics for each GCS included:

1. Number of subassemblies - the number of major reparable components of a GCS, such as the target seeker, amplifier, gyro drive assembly, servo, power supply and guidance computer;

2. Weight - the weight in pounds of a complete GCS[3];

3. Length - the length in inches of a complete GCS;

4. Diameter - the diameter in inches of a GCS at its largest point;

5. Volume - the volume in cubic inches of a complete GCS;

6. Type of guidance employed - either anti-radiation, infrared or semi-active radar.

Performance characteristics data were classified and could not be used in this research effort. All physical data were obtained from the WR-ALC tactical missile technical manager. All of these data are ratio-level data except for type of guidance employed, which is nominal-level data.

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[3]A complete GCS includes all components performing the GCS functions, whether or not separated by any other major missile component, e.g., warhead, but does not include that other component nor wings and fins/canards.

## Developing the Model

The multiple linear regression technique, which was used to develop the GCS depot overhaul cost forecasting model, is detailed in Appendix B. The general form of a MLR model is:

$$y = b_0 + b_1x_1 + b_2x_2 + . . . . + b_kx_k$$

where y is the dependent variable and $x_1$ through $x_k$ are the independent variables.

Identification of variables. The dependent variable is GCS depot overhaul cost, which is predicted by the model. In formulating the model, each observation of the cost data was entered with the corresponding values of the independent variables. The independent variables are acquisition cost, number of subassemblies, weight, length, diameter, volume, density and type of guidance employed. Density was not input directly but rather was computed within the MLR program (Density = Weight $\div$ Volume). Table 3.1 summarizes information concerning these variables. Appendix C contains all observed data and describes its conversion to the format used for the MLR analysis.

Since the independent variable type of guidance employed is nominal-level data, it required the use of categorical variables, sometimes referred to as dummy variables. In the method of differences, which is the technique by which nominal-level data is encoded in a MLR model, one type or category is established as the base level. The

Table 3.1

Identification of Variables

| Name | Designation | Category | Units of Measure | Data Level |
|---|---|---|---|---|
| Depot Overhaul Cost | OHC | Dependent | Dollars | Ratio |
| Acquisition Cost | AC | Independent | Dollars | Ratio |
| Number of Subassemblies | NS | Independent | Units | Ratio |
| Weight | WT | Independent | Pounds | Ratio |
| Length | LH | Independent | Inches | Ratio |
| Diameter | DI | Independent | Inches | Ratio |
| Volume | VO | Independent | Cubic Inches | Ratio |
| Density | DN | Independent | Pounds/Cu. In. | Ratio |
| Type of Guidance Employed | TG1 TG2 | Independent (Categorical) | a | Nominal |

[a]Value of TG1 = 1 if infrared, 0 otherwise.
Value of TG2 = 1 if anti-radiation, 0 otherwise.

remaining categories are then each defined by a categorical variable (10:78). Two categorical variables were required for this model since there are three categories of guidance employed within the population: anti-radiation, infrared and semi-active radar. Semi-active radar was used as the base level since it had the fewest number of observations.

<u>Model manipulation</u>. The AFLC CREATE computer system was used in the development and manipulation of the model. A time-sharing file was established containing all observations of the data under consideration (Figure C.1, page 77). The multiple linear regression was accomplished under the REGRESSION subprogram of the Statistical Package for the Social Sciences (SPSS) system of computer programs using the time-sharing CARDIN subsystem (15:320-367,373-383).

<u>Model evaluation</u>. The methodology described herein resulted in a MLR model, which was the primary objective of this research. For the MLR model to be utilized as a predictor of GCS depot overhaul costs, it was necessary to evaluate it in terms of its statistical significance. The first step in this evaluation was to calculate the coefficient of determination, which measures the relative efficiency with which the independent variables can be used to forecast a value of the dependent variable, GCS depot overhaul cost. The second was to determine the significance of overall regression, which indicates the level of confidence at which the model

is statistically significant. The third step was to determine the statistical significance of each of the independent variables in order to determine whether each variable should remain in the model. This evaluation process is described further in Appendix B.

## Assumptions

Pertinent assumptions made for this research were as follows:

1. The basic assumptions of MLR, as enumerated in Appendix B were applicable.

2. All data were assumed to be accurate.

3. The labor/material breakout for AIM-9 depot overhaul was representative of all missiles in the sample (Appendix A).

4. The indices contained in Appendix A were representative of the inflation experienced for missile acquisition and depot overhaul costs.

## Limitations

Basic limitations on this research were as follows:

1. The population was limited to tactical missile GCS managed by WR-ALC.

2. The independent variables were limited to those for which data were unclassified.

3. The independent variables were limited to those which can be quantified during system development.

# Chapter 4

# ANALYSIS

## Selecting Individual Variables

The first objective of this research was to identify the most important variables which could be used for determining the cost of tactical missile GCS depot overhaul. The initial step in achieving this objective was to examine the correlation coefficient of each independent variable with respect to the dependent variable, depot overhaul cost (OHC). Next, a linear regression was performed for OHC with each independent variable. The residual plots and other information gained from these regressions were then examined as the final step in meeting the first objective and provided the basis for further analysis.

Correlation. Table 4.1 lists the coefficients of correlation between OHC and each of the independent variables. The figures indicate that the highest correlations exist between the dependent variable, OHC, and the four independent variables acquisition cost (AC), weight (WT), length (LH) and volume (VO). Number of subassemblies (NS) and diameter (DI) exhibited lesser correlations. For this reason and reasons set forth in the following paragraph, the latter two variables were determined not to be important. Although its correlation was low, density (DN) was subjected to further analysis, as described later, and found to be an important variable. The correlations for the individual categorical variables, TG1 and TG2, are meaningless since together they represent a single independent variable and must be considered as such.

Table 4.1

OHC Correlation Coefficients

| Independent Variable | Correlation Coefficient (R) |
|---|---|
| AC | 0.82686 |
| NS | -0.71235 |
| WT | 0.82301 |
| LH | 0.83035 |
| DI | 0.55994 |
| VO | 0.81788 |
| TG1 | -0.55994 |
| TG2 | -0.16001 |
| DN | -0.66728 |

Type of Guidance Employed (TG). In order to determine the relationship between OHC and TG, a linear regression of OHC with TG1 and TG2 was performed. The resultant correlation coefficient was 0.86124. This coefficient, higher than any other individual correlation coefficient, indicates the importance of this categorical variable for determining the cost of GCS depot overhaul. It was found that TG1 was perfectly inversely correlated (R = -1.0) with DI. Also, TG (TG1 and TG2 in combination) exhibited a similar relationship with NS. When TG1 and TG2 both equal zero (semi-active radar), NS equals two; when TG1 = 1 and TG2 = 0 (infrared), NS = 5; when TG1 = 0 and TG2 = 1 (anti-radiation), NS = 3. Therefore, when TG1 and TG2 are used in combination, they provide not only information on type of guidance but also information on number of subassemblies and diameter as well, making the independent variables NS and DI unnecessary.

Acquisition Cost (AC). A simple linear regression of OHC with AC confirmed the importance of this independent variable. The relative efficiency ($R^2$) was 0.68371, and was found to be significant at a confidence level greater than 99.9 percent ($F_0 = 58.36 > F_{.001;1,27} = 13.61$)[4].

Weight (WT). In the simple linear regression of OHC with WT, the relative efficiency was 0.67735, and was found to be significant at a confidence level greater than 99.9 percent ($F_0 = 56.68 > F_{.001;1,27} = 13.61$).

Length (LH). Similarly, the simple linear regression of OHC with LH indicated the significance of this independent

[4] See Appendix B for explanation of notation.

variable. The relative efficiency was 0.68948, and was found to be significant at a confidence level greater than 99.9 percent ($F_0 = 59.95 > F_{.001;1,27} = 13.61$).

Volume (VO). A simple linear regression of OHC with VO resulted in a relative efficiency of 0.66894. The relationship was significant at a confidence level greater than 99.9 percent ($F_0 = 54.56 > F_{.001;1,27} = 13.61$).

Plots of standardized residuals. An examination of the plots of standardized residuals associated with each of the variables AC, WT, LH and VO, Figures 4.1-4.4, gave no indication that the basic assumptions of linear regression were violated. Appendix B provides information regarding the examination of residual plots.

Density (DN). A simple linear regression of OHC with DN produced a relative efficiency of 0.44527. An examination of the plot of standardized residuals, Figure 4.5, revealed that the basic linear regression assumption that the expected value of the error term for any given observation equals zero was violated. It also revealed the possibility of a curvilinear relationship. In order to explore this possibility, a multiple linear regression of OHC with DN and DN squared (DNS) was performed. This resulted in a relative efficiency of 0.68472, and a corresponding correlation coefficient of 0.82748 between OHC and the combination of DN and DNS. The $R^2$ value was significant at a confidence

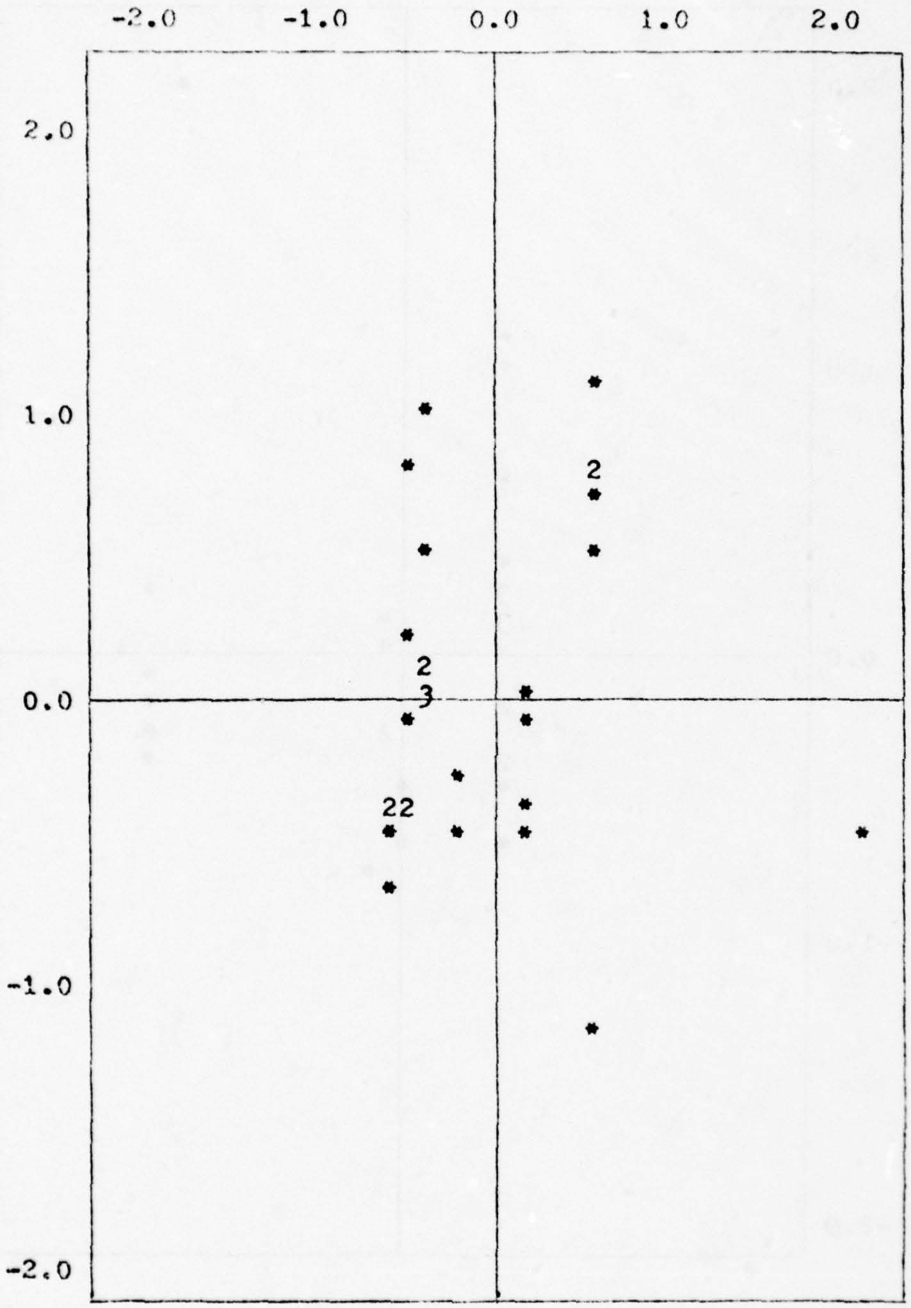


Figure 4.1

Residual Plot for AC

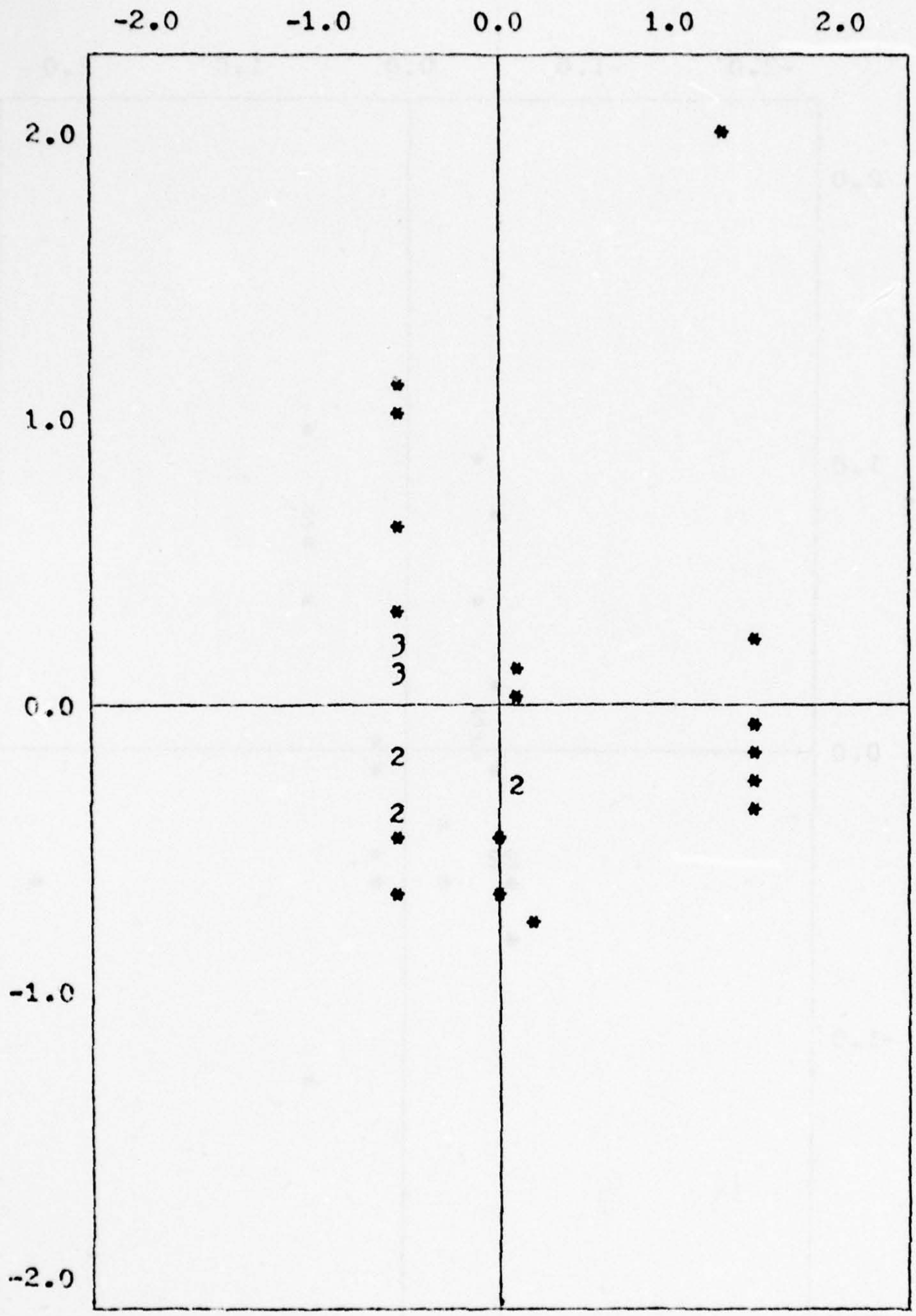


Figure 4.2

Residual Plot for WT

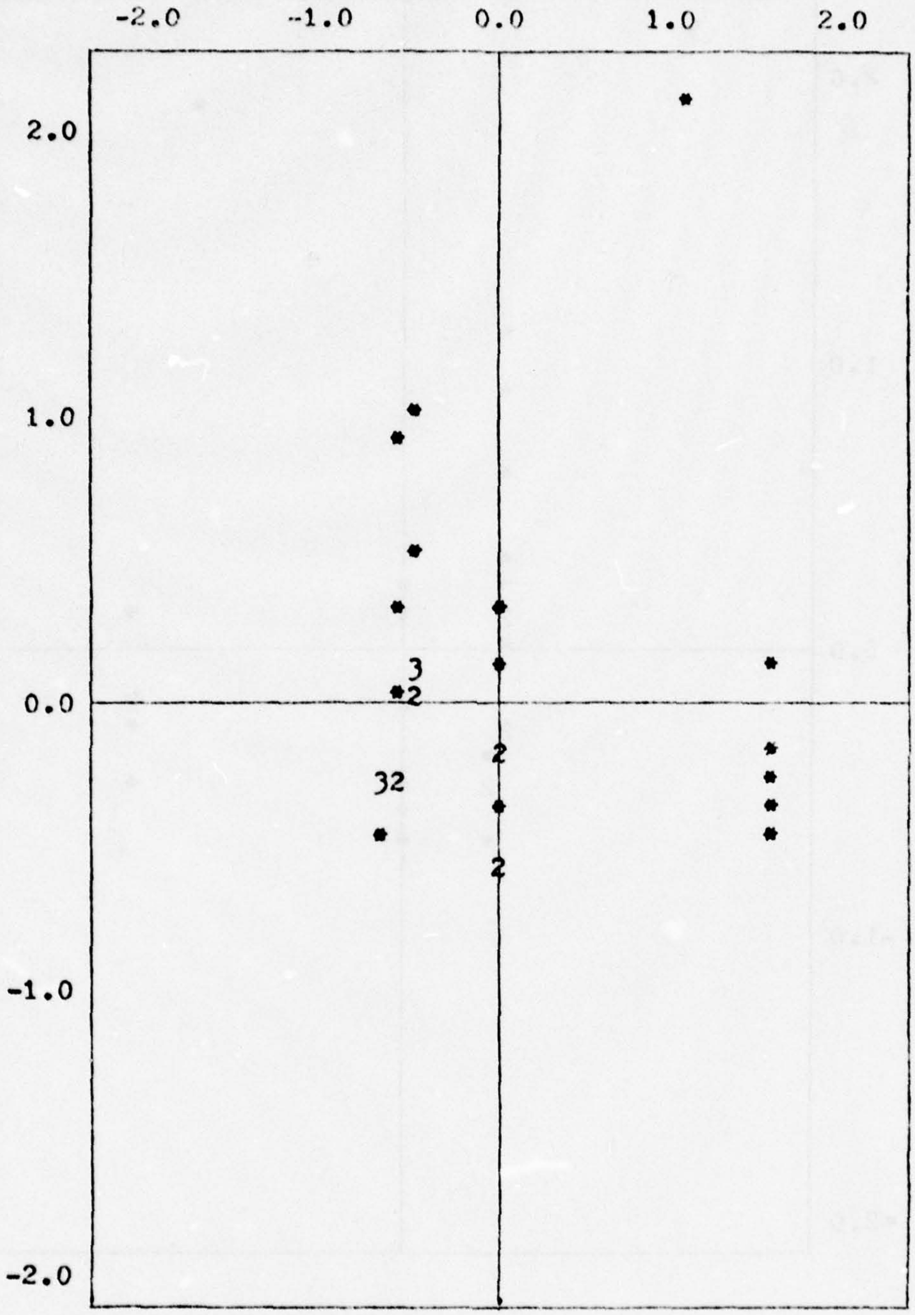


Figure 4.3

Residual Plot for LH

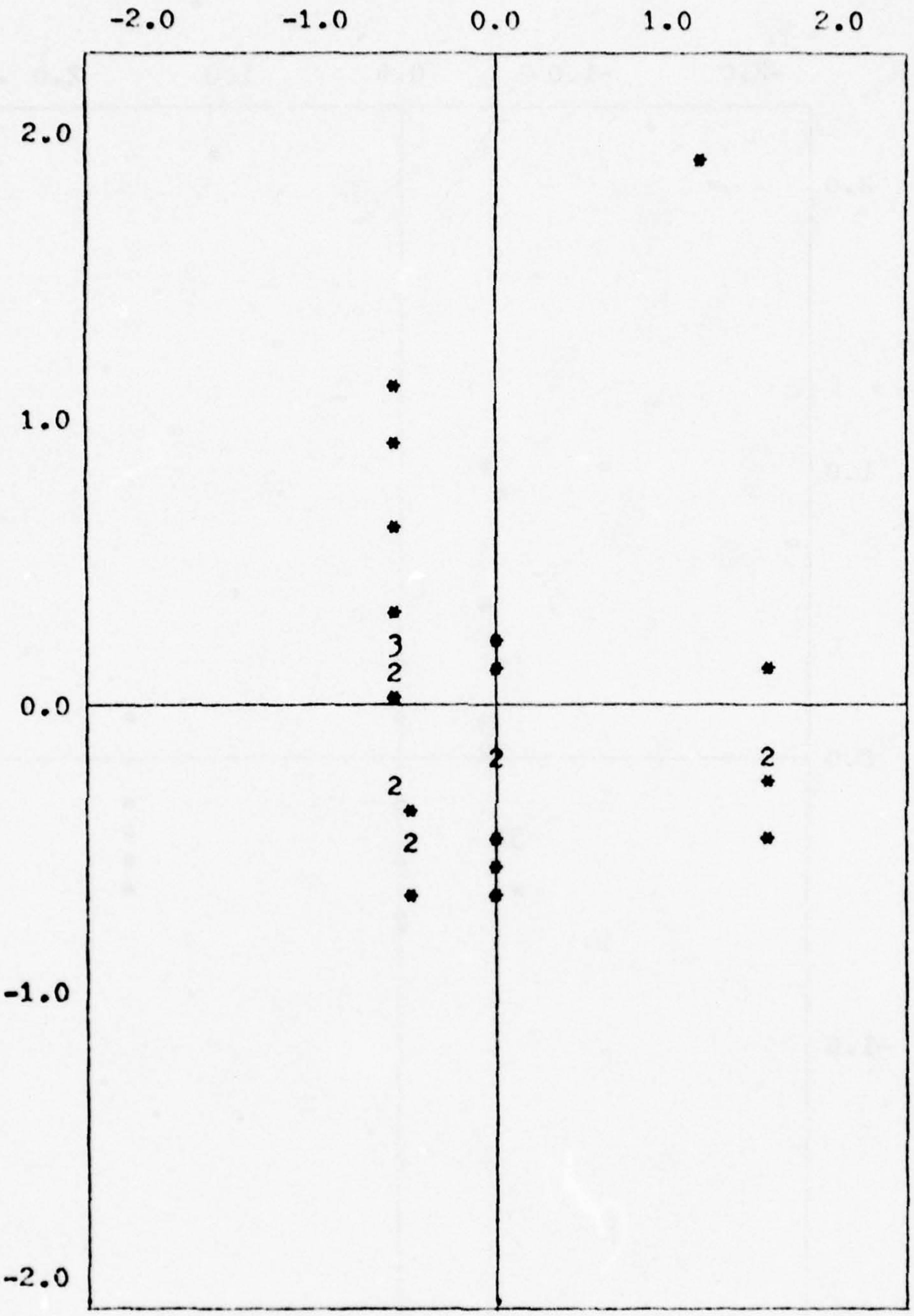


Figure 4.4

Residual Plot for VO

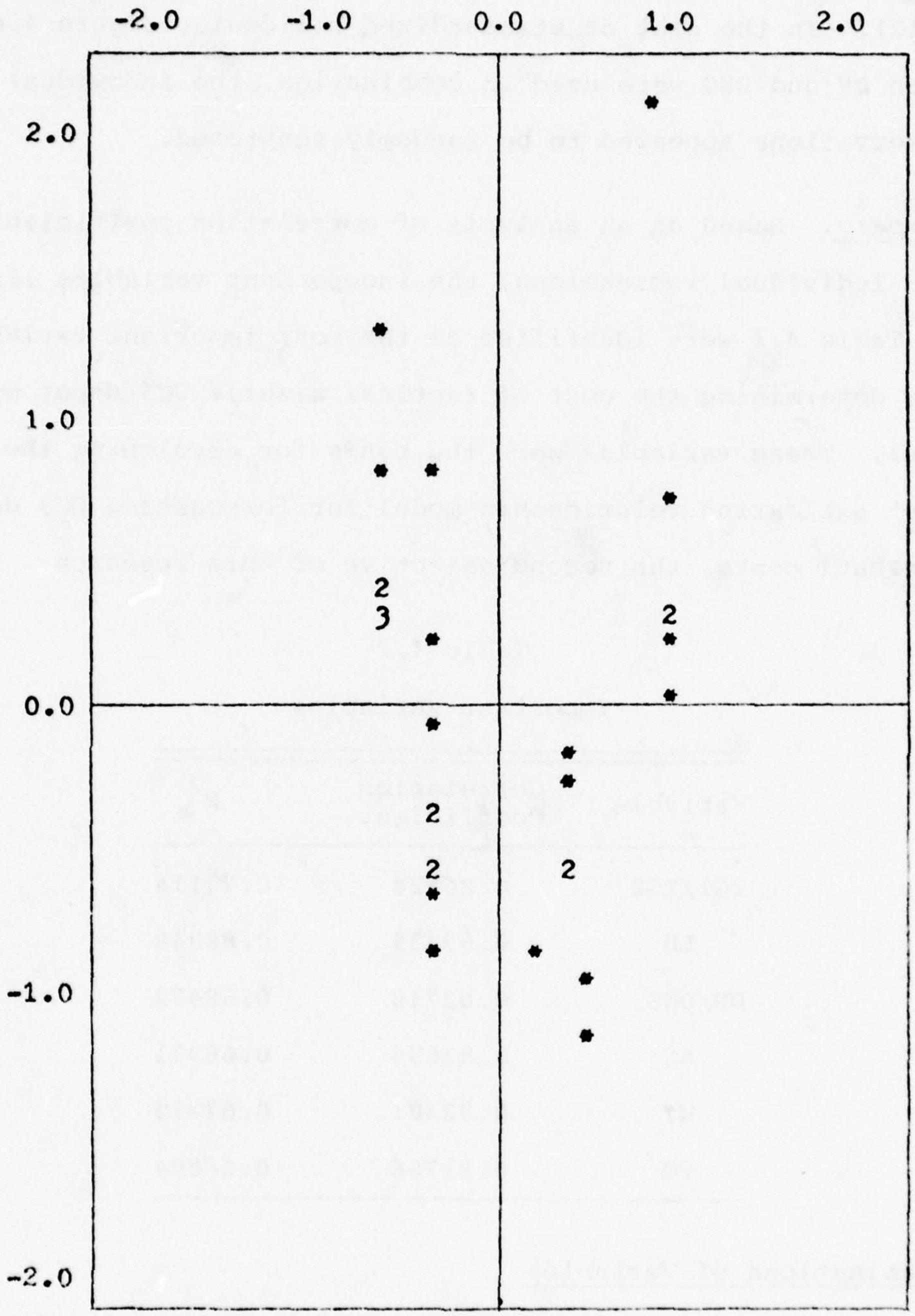


Figure 4.5

Residual Plot for DN

level greater than 99.9 percent ($F_0 = 28.23 > F_{.001;2,26} = 9.12$). In the plot of standardized residuals, Figure 4.6, when DN and DNS were used in combination, the individual observations appeared to be randomly scattered.

Summary. Based on an analysis of correlation coefficients and individual regressions, the independent variables listed in Table 4.2 were identified as the most important variables for determining the cost of tactical missile GCS depot overhaul. These variables were the basis for developing the cost estimating relationship model for forecasting GCS depot overhaul costs, the second objective of this research.

Table 4.2

Important Variables

| Variable | Correlation Coefficient | $R^2$ |
|---|---|---|
| TG1/TG2 | 0.86124 | 0.74174 |
| LH | 0.83035 | 0.68948 |
| DN/DNS | 0.82748 | 0.68472 |
| AC | 0.82686 | 0.68371 |
| WT | 0.82301 | 0.67735 |
| VO | 0.81788 | 0.66894 |

## Combinations of Variables

To meet the second research objective, multiple linear regressions were developed using various combinations

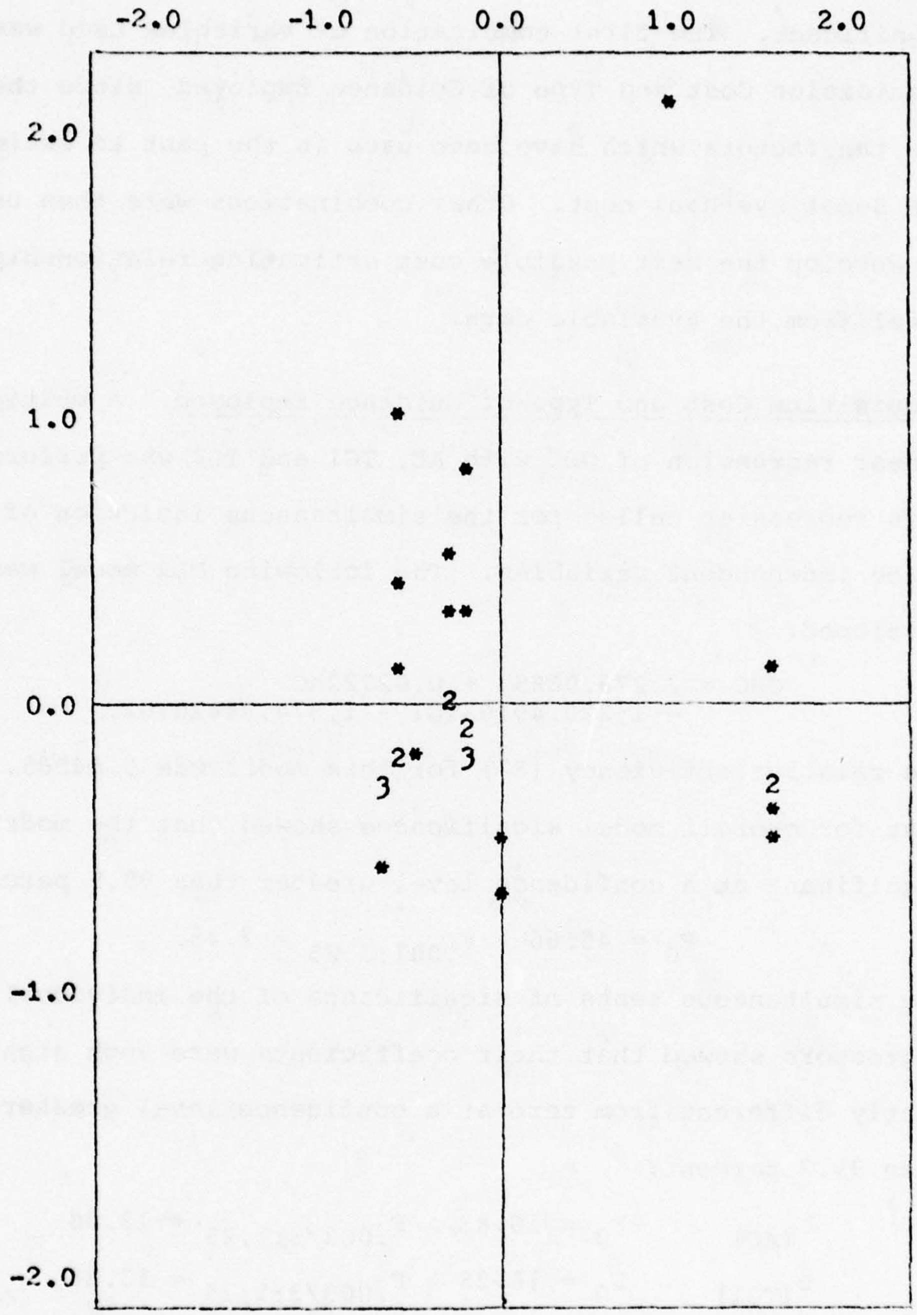


Figure 4.6

Residual Plot for DN/DNS

of the independent variables previously determined to be significant. The first combination of variables used was Acquisition Cost and Type of Guidance Employed, since these are the factors which have been used in the past to estimate GCS depot overhaul cost. Other combinations were then used to develop the best possible cost estimating relationship model from the available data.

Acquisition Cost and Type of Guidance Employed. A multiple linear regression of OHC with AC, TG1 and TG2 was performed. This regression called for the simultaneous inclusion of the three independent variables. The following MLR model was developed:

$$OHC = 2,278.06853 + 0.02722AC - 1,220.49163TG1 - 1,374.84410TG2.$$

The relative efficiency ($R^2$) for this model was 0.84565. The test for overall model significance showed that the model was significant at a confidence level greater than 99.9 percent:

$$F_0 = 45.66 > F_{.001;3,25} = 7.45.$$

The simultaneous tests of significance of the individual regressors showed that their coefficients were each significantly different from zero at a confidence level greater than 99.7 percent:

$$b_{(AC)} \qquad F_0 = 16.83 > F_{.003/3;1,25} = 13.88$$

$$b_{(TG1)} \qquad F_0 = 16.28 > F_{.003/3;1,25} = 13.88$$

$$b_{(TG2)} \qquad F_0 = 26.07 > F_{.003/3;1,25} = 13.88$$

An examination of the plot of standardized residuals, Figure 4.7, gave no indication that the basic assumptions of linear regression were violated.

Stepwise inclusion of all variables. A stepwise regression of OHC with all independent variables except DNS was performed. The regression brought in the six variables, LH, AC, WT, VO, DN and TG2, in the order listed. After the inclusion of WT, step number three, little improvement in the model was achieved through the inclusion of additional variables. VO, brought in on the fourth step, increased $R^2$ by only .00156. Further, its coefficient was not significant even at a 50 percent confidence level:

$$F_0 = 0.39 < F_{.5;1,24} = .47.$$

The extremely low significance level of VO and the lower significance level of the remaining variables were due to the intercorrelation among the independent variables, as shown in Table 4.3. Consequently, the model as developed at step three was subjected to further analysis. This model was as follows:

$$\text{OHC} = -794.75599 + 134.90826\text{LH} + 0.04405\text{AC} - 54.63667\text{WT}.$$

An $R^2$ value of 0.90121 was achieved by this model. The test for overall model significance showed that it was significant at a confidence level greater than 99.9 percent:

$$F_0 = 76.02 > F_{.001;3,25} = 7.45.$$

The simultaneous tests of significance of the individual regressors showed that their coefficients were each

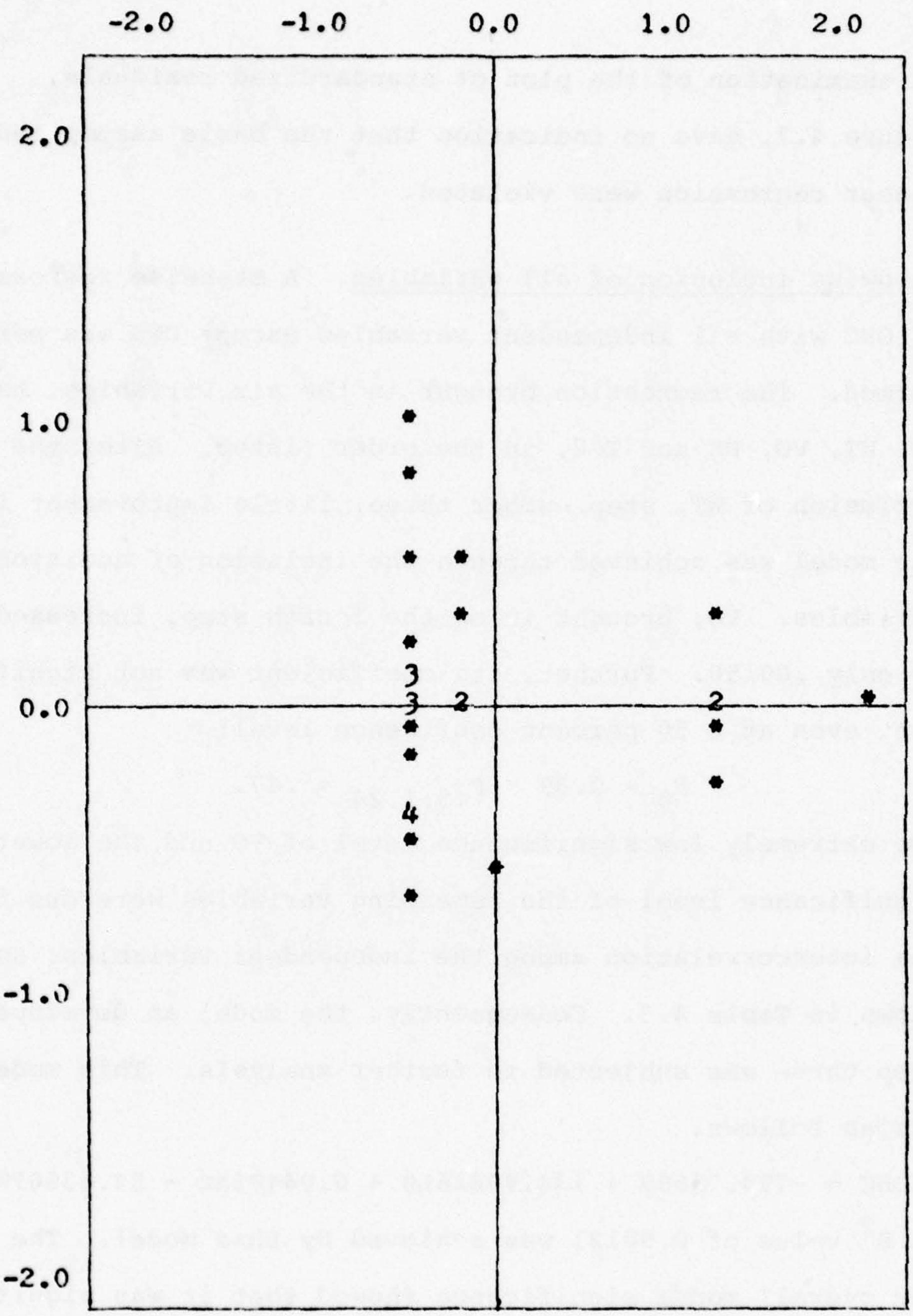


Figure 4.7

Residual Plot for AC/TG

Table 4.3

Independent Variable Intercorrelation

| | AC | NS | WT | LH | DI | VO | TG1 | TG2 | DN | DNS |
|---|---|---|---|---|---|---|---|---|---|---|
| AC | 1.000 | -0.726 | 0.730 | 0.668 | 0.648 | 0.695 | -0.648 | 0.105 | -0.678 | -0.667 |
| NS | -0.726 | 1.000 | -0.936 | -0.895 | -0.965 | -0.912 | 0.965 | -0.399 | 0.978 | 0.970 |
| WT | 0.730 | -0.936 | 1.000 | 0.989 | 0.811 | 0.997 | -0.811 | 0.054 | -0.931 | -0.900 |
| LH | 0.668 | -0.895 | 0.989 | 1.000 | 0.753 | 0.994 | -0.753 | -0.030 | -0.886 | -0.846 |
| DI | 0.648 | -0.965 | 0.811 | 0.753 | 1.000 | 0.775 | -1.000 | 0.626 | -0.930 | -0.939 |
| VO | 0.695 | -0.912 | 0.997 | 0.994 | 0.775 | 1.000 | -0.775 | -0.005 | -0.918 | -0.884 |
| TG1 | -0.648 | 0.965 | -0.811 | -0.753 | -1.000 | -0.775 | 1.000 | -0.626 | 0.930 | 0.939 |
| TG2 | 0.105 | -0.399 | 0.054 | -0.030 | 0.626 | -0.005 | -0.626 | 1.000 | -0.342 | -0.399 |
| DN | -0.678 | 0.978 | -0.931 | -0.886 | -0.930 | -0.918 | 0.930 | -0.342 | 1.000 | 0.997 |
| DNS | -0.667 | 0.970 | -0.900 | -0.846 | -0.939 | -0.884 | 0.939 | -0.399 | 0.997 | 1.000 |

significantly different from zero at a confidence level greater than 99.7 percent:

$$b_{(LH)} \qquad F_0 = 28.93 > F_{.003/3;1,25} = 13.88$$

$$b_{(AC)} \qquad F_0 = 53.55 > F_{.003/3;1,25} = 13.88$$

$$b_{(WT)} \qquad F_0 = 19.79 > F_{.003/3;1,25} = 13.88$$

An examination of the plot of standardized residuals, Figure 4.8, gave no indication that the basic assumptions of linear regression were violated.

Stepwise inclusion of physical variables. A stepwise regression was performed using only the independent variables associated with physical characteristics of the GCS. These included NS, WT, LH, DI, VO and DN. The regression brought in all variables except NS, in the following order: LH, DN, WT, VO, DI. Upon completion of the fifth and final step, all variables included were significant at a confidence level greater than 97.5 percent, as demonstrated by the simultaneous test of individual regressor significance:

$$b_{(LH)} \qquad F_0 = 13.60 > F_{.025/5;1,23} = 9.63 \qquad (97.5\%)$$

$$b_{(DN)} \qquad F_0 = 11.58 > F_{.025/5;1,23} = 9.63 \qquad (97.5\%)$$

$$b_{(WT)} \qquad F_0 = 20.27 > F_{.005/5;1,23} = 14.19 \qquad (99.5\%)$$

$$b_{(VO)} \qquad F_0 = 16.49 > F_{.005/5;1,23} = 14.19 \qquad (99.5\%)$$

$$b_{(DI)} \qquad F_0 = 15.14 > F_{.005/5;1,23} = 14.19 \qquad (99.5\%)$$

The resultant model was as follows:

$$\begin{aligned} OHC = {} & 34{,}393.21697 + 516.81280LH - 409{,}511.21783DN \\ & + 477.69390WT - 28.53265VO - 3{,}646.93593DI. \end{aligned}$$

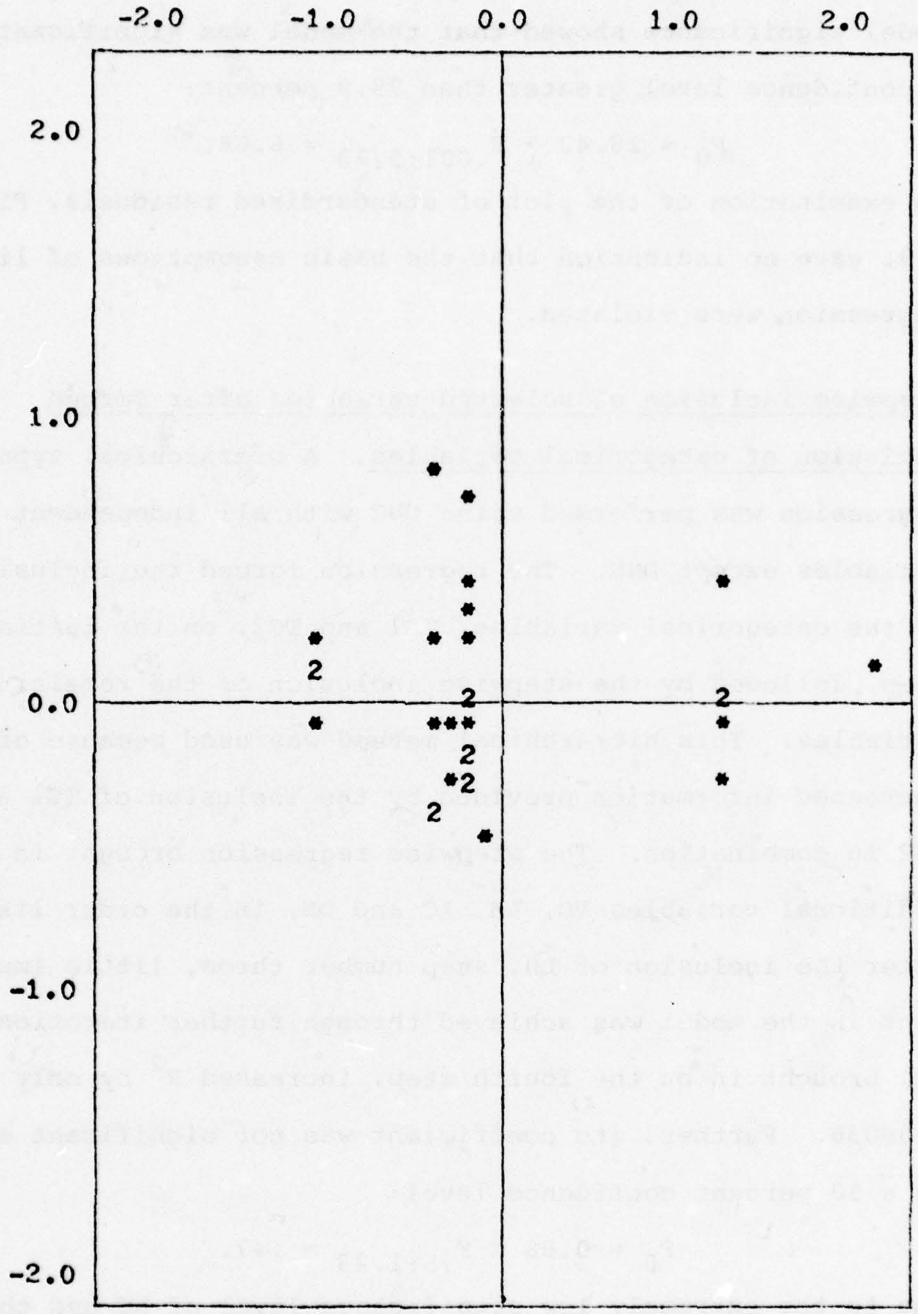


Figure 4.8

Residual Plot for LH/AC/WT

The $R^2$ for this model was 0.86068, and the test for overall model significance showed that the model was significant at a confidence level greater than 99.9 percent:

$$F_0 = 28.42 > F_{.001;5,23} = 6.08.$$

An examination of the plot of standardized residuals, Figure 4.9, gave no indication that the basic assumptions of linear regression were violated.

<u>Stepwise inclusion of selected variables after forced inclusion of categorical variables</u>. A hierarchical type regression was performed using OHC with all independent variables except DNS. The regression forced the inclusion of the categorical variables, TG1 and TG2, on the initial step, followed by the stepwise inclusion of the remaining variables. This hierarchical method was used because of the increased information provided by the inclusion of TG1 and TG2 in combination. The stepwise regression brought in the additional variables VO, LH, AC and DN, in the order listed. After the inclusion of LH, step number three, little improvement in the model was achieved through further iterations. AC, brought in on the fourth step, increased $R^2$ by only 0.00036. Further, its coefficient was not significant even at a 50 percent confidence level:

$$F_0 = 0.08 < F_{.5;1,23} = .47.$$

Due to the extremely low significance level of AC and the lower significance level of DN, the model as developed at step three was subjected to further analysis. This model

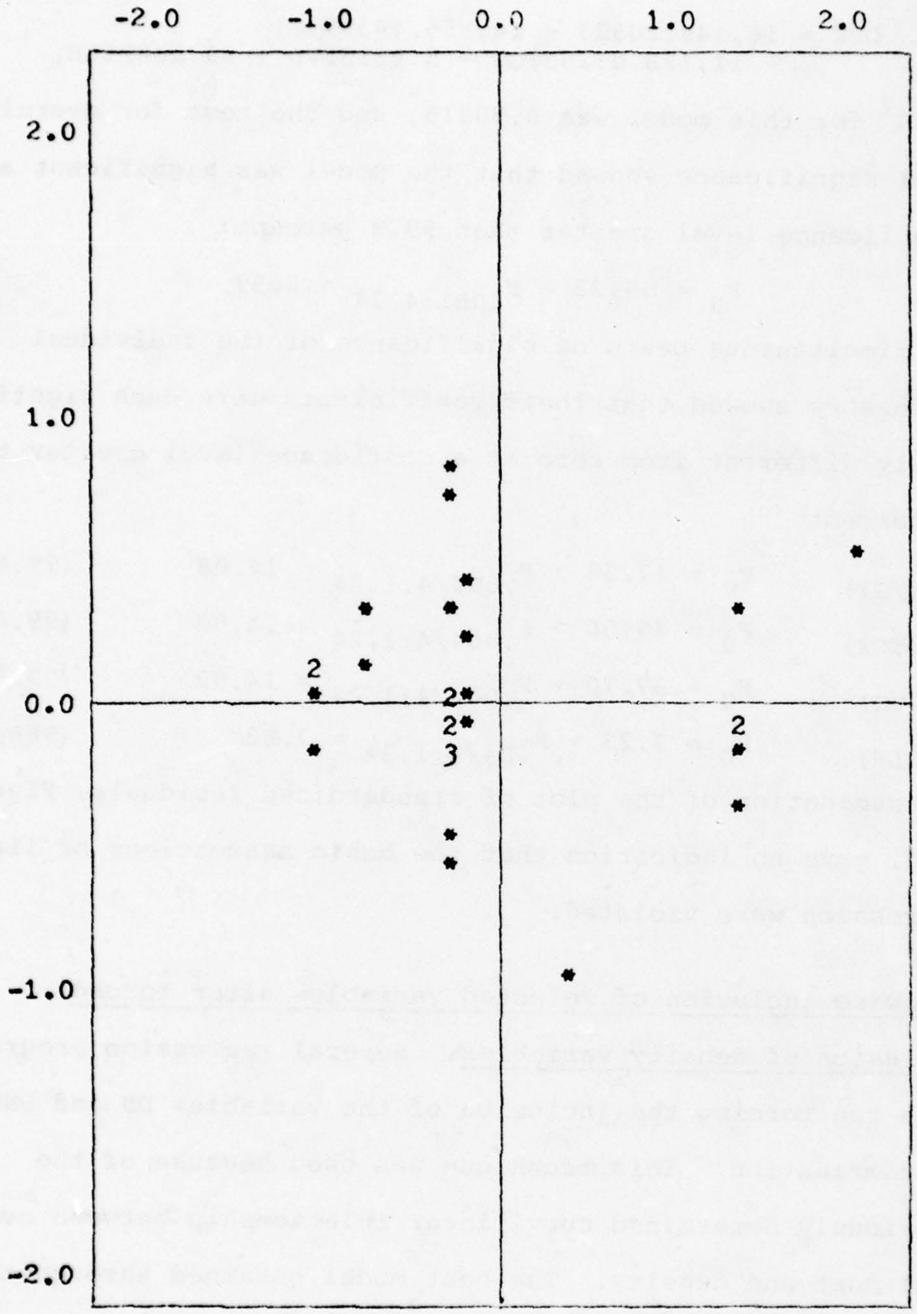


Figure 4.9

Residual Plot for LH/DN/WT/VO/DI

was as follows:

$$OHC = 16{,}148.20523 - 14{,}855.44389TG1 - 11{,}128.03253TG2 - 5.92152VO + 89.20825LH.$$

The $R^2$ for this model was 0.90215, and the test for overall model significance showed that the model was significant at a confidence level greater than 99.9 percent:

$$F_0 = 55.32 > F_{.001;4,24} = 6.59.$$

The simultaneous tests of significance of the individual regressors showed that their coefficients were each significantly different from zero at a confidence level greater than 96 percent:

| | | |
|---|---|---|
| $b_{(TG1)}$ | $F_0 = 47.36 > F_{.004/4;1,24} = 14.03$ | (99.6%) |
| $b_{(TG2)}$ | $F_0 = 49.50 > F_{.004/4;1,24} = 14.03$ | (99.6%) |
| $b_{(VO)}$ | $F_0 = 37.70 > F_{.004/4;1,24} = 14.03$ | (99.6%) |
| $b_{(LH)}$ | $F_0 = 9.23 > F_{.04/4;1,24} = 7.82$ | (96%) |

An examination of the plot of standardized residuals, Figure 4.10, gave no indication that the basic assumptions of linear regression were violated.

*Stepwise inclusion of selected variables after forced inclusion of density variables.* Several regression programs were run forcing the inclusion of the variables DN and DNS in combination. This technique was used because of the previously determined curvilinear relationship between overhaul cost and density. The best model obtained through this technique resulted when the variables DN and DNS were included on the initial step, followed by the stepwise inclusion of

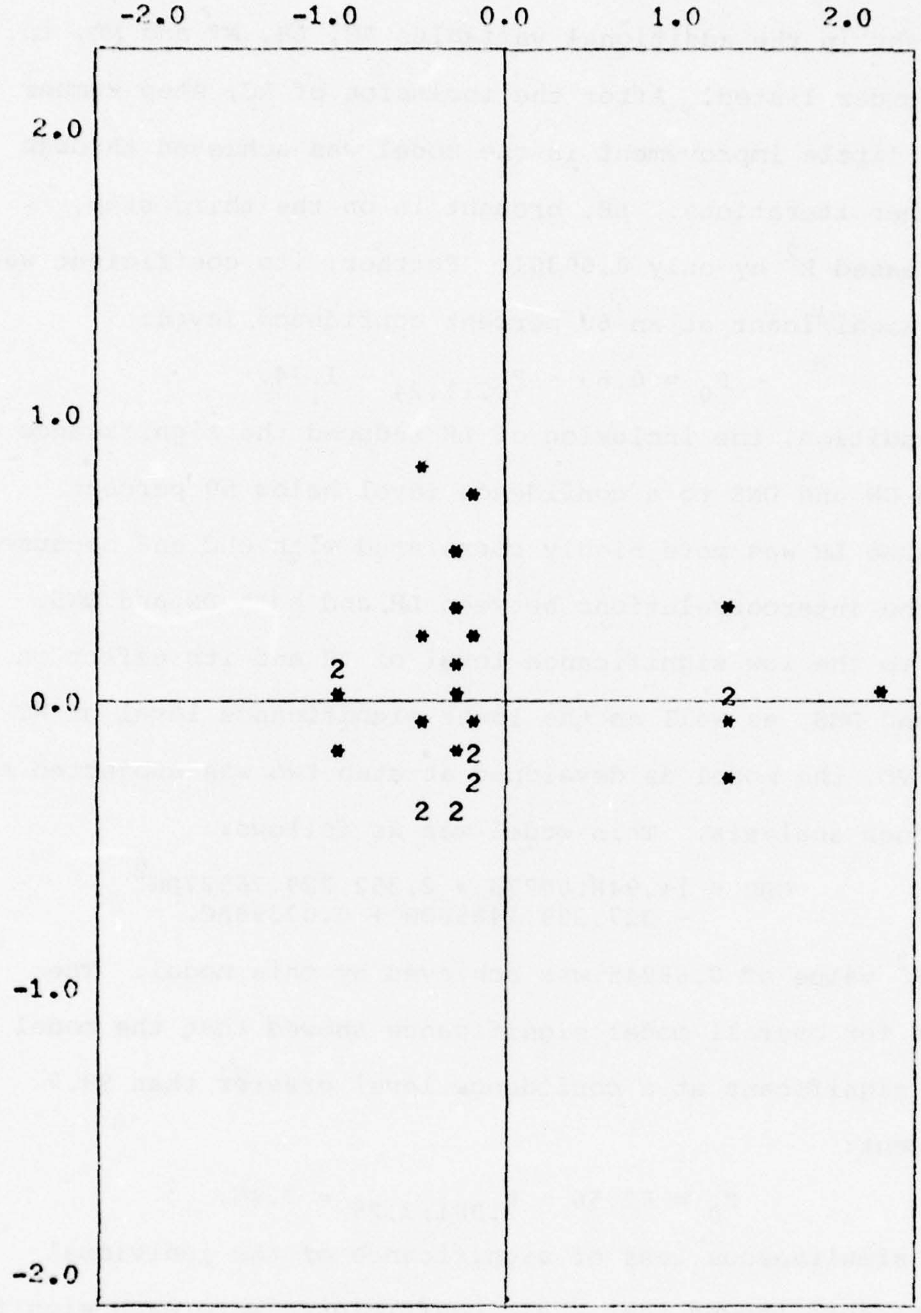


Figure 4.10

Residual Plot for TG/VO/LH

all the remaining variables. The stepwise regression brought in the additional variables AC, LH, WT and VO, in the order listed. After the inclusion of AC, step number two, little improvement in the model was achieved through further iterations. LH, brought in on the third step, increased $R^2$ by only 0.00301. Further, its coefficient was not significant at an 80 percent confidence level:

$$F_0 = 0.63 < F_{.2;1,24} = 1.74.$$

In addition, the inclusion of LH reduced the significance of both DN and DNS to a confidence level below 50 percent because LH was more highly correlated with OHC and because of the intercorrelations between LH and both DN and DNS. Due to the low significance level of LH and its effect on DN and DNS, as well as the lower significance level of WT and VO, the model as developed at step two was subjected to further analysis. This model was as follows:

$$OHC = 11{,}948.00773 + 2{,}352{,}229.76527DN^2 - 327{,}399.14858DN + 0.03390AC.$$

An $R^2$ value of 0.88245 was achieved by this model. The test for overall model significance showed that the model was significant at a confidence level greater than 99.9 percent:

$$F_0 = 62.56 > F_{.001;3,25} = 7.45.$$

The simultaneous test of significance of the individual regressors showed that their coefficients were each significantly different from zero at a confidence level greater than 99.7 percent:

$$b_{(DNS)} \qquad F_0 = 37.79 > F_{.003/3;1,25} = 13.88$$

$$b_{(DN)} \qquad F_0 = 40.23 > F_{.003/3;1,25} = 13.88$$

$$b_{(AC)} \qquad F_0 = 42.05 > F_{.003/3;1,25} = 13.88.$$

An examination of the plot of standardized residuals, Figure 4.11, gave no indication that the basic assumptions of linear regression were violated.

In this and other programs which forced the inclusion of DN and DNS in combination, the inclusion of variables other than AC resulted in a substantial reduction in the significance of DN and/or DNS within the model. This reduction was due to the high intercorrelation between density and the other physical characteristics which were examined.

Summary. Five different models were developed from the multiple linear regression analyses performed. These models, along with their corresponding $R^2$ and F values are listed in Table 4.4. These models were subjected to further evaluation to determine the best model(s) for forecasting GCS depot overhaul cost.

## Subjective Evaluation

The four primary requirements of life cycle cost models listed in Chapter 2 are completeness, sensitivity, validity and availability of input data. The last three are also applicable to the cost estimating relationship model developed herein. The first requirement, completeness, pertains only to cost accounting models, such as LCC models,

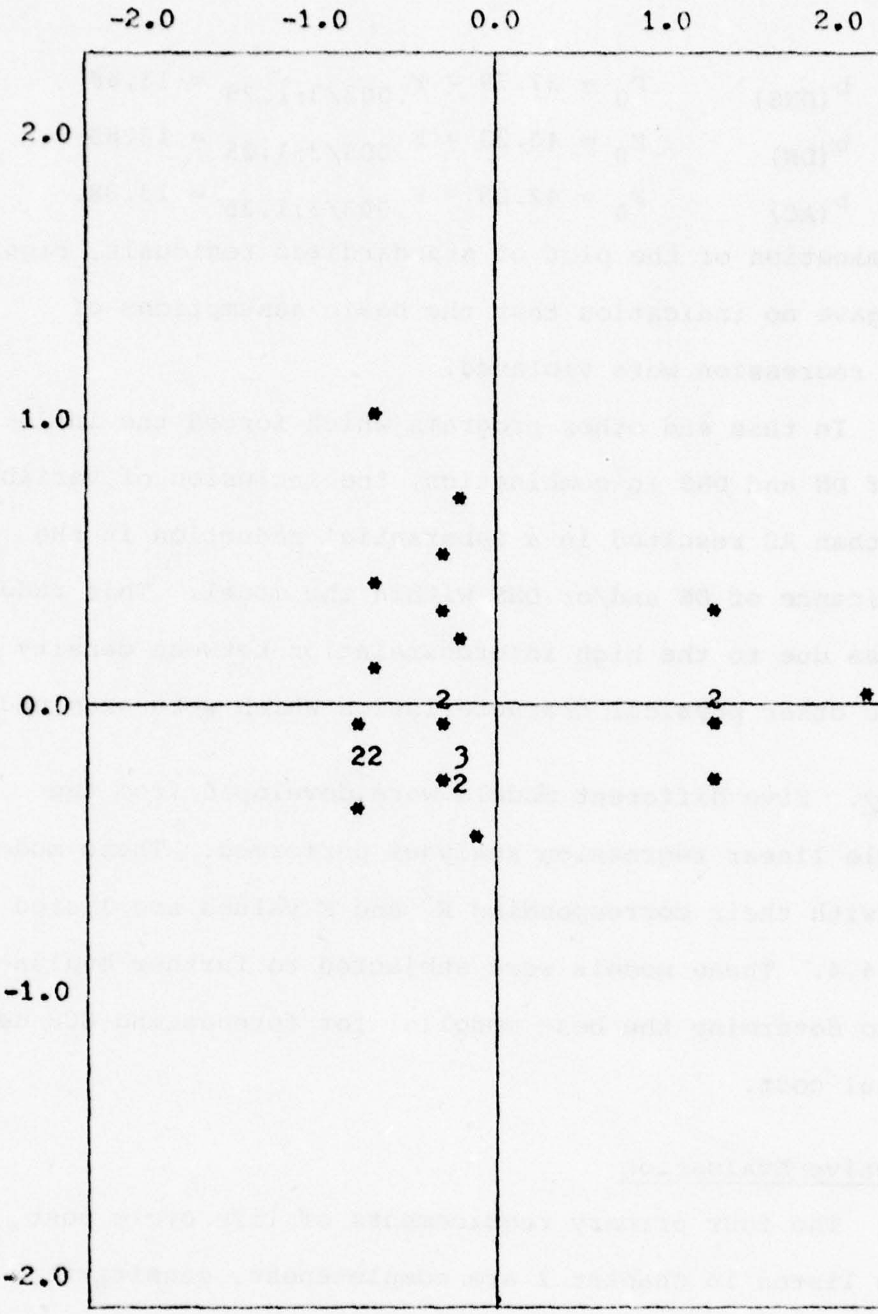


Figure 4.11

Residual Plot for DNS/DN/AC

Table 4.4

MLR Models

| Model | $R^2$ | F |
|---|---|---|
| $OHC = 2,278.07 + 0.03AC - 1,220.49TG1 - 1,374.84TG2$ | 0.84565 | 45.66 |
| $OHC = -794.76 + 134.91LH + 0.04AC - 54.64WT$ | 0.90121 | 76.02 |
| $OHC = 34,393.22 + 516.81LH - 409,511.22DN + 477.69WT - 28.53VO - 3,646.94DI$ | 0.86068 | 28.42 |
| $OHC = 16,148.21 - 14,855.44TG1 - 11,128.03TG2 - 5.92VO + 89.21LH$ | 0.90215 | 55.32 |
| $OHC = 11,948.01 + 2,352,229.77DN^2 - 327,399.15DN + 0.03AC$ | 0.88245 | 62.66 |

which must consider all relevant cost elements. A cost estimating relationship model addresses only a single cost element, which in this case is GCS depot overhaul cost.

Sensitivity. A model must be sensitive to changes in design variables so that differences in the overhaul costs of alternative GCS configurations will be apparent. The physical variables in the models listed in Table 4.2, length, weight, volume, diameter, density and type of guidance employed, are all design variables which could logically impact on GCS depot overhaul cost. The remaining variable contained in the models, acquisition cost, can be considered a design constraint, as in "design to cost." As opposed to that of the design variables, the relationship of acquisition cost to overhaul cost is indirect. When set at a specified level, acquisition cost acts as a constraint upon the design variables, both physical and performance, which in turn affect overhaul cost.

Design variables concerning performance characteristics were not used in the development of the models. Therefore, the sensitivity of these models to changes in performance characteristics cannot be determined. Some possibly important performance variables include maximum lock-on range, guidance miss-distance, maximum "g" capability (maneuverability) and off-boresight capability. As previously discussed, performance variables were excluded from this research due to their classified nature.

Validity. A model must be validated to be of practical use in decision making. The models were validated statistically but not empirically because all the available data were required to develop the models. Although there were 29 total data points, they represented only eight different GCS configurations, as shown in Table C.1, page 70.

Availability of input data. A model can be useful only if accurate input data is available. This requirement is particularly important for the model developed herein because it is intended for use during missile system development. Accurate data for the independent variables included in the models listed in Table 4.4 can be readily obtained during system development except for acquisition cost. Acquisition cost is difficult to project accurately because it varies considerably with learning curve, production quantity, delivery schedule and the marketplace.

## Chapter 5

## SUMMARY AND CONCLUSIONS

### Summary

The development of new air launched tactical guided missiles is a continuing process within the U.S. Air Force. Recently, increased emphasis has been placed on designing systems for supportability due to the significant impact of support costs on the total life cycle cost of the system. One of the most important contributors to tactical missile support costs is the cost of depot overhaul of guidance and control subsystems. Despite its importance, depot overhaul costs are not currently forecast by the operations and support cost model used by WR-ALC, the system manager for tactical missiles. Instead, the model requires an externally derived estimate of this cost as input data. However, accurate estimating techniques have not been developed to forecast the cost of tactical missile guidance and control subsystems depot overhaul during system development.

In order to solve this problem, two objectives were established. The first objective was to identify the most important variables for determining the cost of tactical missile GCS depot overhaul. The second objective was to use the variables to develop a cost estimating relationship model which could be used during tactical missile system development for forecasting GCS depot overhaul cost. Both of these objectives were met by using the technique of multiple linear regression with cost and design data obtained from the AFLC HO36B report and WR-ALC. Data consisted of overhaul cost, acquisition cost, number of subassemblies, weight, length, diameter, volume and type of guidance employed with respect to the GCS for the AGM-45, AIM-7 and AIM-9 series missiles. Performance data were omitted because of their classified nature.

## Conclusions

The analysis of the above data provided the information needed to answer the two basic research questions:

1. What variables are important in determining the cost of tactical missile GCS depot overhaul?

2. What cost estimating relationships would be useful in forecasting GCS depot overhaul cost during tactical missile system development?

Research question #1. Based on the analysis of correlation coefficients and regression models associated with individual variables, the independent variables listed in Table 5.1 were identified as the most important of all the variables considered for determining the cost of tactical missile GCS depot overhaul. The variable density exhibited a curvilinear relationship with OHC, requiring the addition of a density squared factor. These variables were the basis for developing the cost estimating relationship models required to answer the second research question.

Table 5.1

Important Variables

| Variable | Correlation Coefficient | $R^2$ |
|---|---|---|
| Type of Guidance (TG1/TG2) | 0.86124 | 0.74174 |
| Length (LH) | 0.83035 | 0.68948 |
| Density (DN/DNS) | 0.82748 | 0.68472 |
| Acquisition Cost (AC) | 0.82686 | 0.68371 |
| Weight (WT) | 0.82301 | 0.67735 |
| Volume (VO) | 0.81788 | 0.66894 |

Research question #2. The five models developed from the multiple linear regression analyses are listed in Table 5.2. The models were evaluated in terms of their relative efficiency ($R^2$), overall significance (F), individual regressor significance and standardized residual plots. Each model had a relative efficiency in excess of 0.8 and was significant at a confidence level greater than 99.9 percent. The actual values for $R^2$ and F are also contained in Table 5.2. The individual regression coefficients ($b_i$) within each model were significant at a confidence level greater than 96 percent. Finally, the examination of each model's standardized residual plot, Figures 4.7-4.11, pages 34, 37, 39,

Table 5.2

MLR Models

| Model | $R^2$ | F |
|---|---|---|
| OHC = 2,278.07 + 0.03AC - 1,220.49TG1 - 1,374.84TG2 | 0.84565 | 45.66 |
| OHC = -794.76 + 134.91LH + 0.04AC - 54.64WT | 0.90121 | 76.02 |
| OHC = 34,393.22 + 516.81LH - 409,511.22DN + 477.69WT - 28.53VO - 3,646.94DI | 0.86068 | 28.42 |
| OHC = 16,148.21 - 14,855.44TG1 - 11,128.03TG2 - 5.92VO + 89.21LH | 0.90215 | 55.32 |
| OHC = 11,948.01 + 2,352,229.77$DN^2$ - 327,399.15DN + 0.03AC | 0.88245 | 62.66 |

41 and 44, gave no indication that the basic assumptions of linear regression were violated.

In addition to these statistical evaluations, subjective analyses were performed on each model with respect to sensitivity, validity and availability of input data. The models were found to be sensitive to physical design variables, but no determination could be made regarding their sensitivity to performance design variables such as lock-on range and guidance miss-distance.

Although the models were validated statistically, no empirical validation was performed due to the limited number of data observations. With regard to the availability of input data, it was found that data for all independent variables except acquisition cost could be accurately estimated during missile system development. Accordingly, acquisition cost was not considered to be a desirable predictor variable.

Based on the considerations given above, the following model was determined to be the most useful in forecasting GCS depot overhaul cost during tactical missile system development:

$$OHC = 16{,}148.21 - 14{,}855.44TG1 - 11{,}128.03TG2 - 5.92VO + 89.21LH.$$

Three of the other models were eliminated because they each contained acquisition cost as an independent variable. The other model was eliminated because its $R^2$ and F values were lower than those of the selected model, and an additional design variable, weight, would have to be estimated. The model selected requires estimates for only volume and length. The values for TG1 and TG2 do not require estimation since type of guidance is known from the onset of tactical missile system development.

Using the model. The selected model is intended to provide an estimate of GCS depot overhaul cost to be used as input data for the WR-ALC O&S cost model for tactical missiles. The following procedures apply when using the model:

1. Encode information pertaining to the type of guidance employed.

   a. If infrared, TG1 = 1 and TG2 = 0.

   b. If anti-radiation, TG1 = 0 and TG2 = 1.

   c. If semi-active radar, TG1 = 0 and TG2 = 0.

2. Determine the length (LH) and volume (VO) in inches of the GCS from design drawings or specifications. These values should be based on external dimensions. The GCS includes all components performing the guidance and control functions, whether or not separated by any other major missile component, such as the warhead, but does not include that component nor wings and fins/canards.

3. Enter values for TG1, TG2, LH and VO and compute GCS overhaul cost (OHC).

4. Convert computed OHC value to desired fiscal year dollars with an appropriate index of projected inflation.

The 49.4/50.6 percent breakout between labor and material (as developed in Appendix A) can be used to establish a combined index for this purpose.

These procedures can be demonstrated using as an example the AIM-7F GCS, which was included in the sample selected for this research. The AIM-7F GCS employs semi-active radar guidance; therefore, TG1 = 0 and TG2 = 0. Based on Table C.7, page 76, LH = 67.5 and VO = 2926. Substituting these values into the model as follows:

$$OHC = 16{,}148.21 - 14{,}855.44(0) - 11{,}128.03(0) - 5.92(2926) + 89.21(67.5);$$

the computed value for OHC is $4848 (in FY77 dollars).

This model enables its user to forecast GCS depot overhaul cost with a few easily estimated physical parameters and relatively simple computations. This procedure, however, provides information which, when input into the WR-ALC cost model, may account for as much as 80 percent of the total annual O&S cost associated with a tactical missile.

<u>Recommendations</u>. As previously mentioned, no empirical validation was performed on this model. It is therefore recommended that a validation study be conducted using missile systems currently in development or initial

production. Possible candidates for validation include the AIM-7F and AIM-9L.

Although performance characteristics were excluded from this research because of their classified nature, they may be important in forecasting GCS depot overhaul cost. Therefore, a classified study should be conducted to determine which performance variables are important and to expand the model accordingly. The expansion of the model would entail additional regression analyses using the variables identified by this research (Table 5.1, page 50) along with the desired performance variables. Some possible performance variables to consider are lock-on range, guidance miss-distance, maximum "g" capability (maneuverability) and off-boresight capability.

APPENDICES

APPENDIX A

INDEX DEVELOPMENT

In order to perform the regression analyses it was necessary to adjust all cost data, both acquisition and overhaul costs, to a common base, which for this research was FY 1977. This adjustment was based on the DOD indices contained in the OASD (Comptroller) National Defense Budget Estimates for FY 1977, from which Table A.1 was extracted. It was assumed that these indices were representative of the inflation experienced for missile acquisition and depot overhaul costs. The Industry Purchases Index shown in this table was used to adjust acquisition cost data.

Depot overhaul costs included both labor and material costs; consequently, a combined index was required. To develop this index the overhaul cost data were analyzed to determine the percentage breakout of civilian labor and material costs. The only data for which this breakout was available were the costs for overhaul conducted in-house on AIM-9 missiles. It was assumed that this breakout was representative of all missiles within the sample. The total civilian labor costs and direct material costs for FY 1974-FY 1977 for AIM-9 GCS in-house depot overhaul were $3,695,450 and $3,783,812, respectively. These costs represent a breakout of 49.4 percent for labor and 50.6 percent for materials.

Table A.1

DOD Indices
(Base Year: FY 1977 = 100)

| FY | Industry Purchases | Composite Civil Service Pay |
|---|---|---|
| 1965 | 49.6 | 47.4 |
| 1966 | 50.3 | 48.7 |
| 1967 | 51.5 | 50.4 |
| 1968 | 53.3 | 52.3 |
| 1969 | 54.8 | 55.5 |
| 1970 | 57.6 | 61.7 |
| 1971 | 61.1 | 66.1 |
| 1972 | 63.3 | 70.8 |
| 1973 | 66.0 | 74.7 |
| 1974 | 73.5 | 80.0 |
| 1975 | 86.2 | 86.6 |
| 1976 | 92.4 | 93.1 |
| 197T | 96.9 | 96.3 |
| 1977 | 100.0 | 100.0 |

Source: National Defense Budget Estimates for FY 1977, OASD (Comptroller)

A combined index for each fiscal year was calculated by multiplying the appropriate index number from Table A.1 by its appropriate breakout percentage and summing these weighted partial indices. The resultant combined indices are contained in Table A.2 below.

Table A.2

Overhaul Cost Indices
(Base Year: FY 1977 = 100)

| FY | Index |
|---|---|
| 1974 | 76.7 |
| 1975 | 86.4 |
| 1976 | 92.7 |
| 197T | 96.6 |
| 1977 | 100.0 |

APPENDIX B

MULTIPLE LINEAR REGRESSION (MLR)

Basic MLR

The basic multiple linear regression model is given by:

$Y_i = B_0 + B_1X_{i,1} + B_2X_{i,2} + . . . + B_kX_{i,k} + e_i \quad i = 1,2,. . .,n$

where:

$Y_i$ = Value of the dependent variable in the ith observation.

$B_0, B_1, B_2, . . ., B_k$ = Population regression parameters.

$X_{i,j}$ = Value in the ith observation of the jth independent variable, j = 1,2,. . .,k.

$e_i$ = Random error term in the ith observation.

n = Number of sample observations (18:544).

The assumptions associated with the multiple linear regression model are:

1. The random error terms $e_i$ are uncorrelated.
2. The expected value of $e_i$ for the ith observation is zero.
3. The variance of $e_i$ is constant for all observations.
4. The distribution of $e_i$ is normal.
5. The number of sample observations is greater than the number of population regression parameters (k + 1).
6. The independent variables are linearly independent.

7. Observational errors are associated with the dependent variable only (10:12,89).

The estimator of the population regression model is:

$$\hat{y} = b_0 + b_1x_1 + b_2x_2 + \ldots + b_kx_k$$

which in the least squares method[5] is derived from the system of normal equations, which are defined by:

$$\frac{\partial(\Sigma e_i^2)}{\partial b_j} = 0 \qquad j = 0,1,\ldots,k \qquad (10:54,55).$$

Model Development and Evaluation

The SPSS REGRESSION subprogram, which was used to develop the model, offers the option of forward (stepwise) inclusion. This option provides for the isolation of a subset of the independent variables which yields an optimal MLR equation containing the fewest possible terms. The order in which independent variables are included in the equation is determined by their respective contribution to the explanatory power of the model based on specified minimum inclusion criteria. The preset minimum criteria (default values) provided within the forward inclusion option were used in order to obtain statistical information on a sufficient

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[5]The least-squares method selects the regression model which minimizes the sum of the squared deviations of the actual values from the predicted values of the variable of interest (minimizes $\Sigma e_i^2$). This method provides the best linear unbiased estimate of the population regression parameters (18:401-403).

number of possibly significant variables (15:345-346). The output of the SPSS REGRESSION subprogram includes not only the MLR model itself but also the statistical information required to evaluate it.

Coefficient of determination. The coefficient of determination ($R^2$) is a measure of the relative efficiency of the MLR model. The SPSS forward inclusion option utilizes this measure in determining the order in which independent variables are entered. It is defined by the following ratio:

$$R^2 = \frac{\text{explained variation (EV)}}{\text{total variation (TV)}}$$

where:

$$TV = \Sigma y_i^2 - \frac{(\Sigma y_i)^2}{n}$$

$$EV = TV - \Sigma e_i^2$$

An $R^2$ of 0.8 or greater signifies that a "strong" linear relationship exists between the dependent and independent variables (10:19,62-63).

Significance of overall regression. The significance of the relative efficiency ($R^2$) of the MLR model can be determined utilizing the following hypothesis test:

$$H_0\text{:}\quad B_1 = B_2 = . . . = B_k = 0$$

$$H_1\text{:}\quad \text{at least one } B_j \neq 0 \quad j = 1,2,. . .,k$$

The appropriate test statistic is given by the following:

$$F_0 = \frac{R^2/k}{(1 - R^2)/(n - k - 1)}$$

where: k = number of independent variables.

The test is conducted as a one-tailed test to the right: reject $H_0$ if $F_0 > F_{\alpha;k,n-k-1}$ where $\alpha$ is the level of significance, $1 - \alpha$ is the confidence level (10:65), k is the numerator degrees of freedom and n - k - 1 is the denominator degrees of freedom.

Significance of individual regressors. In addition to overall regression significance each independent variable can be evaluated for the significance of its contribution to the model. The appropriate hypothesis test is as follows:

$$H_0: \; B_j = 0$$

$$H_1: \; B_j \neq 0$$

with test statistic:

$$F_0 = \frac{b_j^2}{s_{b_j}^2}$$

where $s_{b_j}$ is the estimator of the deviation of the regression coefficient $B_j$ from the regression of Y on all X. The test may be conducted with variables in isolation or simultaneously. The simultaneous test is conducted as a one-tailed test to the right: reject $H_0$ if $F_0 > F_{\text{equivalent } \alpha;1,n-k-1}$ where equivalent $\alpha = \alpha \div$ number of variables being tested simultaneously. In isolation, the test is conducted as a one-tailed test to the right: reject $H_0$ if $F_0 > F_{\alpha;1,n-k-1}$ (10:72-75).

Plot of standardized residuals. The plot of standardized residuals is a scatterplot of the deviations of the observed values from the predicted values of the dependent variable. An examination of the overall pattern of the scatter gives an indication of the extent to which the basic assumptions of linear regression are met. Figure B.1 depicts four basic scatterplot patterns. Patterns b, c and d indicate the possibility that one or more assumptions have been violated. In pattern b, the variance of the error terms is not constant for all observations. In patterns c and d, the error terms are not uncorrelated and the expected values of the error terms are not zero for all observations. Additionally, in pattern d, the possibility of a curvilinear relationship exists. Pattern a, on the other hand, indicates that the basic assumptions of linear regression have not been violated (15:341-342).

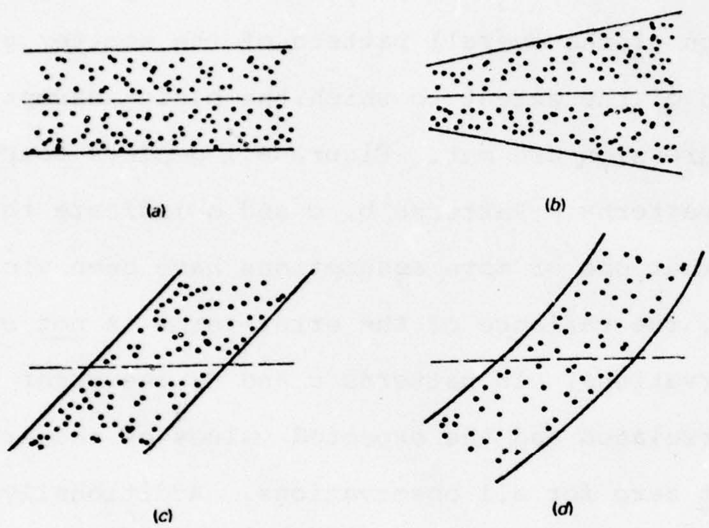


**Figure B.1**

**Basic Scatterplot Patterns**

**Source:** (15:342)

# APPENDIX C

## OBSERVED/CONVERTED DATA

Depot Overhaul Cost

Depot overhaul costs were obtained from both the WR-ALC missile production manager and the HO36B report. WR-ALC furnished unit overhaul costs (OHC) for the AIM-7E and AGM-45 GCS for each of the fiscal years 1974-1977, as contained in Table C.1.

To provide a single data point for the AIM-7E for each fiscal year, a weighted average[6] was determined based on the two depots. Table C.2 contains these weighted averages and their adjusted values based on the Overhaul Cost Indices of Table A.2, page 60.

To provide a single point for the AGM-45 for each fiscal year, a GCS depot overhaul unit cost was obtained by summing the unit costs for each of the components. The GCS depot overhaul unit costs and their adjusted values are set forth in Table C.3.

The AIM-9 OHC data were obtained from the HO36B report. A single data point for each fiscal year for each of the AIM-9B, E and J series GCS was determined by calculating a weighted average OHC based on the total quantity

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[6]The data sources did not provide the cost information on an individual unit basis. Rather, cost data were recorded for various lots of various quantities for a given time period. Since SPSS regression treats each data point equally, it was necessary to develop a representative cost figure for each particular time period for each particular missile. A weighted average approach was used for this purpose.

Table C.1

WR-ALC OHC Data

| AIM-7E | | | | |
|---|---|---|---|---|
| Depot | FY74 | FY75 | FY76 | FY77[a] |
| Alameda | 2,332 | 2,768 | 2,900 | 3,420 |
| Norfolk | 2,209 | 2,548 | 2,798 | 3,350 |

| AGM-45 (All Alameda Depot) | | | | |
|---|---|---|---|---|
| Component | FY74 | FY75 | FY76 | FY77[a] |
| Guidance | 940 | 1,141 | 953 | 1,085 |
| Control | 397 | 505 | 417 | 350 |

[a]FY77 includes FY7T.

Table C.2

AIM-7E OHC Input Data

| FY | Weighted Average OHC | Adjusted OHC (FY 1977) |
|---|---|---|
| 74 | 2,258 | 2,944 |
| 75 | 2,636 | 3,051 |
| 76 | 2,838 | 3,061 |
| 77 | 3,378 | 3,378 |

Table C.3

AGM-45 OHC Input Data

| FY | OHC | Adjusted OHC (FY 1977) |
|---|---|---|
| 74 | 1,337 | 1,743 |
| 75 | 1,646 | 1,905 |
| 76 | 1,370 | 1,477 |
| 77 | 1,435 | 1,435 |

and cost of overhaul for each fiscal year. Table C.4 contains these weighted average costs and their adjusted values. The AIM-9J GCS were repaired both in-house and under commercial contract. The first listed data points for FY 76 and FY 7T are associated with commercial contract unit prices.

Table C.4

AIM-9 OHC Input Data

| Series | FY | Weighted Average OHC | Adjusted OHC (FY 1977) |
|---|---|---|---|
| B | 74 | 530 | 691 |
| | 76 | 664 | 716 |
| | 7T | 624 | 646 |
| | 77 | 434 | 434 |
| E | 74 | 649 | 846 |
| | 75 | 703 | 814 |
| | 76 | 1,298 | 1,400 |
| | 7T | 1,097 | 1,135 |
| | 77 | 2,043 | 2,043 |
| J | 74 | 934 | 1,217 |
| | 75 | 1,046 | 1,210 |
| | 76 | 2,044 | 2,204 |
| | 76 | 1,581 | 1,704 |
| | 7T | 1,267 | 1,312 |
| | 7T | 1,299 | 1,345 |
| | 77 | 1,283 | 1,283 |

Beginning with FY 7T, the HO36B report contained interservicing depot overhaul costs. These costs were obtained for the AIM-7E, AIM-7F and AGM-45 and are set forth in Table C.5 along with their adjusted values.

Table C.5

Additional OHC Input Data

| Missile | FY | OHC | Adjusted OHC (FY 1977) |
|---|---|---|---|
| AIM-7E | 77 | 2,768 | 2,768 |
| AIM-7F[a] | 77 | 4,836 | 4,836 |
| AGM-45[b] | 77 | 1,047 | 1,047 |
| | 7T | 1,180 | 1,221 |
| | 77 | 1,011 | 1,011 |

[a]Only one unit was repaired in FY 7T at an adjusted OHC of $7,702. In order to avoid an overemphasis upon this single unit, it was averaged with the units repaired in FY 77.

[b]The first AGM-45 data point was determined by summing the weighted averages of the MK36/MK49 guidance units and the weighted average of the MK5-1/2 control units. The second and third AGM-45 data points were determined by summing the weighted averages of the MK24/MK25 guidance units and the weighted average of the MK1/MK5 control units. This distinction was required because the MK1 control unit cannot be used with the MK36/MK49 guidance units.

Acquisition Cost

Acquisition costs (AC) were the latest purchase price for each GCS in the sample, adjusted to constant FY 1977 dollars in accordance with the Industry Purchases Index in Table A.1, page 59. These cost data are set forth in Table C.6.

Table C.6

Acquisition Cost Input Data

| Missile | Acquisition Completed (FY) | AC | Adjusted AC (FY 1977) |
|---|---|---|---|
| AIM-7E | 1971 | 16,984 | 27,797 |
| AIM-7F | Current | 95,000 | 95,000 |
| AIM-9B | 1965 | 1,497 | 3,018 |
| AIM-9E | 1971 | 3,196 | 5,231 |
| AIM-9J | 1975 | 4,696 | 5,448 |
| AGM-45[a] | | | 27,457 |
| | | | 11,701 |
| | | | 19,579 |

[a]For reasons outlined in footnote b to Table C.5, the first two data points were determined based on weighted averages of adjusted acquisition costs of separate components. The third data point is the average of the first two and was required for use with the AGM-45 OHC data obtained from WR-ALC, since these data did not differentiate between the two configurations.

## Physical Characteristics

The physical characteristics and their associated values are set forth in Table C.7. For reasons outlined in footnotes to Tables C.5 and C.6, three different weights for the AGM-45 were obtained, one for each configuration and an average of the two. All other physical characteristics are the same for both configurations.

## Time-Sharing File

All data for depot overhaul cost, acquisition cost and physical characteristics were entered on a time-sharing file which is reproduced as Figure C.1. The data matrix consists of 29 lines (data points) and ten columns. The columns from left to right represent line number, depot overhaul cost, acquisition cost, number of subassemblies, weight, length, diameter, volume, categorical variable one and categorical variable two.

Table C.7

Physical Characteristics Input Data

| Missile | Number of Subassemblies | Weight (Pounds) | Length (Inches) | Diameter (Inches) | Volume (Inches$^3$) |
|---|---|---|---|---|---|
| AIM-7E | 2 | 151.0 | 80.4 | 8 | 3,425 |
| AIM-7F | 2 | 141.2 | 67.5 | 8 | 2,926 |
| AIM-9B | 5 | 37.1 | 24.0 | 5 | 472 |
| AIM-9E | 5 | 33.7 | 27.0 | 5 | 420 |
| AIM-9J | 5 | 36.8 | 30.0 | 5 | 420 |
| AGM-45 (MK36/49) | 3 | 77.2 | 40.0 | 8 | 1,213 |
| AGM-45 (MK24/25) | 3 | 68.8 | 40.0 | 8 | 1,213 |
| AGM-45 (Combined) | 3 | 73.0 | 40.0 | 8 | 1,213 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 100 | 434 | 3018 | 5 | 37.1 | 24.0 | 5 | 472 | 1 | 0 |
| 105 | 646 | 3018 | 5 | 37.1 | 24.0 | 5 | 472 | 1 | 0 |
| 110 | 691 | 3018 | 5 | 37.1 | 24.0 | 5 | 472 | 1 | 0 |
| 115 | 716 | 3018 | 5 | 37.1 | 24.0 | 5 | 472 | 1 | 0 |
| 120 | 814 | 5231 | 5 | 33.7 | 27.0 | 5 | 420 | 1 | 0 |
| 125 | 846 | 5231 | 5 | 33.7 | 27.0 | 5 | 420 | 1 | 0 |
| 130 | 1011 | 11701 | 3 | 68.8 | 40.0 | 8 | 1213 | 0 | 1 |
| 135 | 1047 | 27457 | 3 | 77.2 | 60.0 | 8 | 1213 | 0 | 1 |
| 140 | 1135 | 5231 | 5 | 33.7 | 27.0 | 5 | 420 | 1 | 0 |
| 145 | 1210 | 5448 | 5 | 36.8 | 30.0 | 5 | 420 | 1 | 0 |
| 150 | 1217 | 5448 | 5 | 36.8 | 30.0 | 5 | 420 | 1 | 0 |
| 155 | 1221 | 11701 | 3 | 68.8 | 40.0 | 8 | 1213 | 0 | 1 |
| 160 | 1283 | 5448 | 5 | 36.8 | 30.0 | 5 | 420 | 1 | 0 |
| 165 | 1312 | 5448 | 5 | 36.8 | 30.0 | 5 | 420 | 1 | 0 |
| 170 | 1345 | 5448 | 5 | 36.8 | 30.0 | 5 | 420 | 1 | 0 |
| 175 | 1400 | 5231 | 5 | 33.7 | 27.0 | 5 | 420 | 1 | 0 |
| 180 | 1435 | 19579 | 3 | 73.0 | 40.0 | 8 | 1213 | 0 | 1 |
| 190 | 1477 | 19579 | 3 | 73.0 | 40.0 | 8 | 1213 | 0 | 1 |
| 200 | 1704 | 5448 | 5 | 36.8 | 30.0 | 5 | 420 | 1 | 0 |
| 205 | 1743 | 19579 | 3 | 73.0 | 40.0 | 8 | 1213 | 0 | 1 |
| 210 | 1905 | 19579 | 3 | 73.0 | 40.0 | 8 | 1213 | 0 | 1 |
| 215 | 2043 | 5231 | 5 | 33.7 | 27.0 | 5 | 420 | 1 | 0 |
| 220 | 2204 | 5448 | 5 | 36.8 | 30.0 | 5 | 420 | 1 | 0 |
| 225 | 2768 | 27797 | 2 | 151.0 | 80.4 | 8 | 3425 | 0 | 0 |
| 230 | 2944 | 27797 | 2 | 151.0 | 80.4 | 8 | 3425 | 0 | 0 |
| 235 | 3051 | 27797 | 2 | 151.0 | 80.4 | 8 | 3425 | 0 | 0 |
| 240 | 3061 | 27797 | 2 | 151.0 | 80.4 | 8 | 3425 | 0 | 0 |
| 245 | 3378 | 27797 | 2 | 151.0 | 80.4 | 8 | 3425 | 0 | 0 |
| 250 | 4836 | 95000 | 2 | 141.2 | 67.5 | 8 | 2926 | 0 | 0 |

Figure C.1

Time-Sharing File

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