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**ESTIMATING REQUIRED CONTINGENCY FUNDS FOR  
CONSTRUCTION PROJECTS USING MULTIPLE LINEAR REGRESSION**

THESIS

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AFIT/GEM/ENV/06M-02

**DEPARTMENT OF THE AIR FORCE  
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***AIR FORCE INSTITUTE OF TECHNOLOGY***

**Wright-Patterson Air Force Base, Ohio**

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PROJECTS USING MULTIPLE LINEAR REGRESSION**

THESIS

Presented to the Faculty

Department of Systems and Engineering Management

Graduate School of Engineering and Management

Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the  
Degree of Master of Science in Engineering Management

Jason J. Cook, BS

Captain, USAF

March 2006

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PROJECTS USING MULTIPLE LINEAR REGRESSION**

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### **Abstract**

Cost overruns are a critical problem for construction projects. The common practice for dealing with cost overruns is the assignment of an arbitrary flat percentage of the construction budget as a contingency fund. This research seeks to identify significant factors that may influence, or serve as indicators of, potential cost overruns. The study uses data on 243 construction projects over a full range of project types and scopes gathered from an existing United States Air Force construction database. The author uses multiple linear regression to analyze the data and compares the proposed model to the common practice of assigning contingency funds. The multiple linear regression model provides better predictions of actual cost overruns experienced. Based on the performance metric used, the model sufficiently captures 44% of actual cost overruns versus current practices capturing only 20%

The proposed model developed in this study only uses data that would be available prior to the award of a construction contract. This allows the model to serve as a planning tool throughout the concept and design phases. The model includes project characteristics, design performance metrics, and contract award process influences. This research supports prior findings of a relationship between design funding and design performance as well as the influence of the contract award process on cost overruns. While the proposed model captures 44% of actual cost overruns, its application reduces average contingency budgeting error from -11.2% to only -0.3% over the entire test sample.

## Acknowledgments

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Jason J. Cook

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# ESTIMATING REQUIRED CONTINGENCY FUNDS FOR CONSTRUCTION PROJECTS USING MULTIPLE LINEAR REGRESSION

## I. Introduction

Contingency funds and management reserves are moneys held in reserve to pay for mandatory and optional changes initiated either by the user or construction agent after construction contract award (USAF PM Guide, 2000). These post contract award changes, collectively referred to as cost overruns, represent additional expenses during the construction phase that increase the amount spent on a project beyond planned budgets. The normal method of determining the amount of required contingency funding to cover these cost overruns is to use an arbitrary percentage of the basic construction cost (Chen and Hartman, 2000). To provide a more objective method of estimating the contingency funding required, research efforts have identified various sources of risk and linked them to construction cost overruns (Federle and Pigneri, 1993). Therefore, using these identified sources of risk as predictors, a statistical analysis should be able to produce a predictive model for project cost overruns and the associated need for construction contingency funds.

### General Background

Adhering to a budget and managing costs is arguably the most critical measure of a construction project's success. In most cases, a project manager can decrease the scope of a project or "trade time for money" with a contractor in order to handle cost overruns. However, acquiring additional funding if cost overruns are excessive is not an easy task.

Cost overruns on construction projects create budgeting problems for project managers, use money that may have supported other projects, and have cascading effects on budgets for comprehensive construction programs.

To better understand cost overruns, it is useful to think of them as a by-product of risk – risk in the design package, construction estimate, bid environment, labor and material market during construction, and many other facets of the construction process. While many of these factors are beyond the project manager’s influence, the design process typically implements various controls to reduce risks. Comprehensive reviews by construction experts seek to catch any errors and omissions that might go unnoticed in the final design package. During the design process, there is also a concerted effort to incorporate all known user requirements. User-initiated change requests during construction often represent improperly identified project requirements. However, it is common for requirements initially considered unnecessary during the design phase to be added to the project because of leftover contingency funding. Of all the factors that introduce risk into a project budget, design effectiveness is an area in which there is sufficient information prior to contract award to be able to gage the effectiveness of controls in the design process and predict with statistical significance the potential for cost overruns.

A properly designed project minimizes controllable risks as much as possible. However, there are certain factors (i.e., risk indicators) that may raise the potential for design errors and therefore the risk of cost overruns. Shortening the amount of time available for design reviews might increase the potential for mistakes. Spending less money on a design completed by an architect-engineer firm may be an indication of less

time spent on the design and an increased potential for mistakes. Some project types, such as major utility upgrades, are more problematic and may have a higher potential for mistakes in the design due to unforeseen site conditions. Although not always the case, the complexity of a design normally increases with the scope of the project. Therefore, as the scope of a project increases, its potential for design errors will probably also increase. Awarding a design-build contract places responsibility for both the design and construction of a project with a single contractor; this should help reduce the risks in the project. Assessing these risk indicators prior to the start of construction should enable better prediction of risk levels and the potential for cost overruns.

For each risk indicator, a common practice is to assume a probability distribution of financial outcomes. For example, it might be reasonable to assume that uncertainties from material and labor prices would follow a relatively normal distribution. In some cases, the estimate will be higher than actual costs; and at other times, it will be lower. With adequate market research, these estimates should have little deviation from actual prices in most cases. Project managers may make similar assumptions about any factor suspected to contribute to project cost overruns. These assumptions, coupled with subjective assessments of key distribution parameters, are the primary weakness of risk management methodologies.

Project managers use risk management to identify, assess, and plan for uncertainties in both cost and schedule. Although there are small differences among available risk management methodologies, the majority follow a basic six-step process: management planning, identification, qualitative analysis, quantitative analysis, response planning, monitoring and control (Mantel, 2005). This methodology bases both the

qualitative and quantitative analyses on project personnel's subjective assessments. During the qualitative phase, project personnel assign probabilities and financial impacts using loosely defined categorical tables in order to prioritize risks. The quantitative phase analyzes risks deemed as important using a variety of techniques ranging from basic expected value calculations to simulation. Common to all of these techniques are subjective assessments of the probability distributions for each identified risk; therefore, the entire process relies on the judgment and experience of project personnel.

As stated by Chen and Hartman (2000:1), "no empirical method or tool, quantitative or otherwise, is available for forecasting [cost overruns]." While a great deal of research examines causal factors and indicators of construction project cost overruns, relatively little research attempts to develop a method of predicting these cost overruns. In fact, relevant literature appears to identify only two existing models with the express purpose of predicting construction cost overruns. Chen and Hartmann (2000) apply artificial neural networks to the problem of cost overruns. Federle and Pigneri (1993) apply multiple linear regression to develop a predictive model for a limited set of Iowa Department of Transportation (IDOT) construction projects.

The most common method of dealing with risks from a budget perspective is to allocate contingency funding as an arbitrary percentage of the estimated construction cost or bid amount. For example, projects with little uncertainty may receive 5% and projects with great uncertainty, like major utility upgrades, may receive 10%. Assigning a contingency percentage to the budget for overruns is an overly simplistic approach based solely on experience and intuition. The very act of assigning some preset percentage denotes the arbitrariness of this system (Chen and Hartmann, 2000).

## Specific Background

This research will use Air Force projects and data available in the Automated Civil Engineer System Project Management module (ACES-PM). The Air Force measures cost overruns as the difference between the winning bid amount and the final contract price. This definition excludes uncertainties in the estimate and bid environment, which are typically accounted for in the bid price. It also excludes uncertainty in labor and material prices that are passed on to the contractor at the time of contract award – barring any major price or currency fluctuations the government might consider for reimbursement under standard contract clauses.

The projects used in this study generally received 5% contingency funding regardless of any project characteristics; the actual percentage depends on the Major Command in control of the funding. For example, the Air Education and Training Command (AETC) assigns 2% contingency and 3% management reserve (AETC PM Guide, 2004:6-3). In assigning an arbitrary percentage for contingency allowance, there is no attempt to ascertain the risks unique to a particular project. To increase budgeting effectiveness, it is necessary to find a better way of accounting for the inherent uncertainties in project budgeting and assigning an appropriate level of contingency funding to each project.

As previously stated, some of a project's risk comes from design errors and user change requests. For this research though, there is no differentiation between the two categories. A portion of project cost overrun variance should be attributable to the effectiveness of the design process and the quality of the final design package. However, some research has indicated that the contract award process itself may be a source of



inherent risk and project cost overruns (Harbuck, 2004). Since information is available prior to construction contract award related to this factor, this research will investigate the predictive usefulness of potential variables that attempt to characterize the bid climate.

By using available data to develop and validate a statistically significant model for predicting cost overruns, this research could improve the entire method of assigning contingency funding. Rather than assigning an arbitrary percentage, a model would enable the tailoring of contingency funding to correspond with project-specific risks. High-risk projects could justify increased contingency funding up-front and help prevent tradeoffs that may decrease scope or increase construction duration for lack of funding. Assigning fewer contingency dollars to low risk projects helps prevent “artificial” cost inflation from user-change requests and allows allocation of funds to riskier projects of higher priority. Combining the model with appropriate policy and guidance changes would greatly enhance the ability of any project manager to budget effectively.

### **Research Question**

The overall goal of this research is to improve current practices of determining contingency funds in project budgets. Several studies have attempted to predict cost overruns with limited success. Identifying valid indicators of risk factors and building a predictive model for construction cost overruns will greatly enhance current risk management analysis and lead to increased effectiveness in budgeting practices. The main question addressed in this research is what model, based on information available prior to contract award, will provide a statistically significant prediction of cost overruns for construction projects?

## **Investigative Questions**

Using available data on Air Force Military Construction (MILCON) construction projects, this research will explore several key areas of the overall problem. Addressing each of the following questions with appropriate analysis should provide a logical and thorough investigation of the key requirements in identifying indicators of project risk, thereby providing a validated predictive model for construction cost overruns.

1. What models have been identified by experts in the field that have been successful in predicting expected project cost overruns?
2. What risk indicators and causal factors of construction cost overruns have been identified in previous research that can be assessed prior to award of a construction project?
3. What would a proposed model consist of to be able to predict project cost overruns across a range of construction projects based on information available prior to contract award?
4. What is the predictive accuracy of the proposed model?

## **Proposed Methodology**

Using the factors identified in existing models and through a review of relevant literature, this research will develop a multiple linear regression model to predict cost overruns based upon data available prior to award of a construction contract. After development, standard tests can determine the statistical significance and overall usefulness of the model. Finally, application of the proposed model to project data reserved for testing purposes will allow some measurement of model performance and comparison against current practices.

## **Limitations**

The results of this study rely upon the assumption that data entered in ACES-PM are accurate. Inaccuracies in the data may alter the results of the modeling process, to include regression coefficients and associated significance levels. This research takes every effort to eliminate inaccurate information and limit this potential effect; however, the possibility remains.

The purpose of the study is to develop a model using information available prior to the award of a construction contract. By scoping the problem in this manner, this research purposefully overlooks factors and influences that occur after the start of construction that could have direct impacts on project cost overruns, such as market fluctuations for material or labor prices. Therefore, this study does not account for any cost overruns associated with these factors. Additionally, the reliance on available data limits the possible variables that can be examined. While some qualitative variables such as teamwork and communication may have a significant relationship with project cost overruns, the lack of data for these variables prevents their investigation.

## II. Literature Review

This chapter examines current research and information pertaining to construction cost overruns in two main areas. First, this chapter examines in detail two existing models developed with the express purpose of predicting project cost overruns. The remainder of the chapter focuses on identifying potential independent variables that may prove predictive for construction cost overruns. Both portions of the literature review are critical to the successful development of the predictive model proposed in this study.

### Existing Models

Research into existing models revealed only two prospective models. For the first case, Chen and Hartman (2000) used artificial neural networks to develop a predictive model for both project time and cost performance. They present their research as an alternative to the multiple linear regression techniques normally applied to predictive models. For the second case, Federle and Pigneri (1993) used the multiple linear regression methodology to develop a model to predict cost overruns for the Iowa Department of Transportation. Both models are explained in detail in the rest of this section.

#### *Artificial Neural Network (ANN)*

Chen and Hartman (2000:1) applied an artificial neural network (ANN) methodology, a technique they describe as “an information processing technology that simulates the human brain and nervous system,” in developing their model. Essentially, the ANN technique uses a software simulation to replicate basic learning by using

experience (or “training”) to identify complex non-linear relationships. The researcher supplies the software simulation with training data that it uses to identify relationships between available inputs and the outcome it must predict. After each repetition, the simulation improves its ability to predict the outcome variable. Once the training is complete, the software simulation becomes the proposed model for predicting outcomes for other data sets.

Chen and Hartman (2000:1) selected the ANN methodology because it “has been proven that problems that involve complex nonlinear relationships can be better solved by neural networks than by conventional methods.” In their discussion, the researchers compare the ANN methodology to standard linear statistical techniques. They claim that ANN may be more appropriate than these techniques because it does not rely upon the assumption that underlying relationships are linear. Since ANN is capable of detecting and predicting complex non-linear relationships, they cite its appropriateness by stating “real world systems are often nonlinear” (Chen and Hartman, 2000:1). Additionally, the ANN methodology does not rely upon knowledge of the underlying relationships between the input and output variables. This, the authors claim, makes it a more flexible tool for general modeling, especially where nonlinear relationships are probable or expected.

Although Chen and Hartman (2000) modeled both time and cost performance, the remainder of the discussion in this section is limited to the portions related to predicting cost overruns. The researchers applied the ANN methodology to 80 test cases from a large oil and gas company in Canada. Of the 80 available cases, the study used 48 for training the simulation, 16 for testing, and 16 for actual predictions where the simulation

had no prior encounter with the data. Of the 16 cases used for actual predictions, the ANN model correctly categorized 75% of the projects into cost overrun and underrun categories. To compare the technique to multiple linear regression, the researchers computed an  $R^2$  value of 0.519 for the best performing model developed for cost. This means that the model was able to account for roughly 52% of the variance in the cost overrun data for all 80 cases used in the study. The researchers also ran multiple linear regression against the data, and they concluded that the ANN outperformed multiple linear regression from their results.

While the model demonstrated the potential application of the ANN methodology to the problem of predicting cost overruns, Chen and Hartman's (2000) study had several problems that limit its practical application, usefulness, and generalizability to other construction populations. The authors identified the largest problem with the study when comparing ANN to linear statistical techniques: "linear models have advantages in that they can be understood and analyzed in great detail, and they are easy to explain and implement" (Chen and Hartman, 2000:2). Although a properly trained ANN can detect complex non-linear relationships, the final model is in essence a "black box" in which the researcher may have little or no insight into how the program is making its predictions. Therefore, the underlying mathematics was not discussed. Although 19 input variables were used in the model, the researchers did not enumerate which of these were critical to the output calculations.

Another potential weakness is that the input variables are measured subjectively using surveys of project managers. The authors used this method even though they noted that "owner organizations often deal with uncertainties and risks by relying on "expert"

opinions based on personal subjectivity and intuition” (Chen and Hartman 2000:2). The 19 input variables used in the model represented “risk indicators” identified by the researchers. To gather the necessary data, the researchers created and distributed a structured questionnaire explaining the 19 risk indicators and asking project managers to rate their projects. After citing this as a weakness of current practices, Chen and Hartman (2000) appear to rely upon “expert” opinions as well.

### ***Multiple Linear Regression***

Iowa State University undertook a study of construction project cost overruns for the Iowa Department of Transportation (IDOT) using the multiple linear regression methodology (Federle and Pigneri, 1993). The study intended to demonstrate a statistical relationship between the cost estimate, several cost factors, and the project’s final cost overrun/underrun. There were 79 IDOT projects used to develop the model, all of which were completed in 1989 and had completion costs exceeding \$100,000.

The authors generally followed the six-step multiple linear regression methodology explained in Chapter 3 of this paper. They began their analysis by selecting a pool of independent variables for testing in the regression model. They grouped these independent variables, or factors, into three broad categories: project characteristics, economic characteristics, and qualitative characteristics. Project characteristics were variables considered unique to a given project, such as project type. Economic variables were considered indicators of the overall economic climate at the time of construction, such as the level of competition. The authors did not include or address qualitative variables except to indicate that they required subjective analysis and would not be included in the study (Federle and Pigneri, 1993).

The final model included 21 variables, 14 of which were dummy variables, and attained an  $R^2$  value of 0.88. Of the 21 variables included in the model, only seven had statistical significance as specified by the author: project location (as a function of geographic district), number of bids, project type (both grading and concrete repair), design funds, the ratio of low bid to engineer's estimate, and contractor history (Federle and Pigneri, 1993). The current study uses six of these relationships in the list of candidate variables that might have predictive potential. The variable discounted is contractor history because of a lack of information prior to contract award.

While Federle and Pigneri (1993) presented a technically accurate application of the multiple linear regression methodology, they ignored several areas when applying the methodology. Although the authors addressed statistical outliers, there was no discussion of influential data points that may "pull" the regression away from true estimates of statistical relationships. Additionally, the paper did not address collinearity, which is an indication that independent variables may correlate more with each other than with the dependent variable. Finally, the number of sample points seems small considering the number of independent variables.

Besides methodological problems, the study also had significant problems with generalizability. The projects used to develop the model represent a very narrow range of typical construction projects. The model included data from projects managed by one agency, represented by a small group of project types, and constructed with a small static population of contractors. The narrow scope of the model may have also accounted for inflation in the reported  $R^2$  value. The relationships reported by the authors appear



significant and logical, but further analysis is necessary before generalizing them to a broad construction population.

### **Causes of Construction Cost Overruns**

While efforts at predictive modeling appear minimal in the literature, many research efforts have attempted to classify the causes of construction project cost overruns. However, only the research that contributed insight into potential independent variables is discussed in this section. Additionally, this portion of the literature review focuses on information available prior to contract award.

In a study conducted on United States nuclear industry construction projects, the researchers identified 68 causal factors and rated them by impact (Zentner, 1996). Higher-ranking factors were the ones contributing to the largest overruns in the shortest time. From this study, the researchers generated a list of the “top 10” causal factors, as shown in Table 1. Of these factors, 80% relate directly to scope identification and control (Zentner, 1996). The research identified poor estimating technique and poor performance tracking as major categories as well. This study indicates a clear link between design phase problems and an increased risk of cost overruns during the construction phase.

Table 1. Top 10 Cost Overrun Causal Factors (Zentner, 1996)

No.	Factor
1	Original scope definition and documentation less than adequate
2	Unclear description of problem by user
3	Unrestrained scope changes, poor scope control
4	Scope changes to incorporate late design comments
5	Architect engineer (AE) provided estimate before scope completely defined
6	User input not obtained early enough
7	Installer input less than adequate
8	User input during conceptual design phase inadequate
9	Major design changes not accessed against the original budget
10	Lack of accountability to the estimate

In a similar attempt, Giegerich (2002) documented the early warning signs or “red flags” of troubled projects and provided a list of the 10 factors shown in Table 2 that can lead to cost, schedule, or quality problems. Scope changes and design difficulties are two of the factors. Design difficulties included both architect-engineer performance and design support during construction, so this category has an element that applies both before and after award of the construction contract. Two other factors that pertain to the design period are performance of project personnel and lack of teamwork.

Table 2. Early Warning Signs of Troubled Projects (Giegerich, 2002)

Early Warning Signs
Delays and schedule change
Design difficulties
Payment irregularities
Scope changes
Unsatisfactory quality of work
Slow completion of work
Owner actions
Performance of project personnel
Lack of teamwork
Disputes and claims

In a study conducted on Federal Highway Administration projects, Harbuck (2004) proposed that the contracting and award process itself was a potential contributor to a project's cost overrun. He documented three major categories of cost overruns in highway projects: design problems, construction problems, and third party problems. Design problems included design changes, design errors, and ambiguous specifications. Construction problems included differing site conditions, delays, and scope additions. Finally, third party problems included utilities, local government, and permit agencies (Harbuck, 2004). Although the nature of the relationship was undefined, he found evidence that cost overruns are symptomatic of contractor perceptions of risk. Low bidders view the potential risks in an optimistic light, while high bidders perceive the same project risk level pessimistically. With increased competition, the difference between the low and high bid increased. The research implied a need for further investigation into the relationship between bid climate, specifically the number of bidders, and cost overruns. It also noted the difference between the low and median bid seems to correlate with average cost overruns. Unfortunately, this data is not available in the current study's sample to allow exploration of this relationship.

Many researchers have indicated that design problems are causal factors leading to construction cost overruns. In a study of Los Angeles public works projects, Kuprenas and Nasr (2003) linked high design costs with poor performance during the design period. In their study, 28 of 96 projects experienced actual design costs that greatly exceeded the budgeted design costs. Of these projects, over two-thirds of the projects' increased design costs could be attributed directly to "poor pre-design requiring rework

during the design phase” (Kuprenas and Nasr, 2003:1). This would indicate that excessively high design costs might serve as a valid indicator of design problems.

A great deal of the research into cost overruns examines either factors beyond project manager influence or factors unidentifiable prior to construction award. The multiple linear regression model developed by Federle and Pigneri (1993) indicated that funding spent on supervision correlated with increased cost overruns. Singh (2002) identified 13 causes of claims (i.e., cost overruns); however, information relating to 10 of these 13 causes is typically not available until either post contract award or the time of the specific cost overrun event. Without delving into the individual causes, the overall takeaway from the research that focuses on post contract award causes is that the overall variance in cost overruns cannot be captured solely with information available prior to contract award.

## **Conclusion**

Although a predictive model based on information prior to contract award cannot capture all of the variance in the data, the literature indicates there are relationships that will facilitate the development of a predictive model. A number of researchers have found meaningful relationships linking project characteristics, design phase performance, and the contract award process with construction cost overruns. These three categories of independent variables will serve as the framework for the initial steps of the multiple linear regression methodology discussed in the next chapter.

### III. Methodology

This chapter explains the multiple linear regression methodology used in this study to develop a predictive model for construction cost overruns; it addresses each of the six steps in the multiple linear regression process summarized by McClave et al. (2005). The discussion of each step addresses the statistical tests for predictive ability, significance, and required assumptions where appropriate. This is an iterative process, with Chapter 4 discussing how this iterative nature applies specifically to this study.

Multiple linear regression is a probabilistic technique in which several independent variables are used to predict some dependent variable of interest. Models of this type take the form (McClave et al., 2005:768),

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \dots + \beta_kx_k + \varepsilon \quad (1)$$

where  $y$  is the dependent variable,  $x_1, x_2, \dots, x_k$  are the independent variables,  $\beta_0, \beta_1, \dots, \beta_k$  are the regression coefficients, and  $\varepsilon$  is the random error component. Three assumptions, which underlie the correct application of the multiple linear regression methodology, require the random error component of the model to (1) be normally distributed with a mean of zero, (2) have a constant variance, and (3) be probabilistically independent.

#### Step 1: Hypothesize the Deterministic Component of the Model

The purpose of this step is to select the independent variables to be included in the model; it is a critical step due to its implications for data collection and preparation.

There are several different possibilities in identifying independent variables, with the

approach depending upon the overall intent of a proposed study. In some instances, a review of the literature indicates that certain independent variables have proved predictive in the past. In other cases, the researcher may have a hypothesized relationship for which he or she is attempting to provide supporting evidence. It is important to note that selection of independent variables does not rely upon a hypothesized or demonstrated causal relationship. For the purposes of the multiple linear regression methodology, good independent variables correlate with the dependent variable. However, the independent variables may only be indicators and not necessarily causal factors for the response in the dependent variable.

Independent variables can be either quantitative, qualitative, or a combination of both. A regression model includes qualitative variables by the creation of “dummy” variables, which are defined to correspond to distinct levels of the qualitative variable. The actual coding of dummy variables is arbitrary except for one key consideration. A qualitative variable may have  $n$  distinct levels; therefore, the researcher might code  $n$  dummy variables to correspond individually to each of these  $n$  levels. However, a regression model can only contain a maximum of  $n-1$  levels of the dummy variable. The value of the intercept regression coefficient, based on the mathematics involved, includes the  $n$ th dummy variable level.

A useful technique in identifying candidate independent variables is the use of the analysis of variance (ANOVA) test to identify significant breakpoints in quantitative variables. While a quantitative variable may not be predictive in itself, converting it to qualitative dummy variables based on the breakpoints from the ANOVA test may make it predictive. The ANOVA test is a statistical technique for comparing population means.

In this context, ANOVA compares the means of the dependent variable populations for the levels of the independent variable. If the means are statistically different, the new qualitative dummy variable qualifies for further evaluation of predictive ability. A typical way of doing this is to visually inspect bivariate plots of quantitative independent variables versus the dependent variable and search for possible distinct levels within the quantitative variable. For any detected patterns, dummy variables are then coded for the possible distinct levels of the variable of interest.

Often, a researcher may elect to “pool” candidate variables and screen them before making the final decision of which independent variables to include in the model. For the purposes of this study, potential independent variables were identified from past research and a screening of all available data fields; additionally, some potential independent variables were the result of hypothesized relationships to be tested. Only the most predictive variables remained in the final model.

## **Step 2: Estimate Model Parameters**

The purpose of this step is to complete the deterministic portion of the regression model. This step uses sample data gathered on independent and dependent variables; however, researchers normally set aside a portion of their available data for use in step 6. After identifying the independent variables, the method of least squares is used to determine the regression coefficients. This involves the solution of a large number of simultaneous linear equations; therefore, researchers normally rely upon software packages to perform the necessary calculations. The overall intent of the method of least squares is to identify the regression coefficients that minimize the sum of the squares of

the difference between the predicted dependent variable values and the actual dependent variable values. Put another way, the method of least squares finds the model that minimizes the squared error in dependent variable predictions.

### **Step 3: Specify the Probability Distribution of the Random Error Term**

The purpose of this step is to complete the model by specifying the nondeterministic portion, or random error term, of the regression model. This methodology assumes a normally distributed error term with a mean of zero. All that remains is specification of the distribution variance or  $\sigma^2$ . Since the actual variance is unknown, dividing the sum of the squares for the error in the model by the difference in the number of observations and the number of regression coefficients provides a reasonable estimate (McClave et al., 2005).

### **Step 4: Check Assumptions of the Random Error Term**

The outcome of the previous three steps is a fully specified multiple linear regression model. The purpose of this step is to ensure the model meets all of the required assumptions for proper application of the multiple linear regression methodology. Once again, these assumptions surround the random error term of the regression model.

First, the random error term must be normally distributed with a mean of zero. Testing the mean of the error term only requires plotting a distribution of the residuals and calculating the mean. For the purposes of this study, the Shapiro-Wilk test was used to check whether the residuals were normally distributed. With the Shapiro-Wilk test, the



software fits a normal distribution to the residuals and then performs a goodness-of-fit test. The null hypothesis is that the residuals are normally distributed, and the alternate hypothesis is that the residuals are not normally distributed. The probability value ( $p$ -value) generated in this test is compared to the designated  $\alpha$  of 0.05 (indicating the researcher requires a 95% confidence level in the results). If the  $p$ -value is greater than 0.05, there is not enough evidence to support the alternate hypothesis. Since the null hypothesis cannot be rejected, the residuals are assumed to be normally distributed. If the value is less than 0.05, there is enough evidence to indicate that the residuals are not normally distributed.

At this point in the process, it is easy to test for statistical outliers and influential data points. The presence of outliers in the residuals can be evidence of problems with individual data points or the regression model itself. For a normal distribution, 95% of all values should fall within 2 standard deviations of the mean and 99% within 3 standard deviations. Converting the residuals to a “studentized” distribution and then plotting them enables easy inspection for outliers. Converting residuals to studentized values converts them to equivalent values in a normal distribution with a mean of zero and a standard deviation of one. After this conversion, the residuals become numbers that represent the number of standard deviations they are from zero. Therefore, any values greater than three or less than negative three are potential outliers and require further investigation.

Influential data points are different than statistical outliers. An influential data point is an observation included in the model that has a disproportionate effect on calculating the regression coefficients. The resulting effect of the data point is to “pull”

the regression coefficient estimates in order to account for this single data point. An influential data points can result in a regression model that is not representative of the overall data population because of this single point. For the purposes of this study, the Cook's distance statistic was used to detect influential data points. The Cook's distance statistic "measures the shift in the vector of regression coefficients when a particular object is omitted" (Freund et al., 2003:86). While there are no specific rules regarding the results of the Cook's distance statistic, a large value warrants further investigation into an individual observation. For this research, any value greater than 0.25 was considered a sign that further investigation was needed.

The next assumption to be checked is whether the error term exhibits constant variance. This study used the Breusch-Pagan test, in which the null hypothesis states that the residuals have constant variance. The alternate hypothesis is that the residuals do not have constant variance. The researcher records the sum of the squares of the error (SSE) in the model and the number of observations used and then uses the same independent variables in a regression analysis in which the dependent variable is the squared residuals of the proposed model. This regression analysis generates a sum of squares for regression (SSR). These three values allow calculation of a test statistic in the chi-squared distribution with a corresponding  $p$ -value. Similar to the test for normality, this  $p$ -value is compared to the designated  $\alpha$  of 0.05. If the  $p$ -value is greater than 0.05, there is not enough evidence to support the alternate hypothesis. Since the null hypothesis cannot be rejected, the residuals are assumed to exhibit constant variance. If the  $p$ -value is less than 0.05, there is enough evidence to indicate that the residuals do not have constant variance.

The final assumption of independence is the most difficult to test. While there are statistical tests for time-dependent data, these tests do not apply to this study. Therefore, logical arguments must be used and a judgment made as to whether this assumption is valid for the regression model developed in this research. The lack of ability to test this assumption is a limitation that is discussed further in Chapter 5.

### **Step 5: Statistically Evaluate the Usefulness of the Model**

The result of the first four steps is a fully specified regression model that has been tested for compliance with the required assumptions. The purpose of this step is to determine the statistical significance of the regression model. An *F*-test initially determines if at least some portion of the overall model is statistically significant. Hypothesis tests of each regression coefficient are then used to determine if the regression model is statistically different due to the inclusion of the respective independent variable in the regression model.

An *F*-test evaluates the statistical significance of the entire model; its null hypothesis is that all regression coefficients in the model are actually zero. In other words, the null hypothesis is that none of the regression coefficients is statistically significant; the alternate hypothesis is that at least one of the regression coefficients is statistically different from zero. Using an *F*-distribution, a *p*-value is generated and compared to the designated  $\alpha$  of 0.05. If the *p*-value is greater than 0.05, there is not enough evidence to indicate the model has any statistical significance. If the *p*-value is less than 0.05, there is enough evidence to reject the null hypothesis and conclude that at least one of the regression coefficients is statistically different from zero.

After verifying the model has at least one significant regression coefficient, similar hypothesis tests are performed on each regression coefficient in the model, including the intercept term. For each regression coefficient, the null hypothesis is that the coefficient is zero; the alternate hypothesis is that the regression coefficient is statistically different from zero. A  $p$ -value is generated and compared to the designated  $\alpha$  of 0.05. If the  $p$ -value is greater than 0.05, there is not enough evidence to reject the null hypothesis. If the  $p$ -value is less than 0.05, there is enough evidence to conclude that the regression coefficient is statistically different from zero.

A problem of concern in a regression model, depending on its application, is collinearity. Collinearity means that independent variables correlate more with each other than with the dependent variable. Collinearity is a concern because it makes the value of regression coefficients unstable. This problem can be detected using variance inflation factors (VIFs). There are no formal criteria for using the VIF scores, but the researcher compared the VIFs to a baseline statistic calculated by taking the inverse of the model  $R^2$  value, explained in the next paragraph, subtracted from one (Freund et al., 2003:110). If the VIF is greater than the baseline statistic, it is an indication that collinearity exists with other independent variables with similarly high VIF scores. This method is useful for models with lower  $R^2$  values and is more conservative than other methods.

The final test of the statistical significance of the regression model is the adjusted  $R^2$  value. The multiple linear regression methodology utilizes the method of least squares, which chooses a model equation that minimizes the sum of the squares of the error term (SSE). The methodology calculates the best regression equation to explain the

variance in the dependent variable data. The sum of squares of the regression (SSR) refers to this explained variance. An  $R^2$  value is determined by calculating the ratio of the variance explained, or SSR, to the total variance in the data. Ranging from 0 to 1, the  $R^2$  value indicates the percentage of sample variance explained by the regression model. Therefore, a higher  $R^2$  value indicates a better regression model than one with a lower value. One weakness of this measure is that the addition of any independent variable will improve the  $R^2$  value regardless of its statistical significance. Another weakness of the  $R^2$  value is that it does not account for sample size. Therefore, the adjusted  $R^2$  is a better measure of a model's statistical significance. This value is simply the  $R^2$  of the model adjusted to account for the total number of variables, or regression coefficients, included in the model and the sample size. The adjusted  $R^2$  value is calculated by the equation (McClave et al., 2005:789),

$$R_a^2 = 1 - [(n-1)/(n-(k+1))](1-R^2) \quad (2)$$

where  $R^2$  is the multiple coefficient of determination,  $n$  is the number of observations in the sample, and  $k$  is the number of regression coefficients.

### **Step 6: Use the Model for Prediction**

The ultimate test of any model is whether it is useful in practical application. The outcome of the previous five steps is a fully specified model tested for required assumptions and statistically evaluated for usefulness. The purpose of this step is to determine how well the model does in actual practice. This is typically done by using the model to predict the dependent variable of interest for data that was not a part of the sample used to create the model. For this study, the researcher randomly selected a

portion of the available data for this purpose. This data was set aside and unexamined until completion of all previous steps through several iterations. A pre-identified comparison metric evaluates these predictions against actual values to determine some type of performance statistic. Normally this step attempts to demonstrate that the new model is better than an existing practice or another model.

## **Conclusion**

The methodology presented in this chapter serves as guidance for data analysis. Its proper application ensures that the outcome of this process is a statistically accurate, significant, and tested model that meets all required assumptions. Use of this methodology allows the investigation and definition of relationships between any number of independent variables and the dependent variable of interest. This methodology is the most appropriate of those available for the area of interest, construction cost overruns, and the intentions of this study.

## IV. Results

This chapter summarizes the development of a predictive model for construction cost overruns using available data on Air Force projects. The data collection section discusses the source of project data and the steps used in determining a sample population of projects with required project information. The remaining sections cover the methodology steps described in Chapter 3.

### Data Collection

Data used to develop the proposed multiple linear regression model was captured from the Air Force's Automated Civil Engineer System – Project Manager (ACES-PM) module, which is an existing database used to capture project management information. This system contains hundreds of data fields, but the use of these fields varies depending on project type, funding source, and user needs. Therefore, the data was thoroughly reviewed for completeness.

The data set contained 348,427 individual project entries as of August 2005. Of these projects, approximately 24,000 were considered complete; in other words, they contained the basic information required to calculate a construction cost overrun percentage. After examining these records, it quickly became apparent that consistency in the use of available data fields existed only for Air Force Military Construction (MILCON) projects. MILCON projects are typically larger in scope and cost than other Air Force projects; therefore, the requirements for data maintenance and upkeep appear stricter. Further screening of the MILCON resulted in 243 projects that contained

information on the independent variables of interest; these projects ranged in cost from \$346,997 to \$46,131,823. Of these 243 projects, 25 were randomly selected (approximately 10%) and set aside for step 6 of the multiple linear regression methodology; this left 218 projects to be included in the development process.

### **Identification of Candidate Independent Variables**

The literature review in Chapter 2 identified three broad categories of independent variables: project characteristics, design performance indicators, and contract award process indicators. Using this framework and the requirement that data be available prior to contract award results in the pool of candidate variables shown in Table 3. Visual inspection of data plots and the use of ANOVA tests helped identify many of these variables. In total, this study identified 42 independent variables for further examination of predictive ability.



Table 3. Candidate Independent Variables (Bold Items Included in Final Model)

Variable	Description
<b>Project Characteristics</b>	
Location (Air Force Base)	Geographic location of the project
Major Command (MAJCOM)	Agency responsible for project funding and oversight
Design Agent	Agency responsible for implementing a project design
Construction Agent	Agency responsible for oversight during construction
Construction Agent (Non Air Force)	The construction agent was non Air Force
Construction Duration	Duration specified in the construction contract in days
Construction Duration < 1 year	The construction contract specifies a duration less than a year
Construction Duration > 2 years	The construction contract specifies a duration greater than 2 years
<b>Type of Work (EEIC)</b>	Project type as specified by AF funding code
Infrastructure Project	The project's primary purpose involves major utility systems
Housing Project	The project's primary purpose involves housing units
Medical Project	The project's primary purpose involves medical facilities
Dorm Project	The project's primary purpose involves dormitories
Paving Project	The project's primary purpose involves asphalt or concrete paving
New Construction	The primary purpose is the construction of a new facility
Fiscal Year (FY)	The year in which the project was funded
<b>FY 2000 and Later</b>	The project was started after October 1, 1999
<b>Design Performance Indicators</b>	
Programmed Amount (PA)	Construction funding budgeted at the conceptual design phase
Estimate Amount (Estimate)	The estimated cost at the end of the design phase
Design Cost	The total cost of designing the project
Design Length	The total time to complete the project design in days
<b>Normalized Design Length</b>	Design length divided by design cost (days/\$)
Normalized Design Length (Estimate)	Design length divided by the estimate amount (days/\$)
Normalized Design Length (Cost at Award)	Design length divided by the cost at award (days/\$)
Design Less than 3 Months	The design was completed in less than 3 months
<b>Design Greater than 2 Years</b>	The design was completed in more than 2 years
Design Cost % of Estimate	Design cost divided by the estimate amount
Design/Estimate Cost > 10%	The previous variable is greater than 0.10
Design Cost % of Cost at Award	Design cost divided by the cost at award
<b>Design/Cost at Award &gt; 10%</b>	The previous variable is greater than 0.10
<b>Estimate % of Cost at Award</b>	Estimate amount divided by the cost at award
Low Estimate	The estimate is less than the cost at award
<b>Estimate % of PA</b>	Estimate amount divided by the PA
Estimate > PA	The estimate is greater than the PA
Contract Award in August	The contract award occurred in August
<b>Contract Award in September</b>	The contract award occurred in September
Contract Award in October	The contract award occurred in October
<b>Contract Award Process Indicators</b>	
Bid Protest	A bid protest occurred
Number of Bidders	The number of bids submitted on a project
High Competition > 4 Bidders	The number of bids submitted on a project is more than 4
High Competition > 5 Bidders	The number of bids submitted on a project is more than 5
<b>High Competition &gt; 9 Bidders</b>	The number of bids submitted on a project is more than 9

## **Iterative Process of Modeling**

As mentioned in Chapter 3, the multiple linear regression methodology is an iterative process. The current study was not an exception to this rule, and the model presented in the remainder of this chapter is the result of multiple iterations. Following is a discussion of the reasons that resulted in multiple iterations of the entire modeling process.

Initially, no combination of independent variables could produce a model that would pass the required tests of assumption. Specifically, the test for normality of residuals failed even after careful selection of independent variables and the removal of outliers and influential data points. After several dozen iterations, some other approach became necessary. The solution to this problem was changing the dependent variable by transforming it to the natural logarithm of the cost overrun percentage; as it turns out, logarithmic transformations are a common solution to passing the tests of assumptions for economic data (McClave et al., 2005).

However, this transformation has several implications for the applicability and usefulness of the study. For example, the most fundamental impact is that it prevents the prediction of cost underruns, which caused the exclusion of five additional projects. After further examination of the data, eight outliers and two influential data were removed. Histograms of studentized residuals and Cook's distance allowed detection of these points as described in Chapter 3. Excessively high or low cost overrun values are the likely cause of five of the outliers; however, no cause could be identified for the remaining outliers or the influential data points. Removing the outliers and influential

data points enables the model to pass the required tests of assumptions. Thus, 203 projects were used in the development of the proposed model.

### Proposed Model

This study used the JMP<sup>®</sup> Statistical Discovery Software package (Copyright © 2003 SAS Institute Inc.) to develop the multiple linear regression model presented in this section. The software's stepwise regression function assisted in selecting the most statistically significant independent variables. With this function, the user specifies statistical significance tolerances that guide the computer's selection of independent variables. While this is a valuable tool, a manual investigation was performed to confirm the software tool's selections. The final model in equation form is,

$$\begin{aligned} \ln (\% \text{ Overrun}) = & -2.151 - 19.285x_1 + 1.018x_2 + 0.140x_3 + 0.133x_4 - 0.216x_5 \\ & - 0.234x_6 - 1.008x_7 - 0.696x_8 - 0.958x_9 + 0.295x_{10} \end{aligned} \quad (3)$$

where

$x_1$  = normalized design length (design length divided by the design cost),

$x_2$  = estimate % of cost at award (estimate amount divided by the cost at award),

$x_3$  = design cost/cost at award > 10% (dummy variable – 1 if > 10% and 0 if ≤ 10%),

$x_4$  = September award (dummy variable – 1 if contract award in September and 0 if not),

$x_5$  = high competition > 9 bidders (dummy variable – 1 if >9 and 0 if ≤ 9),

$x_6$  = FY 2000 and later (dummy variable – 1 if funded after October 1, 1999 and 0 if not),

$x_7$  = estimate % of PA (estimate amount divided by the programmed amount),

$x_8$  = type of work is emergency MILCON – EEIC341 (dummy variable – 1 if EEIC is 341 and 0 if not),

$x_9$  = type of work is housing - EEIC713 (dummy variable – 1 if EEIC is 713 and 0 if not), and

$x_{10}$  = design greater than 2 years (dummy variable – 1 if > 2 years and 0 if  $\leq$  2 years).

### Test the Proposed Model against Methodology Assumptions

Chapter 3 indicated three assumptions underlying correct application of the multiple linear regression methodology. Therefore, this section provides the results of testing each of these assumptions. For all statistical tests a significance level of 95% (i.e.,  $\alpha = 0.05$ ) is used. Before proceeding to the statistical tests, visual inspection of the residuals can serve as an indicator of potential problems. Figure 1 is a plot of the residuals versus the predicted values. This plot shows visually that the residuals seem centered on zero with a random spread that does not indicate problems with constant variance.

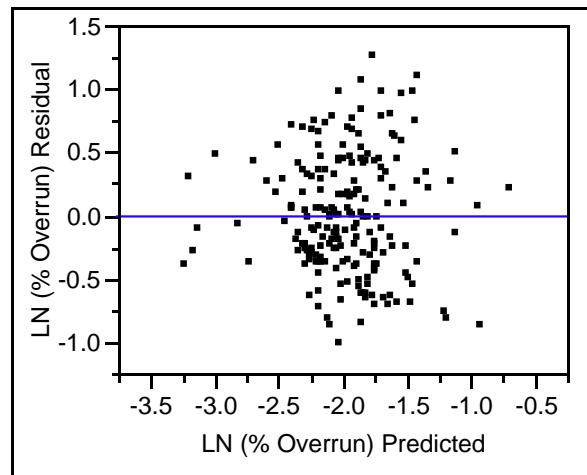


Figure 1. Plot of Model Predicted Values vs. Residuals

Although visual inspection indicates no problems with constant variance, the Breusch-Pagan test provides statistical evidence that the assumption is justified. For the proposed model, the  $p$ -value is 0.173. Comparing this to our significance level ( $\alpha = 0.05$ ) shows that there is not enough evidence to reject the null hypothesis. Therefore, the residuals appear to have constant variance, thereby passing the test of assumption.

The Shapiro-Wilk test checks the assumption that the error portion of the model has a normal distribution with a mean of zero. Figure 2 shows a histogram of the studentized residuals along with a fitted normal distribution. The JMP<sup>®</sup> software package performs the Shapiro-Wilk test on this fitted distribution and reports a  $p$ -value of 0.0519. Comparing this to our selected significance level ( $\alpha = 0.05$ ) shows that there is not enough evidence to reject the null hypothesis. Therefore, the distribution of the residuals is considered normal and passes the test of assumption. Although the  $p$ -value is extremely close to the significance level, multiple linear regression is robust for violations of the assumption of normality (McClave et al., 2003). Minor violations of this assumption do not have a significant impact on regression coefficient estimates or the associated statistical significance. A visual inspection of Figure 2 also shows that there are no outliers. Figure 3 is a histogram of the Cook's distance for each observation. Recall that high values for this statistic indicate an influential data point; however, a visual inspection of Figure 3 indicates no problems with influential data points.

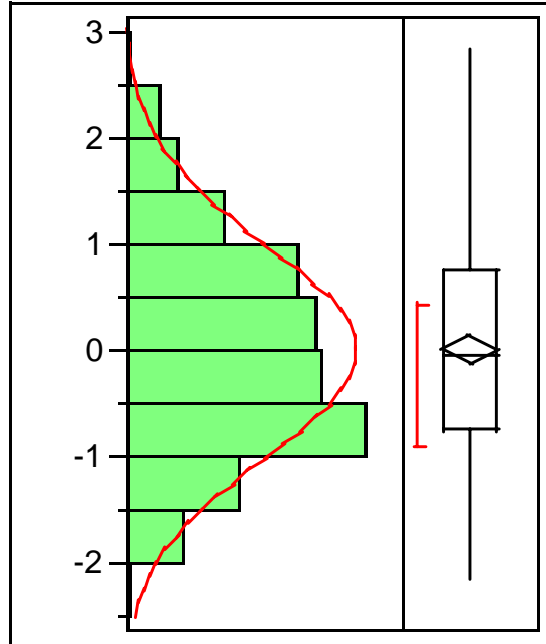


Figure 2. Histogram of Studentized Residuals with a Fitted Normal Distribution

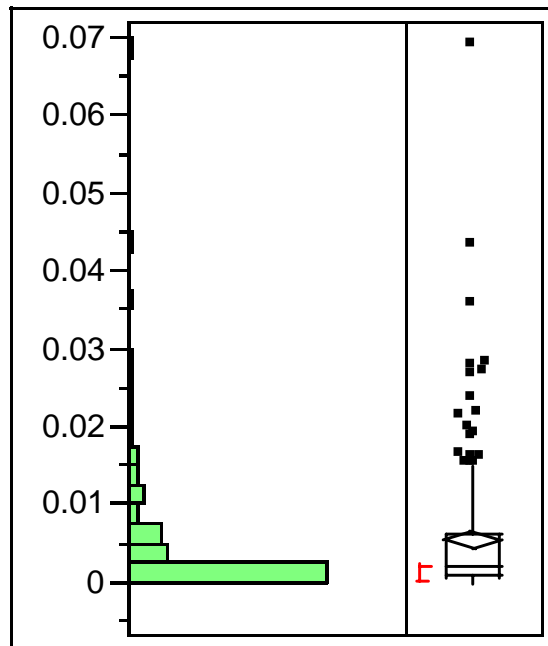


Figure 3. Histogram of Cook's Distance

The final assumption is independence of the observations. Unfortunately, no statistical tests are available that apply directly to cost overrun data and this model. Several issues might cause dependence in cost overrun errors. For example, a contractor working several construction projects simultaneously or consecutively at a single geographic location might cause some dependence between observations. Additionally, large numbers of projects occurring simultaneously at a single geographic location might also introduce dependencies. However, inspection of the project data used in the development of this model does not indicate any situations of concern. The projects cover a large timeframe at widely different geographic locations. Therefore, while statistical testing of the assumption of independence is not possible, there is no evidence to suggest violation of this assumption.

### **Statistically Evaluate the Usefulness of the Model**

The statistical evaluation of the model's usefulness begins with the overall  $F$ -test. This test evaluates whether at least one of the regression coefficients is statistically significant. Assuming the model passes this test, additional hypothesis testing determines the statistical significance of each regression coefficient. The overall adjusted  $R^2$  value helps interpret the amount of variance the model explains in the subject data. Finally variance inflation scores (VIFs) are examined to assure there are no problems with collinearity in the independent variables. The JMP<sup>®</sup> software package provides all the previous information as part of its standard model output, and the appendix to this paper includes this model output. The proposed model passes the  $F$ -test with a  $p$ -value less than 0.0001; it also has an adjusted  $R^2$  value of 0.371 (unadjusted  $R^2 = 0.402$ ). Table 4

summarizes the  $p$ -values for the hypothesis tests for significance of each regression coefficient and its associated VIF score.

Table 4. Regression Coefficient P-values and VIF Scores

Independent Variable	Regression Coefficient	Std Error	P-value	VIF
Intercept	-2.151	0.266	<.0001	.
Normalized Design Length	-19.285	8.588	0.026	1.145
Estimate Percent of Cost at Award	1.018	0.180	<.0001	1.110
Design/Cost at Award > 10%	0.140	0.074	0.059	1.202
Contract Award in September	0.133	0.075	0.078	1.077
High Competition >9	-0.216	0.087	0.014	1.101
FY 2000 and Later	-0.234	0.078	0.003	1.158
Estimate % of Programmed Amount	-1.008	0.246	<.0001	1.119
Type of Work EEIC341 (Emergency MILCON)	-0.696	0.245	0.005	1.049
Type of Work EEIC713 (Housing)	-0.958	0.223	<.0001	1.075
Design Greater Than 2 Years	0.295	0.124	0.018	1.119

As Table 4 indicates, two of the independent variables have  $p$ -values greater than the designated 95% confidence level. However, these regression coefficients are significant and non-zero with at least 90% confidence. Removing these variables from the regression model did not decrease the  $R^2$  value significantly; however, it caused the model to fail the tests for assumptions of the methodology. For this reason, the final model includes both variables.

Based on the  $R^2$  value of 0.402, VIF scores greater than 1.67 would be a concern for collinearity. As Table 4 indicates though, all VIF scores are below this value. Therefore, the estimates of the regression coefficients are stable, meaning the independent variables correlate with the dependent variable and not each other.



## Use the Model for Prediction

Recall that 25 projects were set aside for preliminary testing of the model. Using the model with these projects and comparing the predictions to the current Air Force practice of assigning an arbitrary 5% contingency allowance provides a measure of the model's performance. Since the model predictions represent the natural logarithm, using the natural exponent with the predictions provides raw percentage values in decimal form for testing. However, this type of transformation makes it difficult to evaluate the confidence interval of each prediction; the value returned by this transformation is the median, and not the mean, of the confidence interval around the prediction.

A more practical approach is to set some performance limits and evaluate the model and existing practices against the defined metric. Based on practical considerations, a reasonable metric would be predicting the cost overrun percentage within 5% of the actual value. Using this performance metric, the current Air Force practice of assigning 5% contingency to projects is within the 5% of the actual overrun percentage for only 20% of the projects tested. However, the model's predictions are within 5% of the actual values for 44% of the test projects. Table 5 summarizes the results of this analysis. Additionally, the average difference between the model prediction and the actual overrun is only -0.3% for the 25 test projects, while it is -11.2% for current arbitrary percentages. This indicates that the average project is significantly short in contingency funding.

Table 5. Comparison of Model Predictions to Current AF Practice

Actual		Model		Current AF Practice	
Test Project	Actual %	Predicted %	Within 5%	Predicted %	Within 5%
1	0.0949	0.1296	Y	0.0500	Y
2	0.1762	0.0883	N	0.0500	N
3	0.0948	0.1471	N	0.0500	Y
4	0.1151	0.2067	N	0.0500	N
5	0.1173	0.1998	N	0.0500	N
6	0.2462	0.1596	N	0.0500	N
7	0.1037	0.0998	Y	0.0500	N
8	0.2062	0.3964	N	0.0500	N
9	0.0751	0.1883	N	0.0500	Y
10	0.2937	0.1559	N	0.0500	N
11	0.1119	0.0972	Y	0.0500	N
12	0.2269	0.1292	N	0.0500	N
13	0.2360	0.1756	N	0.0500	N
14	0.1054	0.1452	Y	0.0500	N
15	0.1446	0.0990	Y	0.0500	N
16	0.0884	0.2708	N	0.0500	Y
17	0.2559	0.1234	N	0.0500	N
18	0.2335	0.1893	Y	0.0500	N
19	0.0849	0.0939	Y	0.0500	Y
20	0.1150	0.1382	Y	0.0500	N
21	0.1888	0.1247	N	0.0500	N
22	0.1074	0.1303	Y	0.0500	N
23	0.1408	0.1348	Y	0.0500	N
24	0.3591	0.2269	N	0.0500	N
25	0.1383	0.1380	Y	0.0500	N

## Conclusion

This study resulted in a multiple linear regression model that outperforms existing contingency funding practices using only information available prior to contract award. Preliminary testing indicates it performs well over an extremely wide range of project types and scopes. The model predicted 44% of test cases within 5% of the actual overrun with an average error of -0.3%. The model performance greatly exceeds the 20% performance metric and -11.2% average error for current practices. Chapter 5 further discusses implications of this study.

## V. Conclusions

This chapter discusses the key results and implications of this study, details some of the limitations associated with the multiple linear regression model that was developed, and provides recommendations for use of the model. Additionally, this section presents some ideas for further research that may advance understanding of construction cost overruns and increase the effectiveness of preventing and planning for them.

### Discussion of Results

The final regression model includes 10 independent variables shown to have a relationship with potential cost overruns. To gain insight into these relationships, the following paragraphs discuss each of the variables. Prior to this though, it is important to reiterate that the model provides the natural logarithm of the predicted cost overrun percentage in decimal form. Therefore, the discussions will reference percentages that represent median, and not mean, values.

The most obvious observation of the modeling effort is the intercept coefficient. This value corresponds to a base-line overrun amount of 11.63%, which greatly exceeds the current practice of assigning 5% contingency to a construction project. This is an indication that current practices drastically under-budget for actual overruns experienced. From a macro perspective then, this raises questions regarding the effectiveness of current project cost control activities and measures.

Normalized design length is the total length of the design period in days divided by the total design cost. It is a measure of how much time the designer spends working on the project normalized by the project scope. Although this variable has a relatively small impact on the final overrun percentage, it is very easy to control and has a negative coefficient for the entire range. Over the range of test cases in Table 5, the lowest value decreased the overrun by 0.03% and the highest decreased it by 1.03%. This relationship indicates that allowing designers additional time will decrease resulting overruns. This makes logical sense and provides some assurance that design efforts have positive results on final cost.

Estimate percent of cost at award is an indication of how well the designers estimated the cost of the project. The sign of this coefficient is positive, indicating that it increases the overrun. The test case data indicates that it is better to underestimate than overestimate the cost of the project. However, this is misleading because of probable interaction with the variable estimate percent of programmed amount. Therefore, further investigation of this relationship is required.

If design cost is greater than 10% of the cost at the time of award, the model indicates that cost overruns will increase. This supports the findings of Kuprenas and Nasr (2003) in which they found that high design costs often result from design problems. For the current research effort, the model indicates that high design costs also indicate an increased risk of cost overruns from these design problems. In fact, ignoring the contributions of other variables, indications of high design costs increase the baseline cost overrun amount from 11.63% to 13.37%.

The contract award in September variable is unique to the fiscal year requirements of the government, but is easily applicable to all construction projects. For the purposes of this study, this variable indicates whether the contract award occurred in the month immediately preceding fiscal year rollover (i.e., September). This would indicate potential “rushing” of a project to meet funding deadlines. In these situations, awarding a contract during this month, due primarily to funding constraints, increases the baseline cost overrun amount from 11.63% to 13.29%.

The next variable indicates the presence of high competition, which is the only bidder-based variable that proved significant. Based on the ANOVA analysis, the statistically significant break point for large construction projects seems to be 10 or more bidders. The presence of high competition, based upon the proposed model, is likely to decrease the baseline cost overrun amount from 11.63% to 9.38%. This is similar to the results found by Harbuck (2004).

ANOVA testing of the cost overrun percentages in the sample projects indicates that overruns have decreased slightly in recent years. Therefore, the model includes a variable that accounts for this trend for projects constructed after October 1, 1999. Recent projects have a median cost overrun percentage that is 9.21% as predicted by the model. Inclusion of this variable is necessary in the current study because of a lack of data on recent year projects. However, this value should move into the intercept term for practical application of the model to current projects.

Estimate percentage of programmed amount is the ratio of the final estimate to the estimate at the concept stage of the project. This variable has a negative influence on cost overruns according to the model; however, it most likely interacts with the estimate

percentage of cost at award variable. From the model, it appears that overestimation at the concept stage is an indication of poor project definition and may result in an increased cost overrun.

There are two separate types of work variables in the final model, emergency Military Construction (MILCON) and housing. Emergency MILCON is work funded because of legal requirements or other mitigating factors that make immediate completion of the work critical. In the sample observations, these projects typically represent simple requirements and straightforward designs. This corresponds to the reduced median overruns predicted by the model of 5.80%. Housing work has an even lower median overrun, ignoring other variables, of 4.46%. This relationship may represent the fact that housing work is very “cookie-cutter” and contractors bidding on these projects have enormous experience in bidding on and controlling these types of projects.

The final variable in the model represents a design period that lasts longer than two years. It indicates that a shorter design period is better, which is contrary to the normalized design length variable. The baseline cost overrun predicted by the model increases from 11.63% to 15.63% for excessively long designs. This is most likely an indication of designs “placed on the shelf” and then given a quick update when funding for the project becomes available.

The intention of this study is the prediction of cost overruns using only data that is available prior to contract award. By framing the study in this manner, the proposed model does not account for all the variance in cost overrun data. The adjusted  $R^2$  value of 0.371 clearly demonstrates this fact. However, using the model to predict a best-case

design scenario and bid environment (where the programmed amount, estimate, and cost at award are identical) results in a predicted overrun of approximately 7.5%. This provides evidence of several key assumptions of this study. First, there are sources of overrun variance not accounted for in the model. Second, even the best possible design efforts will not eliminate cost overruns in all cases because some sources of variance are outside the project manager's control. Finally, even under the best circumstances, this model predicts that the median cost overrun will exceed the 5% contingency funds normally assigned to a construction project.

### **Limitations**

Several limitations apply to this research. First, predicting the natural logarithm of the cost overrun percentage means the model cannot predict a cost underrun. However, as mentioned in the Chapter 4 section on model iteration, this only eliminated 5 of 243 projects in the sample population. Since the intention of the study is to assist in estimating contingency fund needs, this limitation does not impair the usefulness of the model for its intended purpose. Additionally, taking the exponent of the model predictions returns the median or 50<sup>th</sup> percentile. This makes interpretation of confidence intervals around the predicted value problematic and less useful for the construction practitioner. However, the median provides a valid planning tool for construction project contingency funds.

As with any predictive methodology, the usefulness of the model is directly dependent upon the accuracy and range of the sample data used in its creation. This study relies on the accuracy of the data pulled from the Air Force's Automated Civil



Engineer System – Project Manger module (ACES-PM) as input by individual project managers throughout the United States and overseas locations. While efforts were made to minimize possible inaccuracies, there is still a possibility that inaccurate data affected the calculation of regression coefficients. Predictive models are only truly useful within the range of the data used to create it. In this respect, the sample population of this study covered a comprehensive range of construction project scopes, location, costs, and other factors; however, prediction outside the range of sample data is extrapolation beyond the intent of the model. Additionally, the data available on the sample population limits the independent variables examined for predictive ability. Qualitative variables such as teamwork and communication may have a relationship with cost overruns, but capturing this relationship is impossible within available data sources.

Finally, the scope of the study limits the total variance explained by the model. By only using information that is available prior to contract award, sources of variance that do not occur until post contract award are ignored and not accounted for in the modeling efforts.

## **Recommendations**

### ***Usefulness of the Model***

The proposed model predicted the actual cost overrun percentages within 5% for 44% of the test projects, while the current practice of assigning 5% performed to the same level in only 20% of test cases. This indicates the model has validity and use as a planning tool up to and including the contract award phase of a project. The average difference between predicted and actual cost overruns was only -0.3% for the proposed

model, while the same statistic is -11.2% for the arbitrary assignment of a 5% contingency. This implies that current practices will always cause a shortage in the allocation of contingency funds, while application of the proposed model will result in a significantly smaller shortage of contingency funds. The application of this model is a step in the direction of correct budgeting for contingency requirements. While individual project predictions may contain errors, the overall impact of applying the model is a significant reduction in the net effect of under-budgeting for all projects under current practices.

### ***Future Research***

The first area for further research is the re-accomplishment of this study using data from projects completed after October 1, 1999 only. The fiscal year variable in the final model represents a potential time-based trend. Further research is necessary to determine if this reduction in overruns is a sustained trend or a result of changes in management or design practices. An overall time trend might indicate possible market changes that would require periodic re-evaluation. If the decrease in overruns represented by this variable is the result of management or design practices, investigation into the causes might shed insight into gaining further reductions.

The housing type of work variable in the final model is possible evidence of the influence of contractor experience. Further investigation into this area may increase the predictive ability of future model revisions and enable the inclusion of additional variables accounting for contractor experience as it applies to other project types. Current data gathering techniques in the Air Force did not make it possible to include this investigation as a part of this study.

The interaction of the programmed amount, estimated amount, and cost at award in the model represents a complex relationship that requires further investigation to understand. The implications of this complex interaction are two-fold. First, these values serve as performance metrics of the design effort. How the relationships of these three values correspond to the quality of a design is important in understanding the impacts to potential cost overruns. Second, understanding the relationships and their predictive ability is critical to determining a control strategy that minimizes potential cost overruns.

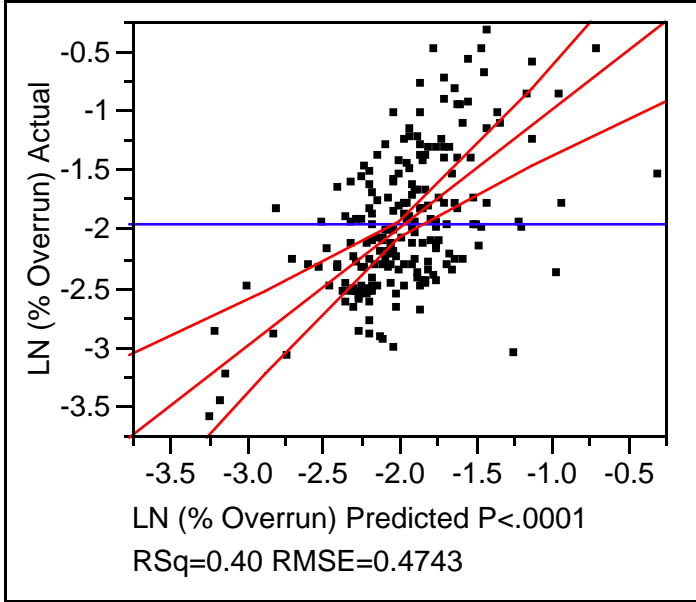
As an Air Force-specific area of further research, investigation into the effectiveness of current construction data gathering practices might improve the quality of data captured in ACES-PM. From the data collection section of Chapter 4, less than 7% of available sample projects had the minimum requisite data fields for capturing cost overrun information. Inconsistencies in data field use and bookkeeping practices throughout Major Commands greatly reduces the overall effectiveness and utility of gathered data. Further research might determine if improving the ACES-PM system would make it more effective, either through software or policy changes.

Finally, this study indicates that no amount of design work will eliminate all potential cost overruns. Regardless of the effort expended, it seems some cost overruns are beyond the project manager's control in the design phase. Research into the "point of diminishing return" for design funding and time would be beneficial in maximizing the return on investment for expended design effort.

## Appendix

### JMP® Regression Model Output

**Response LN (% Overrun)  
Actual by Predicted Plot**



**Summary of Fit**

RSquare	0.402054
RSquare Adj	0.370911
Root Mean Square Error	0.474297
Mean of Response	-1.96494
Observations (or Sum Wgts)	203

**Analysis of Variance**

Source	DF	Sum of Squares	Mean Square	F Ratio
Model	10	29.041921	2.90419	12.9099
Error	192	43.191910	0.22496	Prob > F
C. Total	202	72.233831		<.0001

**Parameter Estimates**





Term	Estimate	Std Error	t Ratio	Prob> t	VIF
Intercept	-2.151282	0.26571	-8.10	<.0001	.
Normalized Design Length	-19.28451	8.588378	-2.25	0.0259	1.1450628
Estimate Percent of Cost at Award	1.0184801	0.179565	5.67	<.0001	1.1099979
Design/Cost at Award > 10%	0.1397122	0.073644	1.90	0.0593	1.2018648
Contract Award in September	0.132996	0.074995	1.77	0.0777	1.0766651
High Competition >9	-0.215583	0.086995	-2.48	0.0141	1.1007514
FY 2000 and Later	-0.233655	0.078134	-2.99	0.0032	1.157993
Estimate % of Programmed Amount	-1.008428	0.245572	-4.11	<.0001	1.1185188
Type of Work EEIC341 (Emergency MILCON)	-0.696249	0.245281	-2.84	0.0050	1.0486791
Type of Work EEIC713 (Housing)	-0.957792	0.222663	-4.30	<.0001	1.0748185
Design Greater Than 2 Years	0.2953019	0.123895	2.38	0.0181	1.1193256

## Effect Tests

Source	Nparm	DF	Sum of Squares	F Ratio	Prob > F
Normalized Design Length	1	1	1.1342166	5.0419	0.0259
Estimate Percent of Cost at Award	1	1	7.2370698	32.1708	<.0001
Design/Cost at Award > 10%	1	1	0.8096502	3.5991	0.0593
Contract Award in September	1	1	0.7074749	3.1449	0.0777
High Competition >9	1	1	1.3814697	6.1410	0.0141
FY 2000 and Later	1	1	2.0117195	8.9427	0.0032
Estimate % of Programmed Amount	1	1	3.7934347	16.8629	<.0001
Type of Work EEIC341 (Emergency MILCON)	1	1	1.8126056	8.0575	0.0050
Type of Work EEIC713 (Housing)	1	1	4.1624278	18.5031	<.0001
Design Greater Than 2 Years	1	1	1.2779806	5.6810	0.0181

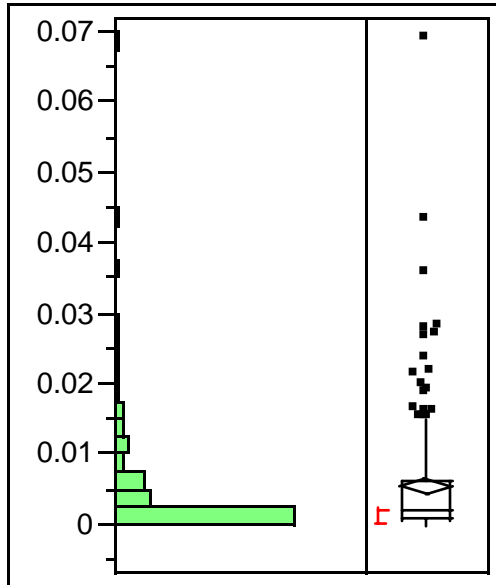
## Scaled Estimates

Continuous factors centered by mean, scaled by range/2

Term	Scaled Estimate	Plot Estimate	Std Error	t Ratio	Prob> t
Intercept	-1.964937		0.033289	-59.03	<.0001
Normalized Design Length	-0.484138		0.215612	-2.25	0.0259
Estimate Percent of Cost at Award	0.8046389		0.141863	5.67	<.0001
Design/Cost at Award > 10%	0.0698561		0.036822	1.90	0.0593
Contract Award in September	0.066498		0.037498	1.77	0.0777
High Competition >9	-0.107791		0.043497	-2.48	0.0141
FY 2000 and Later	-0.116828		0.039067	-2.99	0.0032
Estimate % of Programmed Amount	-0.583984		0.142212	-4.11	<.0001
Type of Work EEIC341 (Emergency MILCON)	-0.348124		0.12264	-2.84	0.0050
Type of Work EEIC713 (Housing)	-0.478896		0.111332	-4.30	<.0001
Design Greater Than 2 Years	0.147651		0.061948	2.38	0.0181

## Distributions

### Cook's D Influence LN (% Overrun)



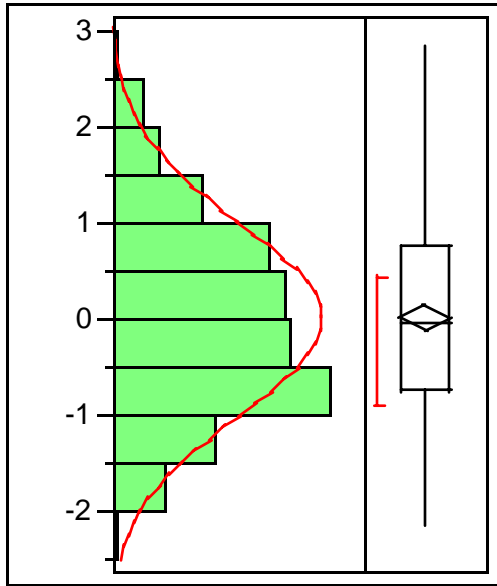
## Quantiles

100.0%	maximum	0.06923
99.5%		0.06871
97.5%		0.02764
90.0%		0.01418
75.0%	quartile	0.00607
50.0%	median	0.00180
25.0%	quartile	0.00051
10.0%		0.00006
2.5%		1.32e-6
0.5%		2.15e-8
0.0%	minimum	2.03e-8

## Moments

Mean	0.0050686
Std Dev	0.0082629
Std Err Mean	0.0005799
upper 95% Mean	0.0062121
lower 95% Mean	0.0039251
N	203

### Studentized Resid LN (% Overrun)



— Normal(0.00094,1.00061)

#### Quantiles

100.0%	maximum	2.794
99.5%		2.786
97.5%		2.096
90.0%		1.439
75.0%	quartile	0.747
50.0%	median	-0.047
25.0%	quartile	-0.744
10.0%		-1.342
2.5%		-1.784
0.5%		-2.148
0.0%	minimum	-2.152

#### Moments

Mean	0.0009386
Std Dev	1.0006109
Std Err Mean	0.0702291
upper 95% Mean	0.1394147
lower 95% Mean	-0.137538
N	203

#### Fitted Normal

##### Parameter Estimates

Type	Parameter	Estimate	Lower 95%	Upper 95%
Location	Mu	0.000939	-0.137538	0.139415
Dispersion	Sigma	1.000611	0.911825	1.108703

#### Goodness-of-Fit Test

Shapiro-Wilk W Test		
W	Prob<W	
.986591	0.0519	



## References

- Chen, Dong, and Francis T. Hartman. "A Neural Network Approach to Risk Assessment and Contingency Allocation," *AACE International Transactions*: RISK.07.01-RISK.07.06 (2000).
- Department of the Air Force. *The United States Air Force Project Manager's Guide for Design and Construction*. Washington: HQ AFCEE, June 2000.
- Department of the Air Force. *Air Education and Training Command Project Manager's Guide for Design and Construction*. Washington: HQ AETC, Spring 2004.
- Federle, Mark O., and Steven C. Pigneri. "Predictive Model of Cost Overruns," *Transactions of AACE International*: L.7.1-L.7.9 (1993).
- Freund, Rudolf, and others. *Regression Using JMP®*. North Carolina: SAS Institute Inc. and John Wiley & Sons, Inc., 2003.
- Giegerich, Donald B. "Early Warning Signs of Troubled Projects," *AACE International Transactions*: CDR.02.1-CDR.02.8 (2002).
- Harbuck, Robert H. "Competitive Bidding for Highway Construction Projects," *AACE International Transactions*: EST.09.1-EST.09.4 (2004).
- Kuprenas, John A., and Elhami B. Nasr. "Controlling Design-Phase Scope Creep," *AACE International Transactions*: CSC.01.1-CSC.01.5 (2003).
- Mantel, Samuel J., Jr. and others. *Project Management in Practice*. New Jersey: John Wiley & Sons, Inc., 2005.
- McClave, James T., and others. *Statistics for Business and Economics* (9th Edition). New Jersey: Pearson Prentice Hall, 2005.
- Singh, Rohit. "Be Prepared for Construction Claims – Globally," *AACE International Transactions*: CDR.04.1-CDR.04.2 (2000).
- Zentner, Randal S. "Accurate Estimates Start with Clear Pictures," *Transactions of AACE International*: C&S/M&C.10.1-C&S/M&C.10.6 (1996).

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