



**DEVELOPING A PREDICTIVE MODEL FOR FACILITY REPAIR COSTS ON
UNITED STATES AIR FORCE INSTALLATIONS**

GRADUATE RESEARCH PROJECT

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AFIT/ILS/ENV/11J-01

**DEPARTMENT OF THE AIR FORCE
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UNITED STATES AIR FORCE INSTALLATIONS

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Abstract

The Air Force Civil Engineering community spends significant effort maintaining and repairing their infrastructure and facilities at their installations worldwide. They continually search for ways to better illustrate the impact of funding decisions on future infrastructure and facility conditions. The purpose of this research was to develop a predictive model for determining future facility repair costs. The research analyzed current and past funding levels as a possible predictor of future repair costs by way of a multiple linear regression. During the research, one variable of specific interest was deferred maintenance. The results provide a predictive model that can be used to forecast repair costs with a 3-year outlook. Given the environmental, political, and economic factors that affect financial decisions, the model provides a solid basis for predicting future costs based on previous expenditures. The model can be used to help support and defend future Air Force funding decisions and can be adapted for use by non-Air Force organizations.

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DEVELOPING A PREDICTIVE MODEL FOR FACILITY REPAIR COSTS ON UNITED STATES AIR FORCE INSTALLATIONS

I. Introduction

America reportedly needs \$2.2 trillion to invest in the nation's infrastructure over the next five years. While Europe is spending 5% of their gross domestic product on improving their infrastructure; China is investing 9%; and the United States is spending only 2.4% (American Society of Civil Engineers, 2009). According to the 2009 Report Card for America's infrastructure, "delayed maintenance and chronic underfunding are contributors to the low grades in nearly every (infrastructure) category" (American Society of Civil Engineers, 2009). Additionally, corporate America is continuing to spend billions if not trillions annually on constructing new facilities and infrastructure for their growing organizations. But, how much are they budgeting for facility and infrastructure repairs? Will corporate America be facing the same low grades as the rest of America for their facilities and infrastructure over the next several years?

Background

Maintaining facilities and infrastructure is an important part of any large organization; in fact, these expenses can become one of the largest investments made in both the public and private sectors (Lufkin, Desai, & Janke, 2005). According to the Building Research Board (1998), only approximately 5-10% of the facility costs are the

actual construction, with 60-85% of the costs being attributed to operations, maintenance and upgrades. The Department of Defense (DoD) is no exception with over 577,000 buildings and structures located at more than 5,300 sites worldwide (GAO, 2008). The Air Force alone has budgeted approximately \$2 billion per fiscal year (FY) from 2008 to 2010 to maintain its facilities to include buildings, runways, roadways, and other infrastructure (e.g., water/electrical lines).

Previous studies have been conducted to determine the best method to properly estimate the amount of funding that is required to maintain DoD facilities (e.g., Hickman, 2008); however, in 2003, the DoD implemented the “facilities sustainment model (FSM)” as the standard for maintenance funding DoD-wide (GAO, 2008). The adoption of the FSM has greatly improved the Air Force’s budgeting consistency over the past several years. Thus, the financial expenditures (or obligations) for facility sustainment are not quite to the level recommended by the FSM. As shown in Table 1, the Air Force obligated less than the FSM recommended amount in 2005 through 2007. This delta between the obligation amounts and the FSM represents what the Government Accountability Office (GAO) refers to as “deferred maintenance” (GAO, 2008).

Table 1. Attainment of Sustainment Goals (GAO, 2008)

Component	Fiscal year 2005		Fiscal year 2006		Fiscal year 2007		Fiscal year 2008	
	Goal	Actual	Goal	Actual	Goal	Actual	Goal	Budgeted
Army	95	64	95	88	95	73	100	89
Navy	95	90	95	79	95	92	100	83
Air Force	95	78	95	84	95	88	100	90
Marine Corps	95	94	95	126	95	113	100	89
DOD-wide*	95	79	95	91	95	90	100	88

Source: DOD.

*Also includes data from the Tricare Management Activity and the DOD Education Activity.

Definition of Terms

Before explaining the problem statement, it is essential to define a few Air Force specific financial terms as they relate to this research.

Facility sustainment – “This category of work provides resources for annual maintenance and scheduled repair activities to maintain the inventory of real property assets through its expected service life. It includes regularly scheduled adjustments and inspections, preventive maintenance tasks, and emergency response and service calls for minor repairs. It also includes major repairs or replacement of facility components (usually accomplished by contract) that are expected to occur periodically throughout the facility life-cycle. This work includes regular roof replacement, refinishing of wall surfaces, repairing and replacement of heating and cooling systems, replacing tile and carpeting, and similar types of work. Not included is the repair or replacement of non-attached equipment or furniture, or building components that typically last more than 50 years (such as foundations and structural members). Sustainment does not include requirements funded elsewhere, such as restoration, modernization, environmental compliance, historical preservation or costs related to unexpected events” (Department of the Air Force, 2003).

Restoration and modernization (R&M) – “Restoration includes repair and replacement work to restore facilities damaged by inadequate sustainment, excessive age, natural disaster (storm damage), fire, accident, or other causes. Modernization includes alteration of facilities solely to implement new or higher standards (including regulatory changes), to accommodate new functions, or to replace building components that

typically last more than 50 years (such as foundations and structural members). R&M also includes mission beddowns” (Department of the Air Force, 2003).

While both of these funding avenues are used for facility projects, there is a key distinction between the two, which is generally maintaining versus repairing. Figure 1 illustrates the specific breakout of program element codes that are used to distinguish between the activities. As depicted in Table 2, facility sustainment is more commonly referred to as “maintenance,” defined as element of expense investment code (EEIC) 521 and “repair (life-cycle),” defined as EEIC 524. Restoration and modernization are mostly referred to as “repair (non-life-cycle)” or EEIC 522 and “minor construction” or EEIC 529. This research, however, will primarily focus on the life-cycle repair component (EEIC 524) and non-life-cycle repair (EEIC 522). The minor construction portion, EEIC 529, of facility projects usually involves construction of an addition or altering a facility’s use, which would be considered a discretionary expenditure instead of one to bring a facility up to standards, as in the traditional repair definition (Department of the Air Force, 2003).

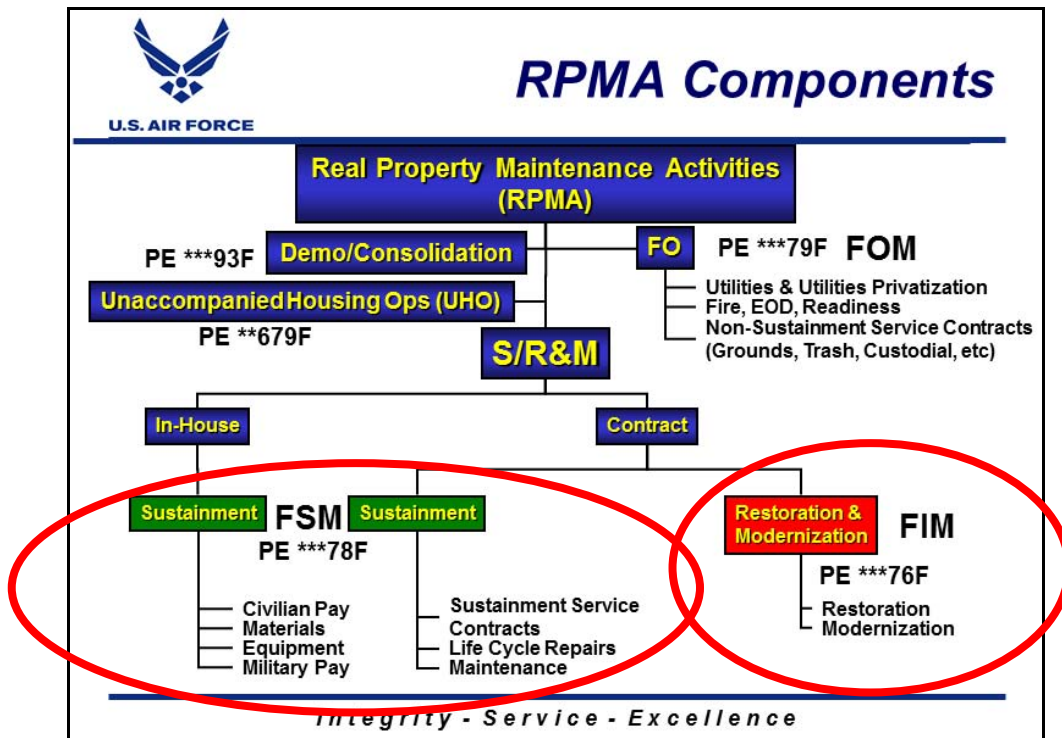


Figure 1. Real Property Maintenance Activity (RPMA) Funding (Petty, 2007)

Table 2. EEICs (Department of the Air Force, 2003)

Work Classification	Description	EEIC	PE Fund Source
Maintenance	See Paragraphs 4.1.1. and 6.1.1.1.	521	PE ***78 Sustainment
Repair (Life Cycle)	See Paragraphs 4.1.2. and 6.1.1.1.	524	PE ***78 Sustainment
Repair (Non-life cycle)	See Paragraphs 4.1.2. and 6.1.1.2.	522	PE ***76 R&M
Minor Construction (Construction < \$750K)	See Paragraphs 5.1.2. and 6.1.1.2.	529	PE ***76 R&M

NOTE: First three digits (***) of the Program Element (PE) are MAJCOM and mission area specific.

Problem Statement

Since 2003, the DoD has instructed the services to budget for no less than 90% of the FSM. In meeting this directive and balancing budgets within the services, the DoD

has underfunded facility maintenance requirements by more than \$3.5 billion in just three FYs, 2005 to 2007 (GAO, 2008). The impact of underfunding the facility maintenance of DoD facilities is unknown, especially as they deteriorate at an increased rate.

Research Objectives

Assuming that the FSM is accurate in calculating the Air Force's maintenance requirements, the goal of this research was to develop a predictive model to determine future Air Force facility repair costs using a regression analysis of cost expenditure data from FY03 to FY10. The resulting model should provide some insight into the effects of decisions made to underfund maintenance requirements. The research objective is to develop a funding advocacy tool to aid Air Force decision makers in supporting the facility sustainment program. In order to accomplish this, the research attempted to determine the relationship, if any, between programs by analyzing the financial expenditure data.

Assumptions / Limitations

There were several assumptions required to conduct this type of research. First, the FSM, as adopted by the DoD, is accurate in defining the required sustainment costs for Air Force facilities. Second, the data in the Air Force's Automated Budget Interactive Data Environment System (ABIDES) and the Commander's Resource Integration System (CRIS) represent accurate expenditures in the expense category (EEIC) that they are recorded. Lastly, the Air Force base level engineer organizations are choosing to fund

the appropriate repair projects at their installation and that political implications made at base or command level will only have a minimal impact on the overall data.

The single largest limitation of this research was that the overall resources are constrained by the overall DoD budget. Therefore, it is unreasonable to say that all our facility repair requirements are being (or ever will be) completely funded. Due to the research focusing on FY03 to FY10 execution data, another limitation will be accounting for the impact of the time lag while facilities have missed or deferred maintenance. This time period was selected to ensure consistency of the data from the point when the FSM was implemented, in 2003, as to not unnecessarily skew the results of the model. Additionally, the lag time between missed maintenance and necessary repairs may pass beyond the window of the reliable data currently available.

Organization

The rest of this paper presents a literature review, methodology, results and analysis, and conclusions and recommendations. The literature review in Chapter II outlines some of the models currently used to determine facility repair funding requirements as well as previous research conducted on the subject. Lastly, the chapter summarizes the possible analysis methodologies. Chapter III includes a detailed discussion of the methodology while Chapter IV focuses on the data analysis. Lastly, Chapter V contains a summary of the results and recommendations.

II. Literature Review

This chapter summarizes the literature relative to this research effort. The information is divided into six sections: 1) a discussion of facility deterioration, 2) description of types of Air Force funding, 3) a review of budget estimation models, 4) a brief overview of the FSM, 5) a discussion of deferred maintenance, and 6) an introduction to the concept of an alternative approach. Through the course of the literature review, it was important to include perspectives of the corporate sector as well as the government perspective.

Facility Deterioration

Concern with facility deterioration began emerging in the 1980s, marking 35 to 40 years after the end of World War II. Choate and Walter (1981) highlighted, to the American public, the current deteriorated condition of the U.S. infrastructure. Since then, we have seen numerous other cries for help to include Grant (1995), who shares several daunting figures as they relate to the infrastructure deterioration. One of his examples was, “more than 10,000 dams are classified as high hazard.” Additionally, Okada, Fang, and Hipel (2001) assert that “infrastructure systems in industrialized nations have been deteriorating.” Our nation has witnessed a continuous deterioration of the Eisenhower Interstate system and bridge collapses such as the 1997 I-35W Mississippi River bridge in Minneapolis, Minnesota, further highlight the need for additional attention on infrastructure. In 2009, the American Society of Civil Engineers assigned grades to each

of the major infrastructure categories in America. These grades were conveyed in a report card format, depicted in Figure 2, with an overall infrastructure grade of D (American Society of Civil Engineers, 2009). More specifically to the DoD, Hamner (2002) claims, “United States military installations’ infrastructure has reached an alarming state of deterioration.”



Figure 2. America's Infrastructure Report Card (American Society of Civil Engineers, 2009)

Facilities deteriorate or decay at different rates based on several factors such as age, size, type of construction materials, type and frequency of use, location, design, and environmental conditions. One of the more obvious factors is of course, facility age. The older a facility is, the more likely it is going to need some additional maintenance or even

repairs to continue its useful life expectancy. Another major determinant of deterioration is the type of construction. A facility made of concrete may not need repair as soon or as often as a facility made of timber. Other factors such as type and frequency of use can either shorten or lengthen the facility maintenance timeline (Christian & Pandeya, 1997). Given proper construction, the same type of roadway that is driven on by only light vehicles will not need maintenance and repairs as soon as one with semi-truck traffic would. Therefore, the light vehicle roadway could conceivably increase the interval between maintenance with minimal impact to the overall roadway performance.

These different facility factors play a large part in determining the specific need for different maintenance and repair activities at different times (Durango & Madanat, 2002). Christian and Pandeya (1997) define maintenance as “the effort to keep a device or system in working condition.” They also note that the deterioration process can be reduced by timely maintenance. For this reason, numerous models have been constructed by the corporate and military sectors to attempt to provide detailed maintenance schedules and representative cost predictions for maintaining their facilities. When it comes to actual allocation of financial resources for maintenance is where the problems begin. Corporate management typically views maintenance budgets as being excessive and perhaps a waste of money while facility management views the budgets as being too meager (Christian & Pandeya, 1997). Viewed in this way, corporate executives will often overlook the long term impact of maintenance budget decisions in an effort to improve the company’s short term bottom line. This short mindedness will have a lasting and potentially unfortunate impact on the company’s facilities. Before describing the

current budget estimation models, it is important to note how the Air Force categorizes their funding as it relates to maintenance and repair.

Types of Air Force Funding

Congress has directed that the DoD divide their facility budgets into distinct expense categories: 1) maintenance and repair, where sustainment expenditures are captured, 2) unspecified minor construction, or restoration and modernization expenditures, and 3) Military Construction (MILCON). These classes of work have detailed descriptions which help Air Force Civil Engineers categorize all facility requirements on an installation. MILCON projects are line-item approved at the congressional level and therefore have very distinct funding. On the other hand, maintenance, repair, and unspecified minor construction projects all compete for Operations and Maintenance (O&M) funding (Department of the Air Force, 2003). All these project requirements are rolled up into an enterprise-wide system database called the Automated Civil Engineer System (ACES) where project information is linked with the Real Property records for every facility on an Air Force installation. Currently under development at the Air Staff, the Air Force Civil Engineering community is constructing a replacement enterprise-wide system to leverage current commercial software platforms. At the time of this research, the “NexGen IT System” was due to be implemented via spirals starting in 2012 (Byers, 2010).

While this research focuses primarily on the maintenance and repair categories of work, it is important to understand that unspecified minor construction and MILCON can

have a significant impact on the levels for other types of funding. Additionally, it should be noted that expenditures to modify or construct new facilities such as minor construction and MILCON will alter the overall life-cycle costs required and therefore change the maintenance and repair requirements for those facilities affected by the alterations or new construction. Take for instance a maintenance hangar that was originally used for C-130 aircraft being altered because of a new C-17 fleet being assigned. The renovation project for the hangar could effectively reset the maintenance and repair requirements for some aspects of the building like the heating, ventilation, and air conditioning, but not affect the schedule for roof maintenance and repairs. This is just one relatively simple example of how the repairs alter the estimates for future work on the facility.

Budget Estimation Models

Ottoman, Nixon, and Lofgren (1999a) classify budget estimation models into four categories: 1) plant value, 2) formula budgeting, 3) life-cycle cost, and 4) condition assessment. The first three models were previously described by Melvin (1992), whereas the fourth category was attributed to The National Research Council's Building Research Board report (1993) and the 1990 U.S. Army Construction Engineering Research Laboratory report.

Ottoman, Nixon, and Lofgren (1999a) assigned categories to gain a better understanding of the types of commonly accepted models. The first approach, the plant value model, is a method of estimating future maintenance or sustainment costs based on

the original construction costs. Facilities that have been renovated would have those costs added to the overall valuation of the facility (Ottoman, Nixon, & Lofgren, 1999b). To ensure costs are representative, this approach either corrects the costs by the average inflation rate or changes the costs to the replacement value. For example, prior to the implementation of the current models, the Air Force would budget their sustainment costs as one percent of the plant replacement value (PRV). The industry average for this method is 2-4% of the PRV which is designed to cover routine maintenance and renewal expenditures (Kaiser, 1995).

The second approach is the formula-based methodology which uses mathematical equations to determine an estimate for facility sustainment costs. Without getting into the details of the numerous formula-based models, the models use variables such as facility age, facility size, original facility construction costs, and type of construction when records are available. The majority of the models are based on a 50-year design life (Cole, 2003). The life-cycle cost method, the third approach, takes a much deeper look at facilities and subdivides them into subsystems or components such as electrical, heating, ventilation, and air conditioning (HVAC), and roofs. This method requires complex tracking and is typically controlled by a building management system (BMS) or building information model (BIM). Cole (2003) explains, “this life-cycle cost methodology is very useful for determining sustainment requirements, but is not able to estimate restoration requirements if proper sustainment is not accomplished.” The last method is the condition assessment. In this method, the facility management teams would assess each system and estimate the required sustainment. This methodology requires intensive

labor and therefore is best suited for companies with a smaller infrastructure footprint (Cole, 2003).

Other researchers have used different terminology to describe similar models. According to Neely and Neathammer (1991), there are five types of facility maintenance prediction models: 1) average of actual expenditures, 2) resources by facility age, 3) facility component description, 4) facility age, and 5) life-cycle cost models. After an 8-year effort, their research cited specific reasons to use each individual model but continued to poke several holes in each one as to their specific usefulness as a prediction of future maintenance costs. The researchers conclude that the best prediction model is the facility component description; however, they point out that this model requires the most detailed inputs to include facility type, age, and date of last repair of major facility systems (e.g., roofs and exterior/interior finishes).

Despite great technological advances in computer programs and systems over the last two decades, the fundamental problems that plague predictive models have remained the same, i.e., using complex data to provide accurate results. This complex data takes a significant amount of time and effort to gather and input into the models and has a tendency to quickly become out of date. To further complicate things, rising utility costs, changing economic conditions, and unforeseen budget constraints can “make accurate future cost predictions difficult” (Christian and Pandeya, 1997).

As with Neely and Neathammer’s (1991) research, many of the Air Force’s budget estimation models were developed for a specific purpose. This research is not challenging the accuracy of the existing models; instead, it is intended to serve as a

baseline for consideration for developing a new predictive model. Accurately quantifying future facility funding requirements continues to be a problem for commercial industry and it is no different in the DoD (Christian & Pandeya, 1997). The Air Force specifically has adopted several methods to capture reliable data to use in various models that ultimately are used to defend the budget. The ACES program feeds a multitude of data to the major commands (MAJCOMs), and the Air Staff where Civil Engineer programmers develop strategies to defend proposed budget levels to the Installation Support Panel and ultimately to the Air Force Corporate Structure. For sustainment requirements, the Air Force uses the FSM, as adopted by the DoD.

Facility Sustainment Model (FSM)

One of the models currently used by the DoD, and an integral part of this research, is the FSM. The DoD mandated the use of the FSM for budgeting sustainment requirements in fiscal year 2003 (GAO, 2008). Once implemented, the original sustainment budget requests increased from the previous 1% of PRV to approximately 1.3% PRV, a \$600 million increase. Directly following the implementation, it was found that installations were redirecting facility sustainment funding to pay for restoration and modernization projects due to underfunding during the mid to late 1990s (Cole, 2003). Since the original implementation, the DoD has adjusted their requirements and currently requires the services to budget for at least 90% of the FSM. However, for FY12, “the Air Force will drive additional efficiencies by funding Facility Sustainment to 80 percent of the FSM” (Department of the Air Force, 2011). By budgeting for and spending less than

100% of the FSM on sustainment, the Air Force is accepting risks as it relates to their facilities.

Deferred Maintenance

The term “deferred maintenance” came about in the 1970s when facility managers recognized the deteriorated state of their facilities. Hutson and Biedenweg (1989) define deferred maintenance as:

The accumulation of physical plant components in need of repair brought about by age, use, and damage from natural causes, and for which remedies have been postponed beyond the useful life of the system. Often, these corrections have been postponed due to insufficient funds. A continued underfunding for facilities renewal results in inadequate building renewal and increases the deferred maintenance backlog.

A further definition of deferred maintenance offered by Kaiser (1995) is, “maintenance work that has been deferred on a planned or unplanned basis to a future budget cycle or postponed until funds are available.” One major problem with deferring maintenance is the compounding effect or backlog it can leave for the facility owner, as illustrated in Figure 3. When an organization continues to underfund maintenance requirements, the deferred maintenance backlog will continue to grow year after year. If funds are not able to be directed toward eliminating the backlog, portions of the facilities will continue to breakdown prior to reaching the design life expectancy, thereby causing additional repairs to systems (Kaiser, 1995).

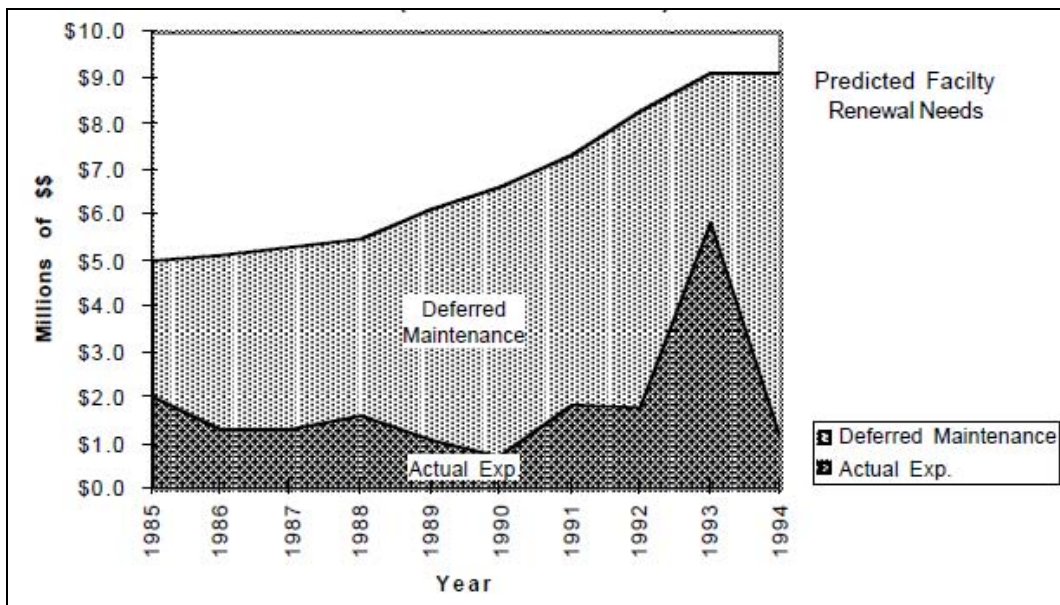


Figure 3. Example of Deferred Maintenance Backlog (Hutson & Biedenweg, 1989)

These definitions are consistent with the current view in the U.S. government as reported by the GAO to highlight the risk taken by the DoD when it comes to maintaining their facilities (GAO, 2008; GAO, 2009). Over the last decade, the GAO has published numerous reports concerning facility sustainment funding within the DoD, taking a critical look at the DoD's efforts to improve facility funding standards by implementing the FSM and tracked the services' abilities to fund to those levels. The GAO has also specifically mentioned the DoD's lack of ability to track and address deferred maintenance (GAO, 2008).

According to Vanier (2001), deferred maintenance does not only take into account the sum of the annual maintenance deficits, but should also account for the compounding effect of this deferment. This is a critical point, and one that is seemingly often overlooked by budget decision makers. Repairing a system that is broken is much more

expensive than performing routine maintenance. De Sitter (1984) claims repair costs will be five times the original maintenance costs conducted at the appropriate time. De Sitter continues to describe that if the repair windows are missed, then the restoration costs are also five times the original repair costs, called the “Law of Fives.”

Depending on the size of an organization’s physical plant, keeping track of maintenance timelines can be a daunting task. To further complicate the task, facility managers must also be able to quantify to decision makers the impact when these required maintenance windows are missed, whether it be from underfunding or oversight. One of the foundational diagrams to illustrate the implications of the underfunding of facility maintenance is the “Lost Service Life Due to Inadequate Sustainment model,” shown in Figure 4 (National Research Council, 1993). The figure illustrates the idea that funding the facility sustainment program at less than 100% of the requirement will result in a “lost capability or cost to restore.” This figure is also a representation of the GAO’s discussion on deferred maintenance as already introduced.

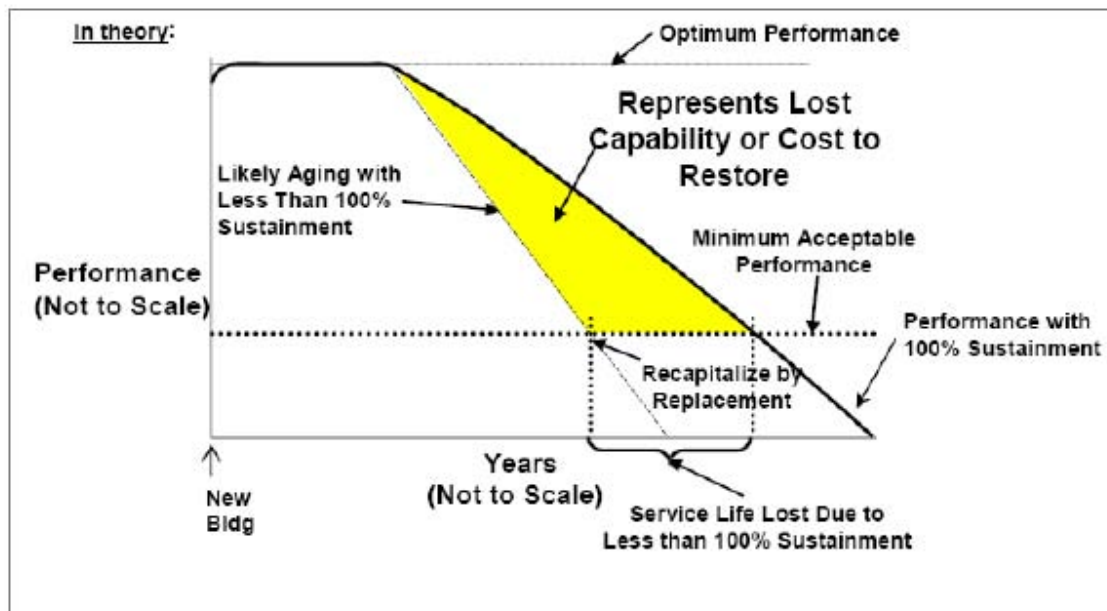


Figure 4. Lost Service Life Due to Inadequate Sustainment (National Research Council, 1993)

As Figure 4 is theoretical, there is no numerical data presented; however, this concept establishes that there is an impact of missing these maintenance windows. The difficult part of this theoretical model is to quantify the “lost capability or cost to restore” or “deferred maintenance.” Naturally, deferred maintenance has gone too far when failure occurs. Failure as defined by Lemer (1996) is when the “performance falls below levels that decision makers judge to be unacceptable, i.e., the infrastructure is ineffective or too likely to become so within the near future or costs are too high.” Air Force Civil Engineers, worldwide, strive to prevent these failures from happening, despite a sustainment budget consistently below the requirements and continually deep budget cuts. The DoD sometimes opts to defer facility sustainment and repair funding to fund weapon system modernization, personnel, training, and quality-of-life initiatives

(Ottoman, Nixon, & Lofgren, 1999a). This research effort focused on quantifying these costs in the form of predicting the future repair requirements to maintain a certain level of sustained performance.

Alternative Approach

This research effort focused on establishing an alternative approach to predicting future repair costs. During her thesis research on budgeting methodologies for facility recapitalization, referred to as restoration and modernization in this research effort, Hickman (2008) noted that “one convincing area that is under-researched is the amount of future cost that could be avoided by execution of properly timed maintenance or recapitalization projects.” She also pointed out that most research performed on deferred maintenance tends to be qualitative in nature. Christian and Chan (1993) claim that historical costs can significantly reduce inaccuracies in predicting maintenance and repair costs. By focusing on a quantitative approach using actual financial figures, the current research effort aims to attain a more commonly accepted and defensible model that can withstand external criticism.

The underlying theme from the literature reviewed was that there is a relationship between funding sustainment at less than 100% and increased future repair costs. With the exception of De Sitter’s (1984) “Law of Fives,” previous research has not revealed any commonly accepted methods to determine the magnitude of the long term effects of deferring maintenance. By focusing on this funding gap as a primary variable, the intent is to develop an easy to use model that offers facility managers and organizations a

predictive model for the future repair costs that could be avoided by fully funding their maintenance requirements.

III. Methodology

This chapter discusses the methodology necessary to explore the possible relationships between several independent variables and future repair costs. The selected methodology was multiple linear regression. Models of this type take the form (McClave, Benson, & Sincich, 2008):

$$y = \beta_0 + \beta_1x_1 + \beta_2x_2 + \dots + \beta_kx_k + \varepsilon$$

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 ε is the random error component. There are three assumptions that must be met to meet the goal of least squares multiple regression, expressed as:

$$\text{Min } \sum \varepsilon^2$$

where ε is the random error component. The first assumption is that the random error component be normally distributed with a mean of zero. Secondly, that it has a constant variance; and, lastly, that it be probabilistically independent (McClave, Benson, & Sincich, 2008).

The chapter is divided into six main sections which correspond to the model development steps, as depicted in Figure 5. The first section is developing the database, which involves determining the sources of data to be analyzed. The second step is selecting the variables of interest for the regression analysis. The third step is to focus on the significant predictors which will ensure the appropriate variables are being utilized within the model. The fourth step is to build the predictive model. The fifth step is to

validate and test the model. Finally, the sixth step is to use the model to make predictions (Cole, 2003).

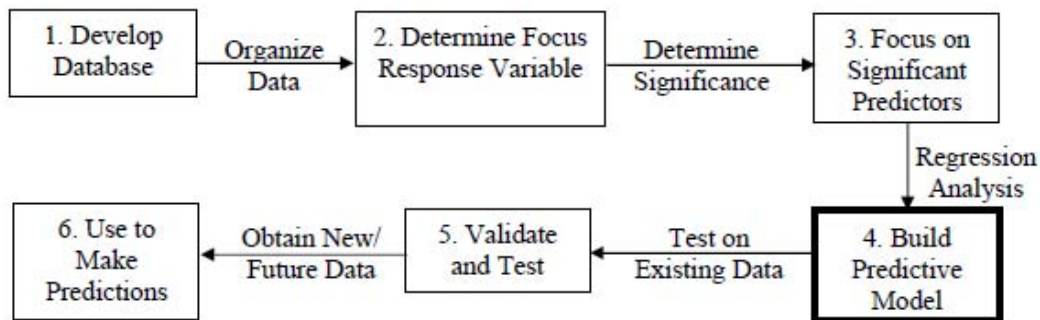


Figure 5. Model Building Process (Cole, 2003)

Step 1: Develop the Database

The review of literature showed that many models have been developed over the last two decades to predict future maintenance and repair costs. Of the ones specifically developed for the Air Force, many models relied heavily on data from the Automated Civil Engineer System (ACES). While this data represents the current requirements as input by Air Force Civil Engineers worldwide, it also has a tendency to contain outdated and even some incorrect information. Additionally, the data in ACES can be easily manipulated by adding phantom projects which could negatively or positively impact the overall results of the models. Instead of using ACES, the data for this research was gathered from two of the primary financial data systems that the Air Force currently uses, the Automated Budget Interactive Data Environment System (ABIDES) and the Commander's Resource Information System (CRIS).

Both systems provide Air Force financial obligation data by fiscal year and provide a further breakdown of the funding expenditures by MAJCOM, base, and unit level. Additionally, the data systems provide an EEIC that can be used to dissect the obligations into the dependent and independent variables. As with any large database that reconciles large amounts of data, the integrity of the data may be partially flawed or incorrectly coded. Through the research, it will be assumed that the data as presented in ABIDES and CRIS are accurate. The largest advantage of using these two data sources is that the data from these systems represent the official Air Force position as it is reported to the U.S. Congress.

The data from ABIDES and CRIS will first be subdivided by fiscal year and then into Program Element Code (PEC) to sort out the sustainment expenditures from other financial obligations. The PECs will then be broken down even further to EEIC level which will separate maintenance from minor repair activities. Other factors that were considered were major command, direct or contingency funding, and storm damage.

Step 2: Selecting the Variables

As pointed out in the previous chapter, the main research focus revolved around the concept of deferred maintenance and what impact making the decision to defer maintenance will have for future facility repairs. Therefore, one of the independent variables for this model development was deferred maintenance. For the Air Force, this can be defined as the difference between the FSM and actual sustainment obligations for any given fiscal year. Since the model is attempting to predict the future repair expenses,

the dependent variables will be the repair costs, defined as EEIC 522 and 524 expenses for the Air Force. Through the model development process, particular components of expenses were analyzed to ensure the model provided the best possible predictive ability.

To obtain the deferred maintenance figures, the actual sustainment expenditures obtained from ABIDES or CRIS were subtracted from the FSM requirement for each fiscal year. This delta was then compared against the next several fiscal years of repair costs (EEIC 522 and 524). To ensure data integrity and a simplified model, the obligation data were directly extracted from the ABIDES and CRIS financial databases.

Step 3: Focus on Significant Predictors

The multiple regression model developed in this research was designed to help predict the future repair costs and it is anticipated that there is an association with underfunding/under executing the facility sustainment program. To more accurately represent the data, supplemental funding for contingency operations, such as Operation IRAQI FREEDOM and Operation ENDURING FREEDOM, and repairs due to damage caused by natural disasters, such as Hurricane Katrina, were removed. These expenses should not be related to deterioration of facilities due to lack of maintenance funding and therefore should not contribute to the repair cost prediction. While deferred maintenance was anticipated to be one of the key predictors, numerous other financial variables were considered. During the analysis, categories such as major command were also evaluated to determine if these factors help improve the prediction capabilities of the model. Other factors were also considered as needed to strengthen the model.

Step 4: Build Predictive Model

During this step, regression analysis was performed based on the data collected in the previous steps. While focusing on the significant predictors, the main focus during this step of the process was to determine a rough time period or lag/delay that occurs between the variables and the relational repair expenditures. Several methods were used to determine if a relationship existed by examining individual fiscal years and MAJCOM groupings. Grouping the expenditure data was expected to smooth out some of the spikes which may have a positive or negative impact to the model results.

Step 5: Validate and Test Model

Once the model was constructed and had some consistent variable coefficients for the regression, the predictive capability of the model was evaluated based on the expenditure data available from FY03 to FY10. This step established the accuracy of the prediction capability of the model. The model's estimation was then compared with actual historical data to enhance the credibility of the model. Due to the unavailability of FSM data prior to implementation in FY03, there was limited data available for the model development which may affect the reliability of the predictions.

Step 6: Use to Make Predictions

The overall purpose of this research effort was to provide predictions of future repair costs within a certain confidence interval tolerance. By using FY03 to FY10 data, the model attempted to predict Air Force wide facility repair expenses for the future. The data could provide the necessary justification to continue sustainment funding in accordance with the FSM. Ultimately, the results from the model may assist the Air Staff, specifically the Installation Support Panel, in justifying existing budget levels and preventing cuts to facility maintenance budgets in future fiscal years.

IV. Results and Analysis

This chapter summarizes the development of a predictive model for facility repair costs using previous fiscal years expenditure data. The data collection section discusses the source of data and the steps used to select the variables for the regression analysis. The remainder of the chapter explains the iterative modeling process used to determine the best possible model.

Data Collection

The data was extracted from ABIDES and CRIS and represent the official Air Force obligation position. During the first round of analysis, the independent variables were: 1) sustainment obligations, 2) FSM, 3) deferred maintenance, and 4) maintenance (EEIC 521). The dependent variable was the repair cost (EEIC 522, 523, and 524). As of 2007, EEIC 523 was deleted; however, to ensure the integrity of data, it was included in the repair category for historical reasons (Air Force Civil Engineer Support Agency). To increase the number of cases for the regression, the data was categorized by MAJCOM and FY. While the data could be considered a pooled data or panel data set due to its time component, it was only analyzed as a cross-sectional data set to ensure the number of cases were large enough to provide accurate results. The deferred maintenance variable was computed and was defined as:

$$\text{Deferred Maintenance} = \text{FSM} - \text{Sustainment Obligations}$$

To match the rest of the data, both figures had to be categorized by MAJCOM and FY. The FSM breakout was provided by HQ AF/A7C and the sustainment obligations were pulled from ABIDES and CRIS databases. To ensure data integrity, contingency operations and storm damage expenditures were excluded from the variables. Removing these categories that are unrelated to normal facility deterioration provided a more accurate comparison of expenditures.

After analysis of the regression output, it was discovered that there may be a multicollinearity issue with the variables due to overlap of specifically the FSM, sustainment obligations, and deferred maintenance costs. The data for the independent variables was then categorized by EEIC in the following groups as shown in Table 3: 1) maintenance (EEIC 521), 2) minor construction (EEIC 529), and 3) deferred maintenance. It was also determined that another variable should be added to analyze the impact of the overall budget; this variable was called “total obligations” and represented the sum of all CE related O&M expenditures. This included Facility Operations, Sustainment, Restoration & Modernization, Environmental Quality, Demolition, Unaccompanied Personnel Housing Services, Chemical Biological Radiological and Nuclear, and RED HORSE programs. The reason for adding the additional variable was to determine if the overall funding levels affect the ability of the model to predict repair costs. Other models currently being used do not rely on prior expenditure data; and therefore, are not impacted by the funding actually allocated.

Before computing the revised regression model, an analysis to identify trends in the data was conducted using the fitted line plot for the data prior to any lag adjustments.

The overall trend over the last eight FYs shows a decrease in the amount of repair obligations (Figure 6). Likewise, the trend for the same eight FYs show a decrease in the deferred maintenance costs (Figure 7). These observations in and of themselves are not sufficient evidence of any correlation of these two variables, but they serve as a basis for obtaining a better understanding of these variables as they relate to actual time.

Table 3. EEIC Categories

EEIC Category	COST-CAT GRP	COST-CAT CODE	COST-CAT DESCRIPTION
Maint	521	COST-CAT 52100	SUSTAINMENT MAINTENANCE PROJECTS
		COST-CAT 52101	SUST MAINT - ARMY CORPS, NAVFAC, AFCEA
		COST-CAT 52102	SUST MAINT - PROTECTIVE COATING
		COST-CAT 52104	SUST MAINT - SABER
		COST-CAT 52105	SUST MAINT - PAVEMENTS
		COST-CAT 52106	SUST MAINT - UTILITIES
		COST-CAT 52110	SUST MAINT - HAZ WASTE MGMT TREAT
		COST-CAT 52120	SUST MAINT - UNDERGROUND STORAGE TANK COMPLI
		COST-CAT 52130	SUST MAINT - AIR POLLUTION COMPLIANCE
		COST-CAT 52150	SUST MAINT - WASTE WATER TREATMENT
		COST-CAT 52160	SUST MAINT - ASBESTOS ABATEMENT
		COST-CAT 52170	SUST MAINT - GROUND WATER MONITORING
		COST-CAT 52171	SUST MAINT - PESTICIDES
		COST-CAT 52172	SUST MAINT - RADIATION
		COST-CAT 52174	SUST MAINT - PCBS W/O LEAD
		COST-CAT 52175	SUST MAINT - LEAD BASED PAINT
		COST-CAT 52180	SUST MAINT - HOST NATION ENV COMP
		COST-CAT 52190	SUST MAINT - OTHER POLLUTION PREVENTION
		COST-CAT 52195	SUST MAINT - ALL OTHER AS A CLASS OF WORK
		COST-CAT 521XT	SUST MAINT - ANTI-TERRORISM/FORCE PROTECTION
Repair	522	COST-CAT 52200	RESTORE & MODERNIZATION REPAIR PROJECTS
		COST-CAT 52201	RESTORE & MOD - ARMY CORPS, NAVFAC, AFCEA
		COST-CAT 52202	RESTORE & MOD - BUILDINGS
		COST-CAT 52203	RESTORE & MOD - OTHER
		COST-CAT 52204	RESTORE & MOD - SABER
		COST-CAT 52206	RESTORE & MOD - PAVEMENTS
		COST-CAT 52208	RESTORE & MOD - EQUIPMENT PROCUREMENT
		COST-CAT 52210	RESTORE & MOD - HAZ WASTE MGMT TREAT
		COST-CAT 52216	RESTORE & MOD - HAZ WASTE REDUCT INITATIVES
		COST-CAT 5221A	RESTORE & MOD - AWARD FEES
		COST-CAT 52220	RESTORE & MOD - UNDERGROUND STORAGE TANKS
		COST-CAT 52230	RESTORE & MOD - AIR POLLUTION CONTROL
		COST-CAT 52232	RESTORE & MOD - AIR EMISSIONS PREVENTION
		COST-CAT 52240	RESTORE & MOD - DERA W/O LBP
		COST-CAT 52250	RESTORE & MOD - WASTE WATER TREATMENT
		COST-CAT 52260	RESTORE & MOD - ASBESTOS ABATEMENT
		COST-CAT 52270	RESTORE & MOD - GROUND WATER MONITORING
		COST-CAT 52271	RESTORE & MOD - PESTICIDES
		COST-CAT 52274	RESTORE & MOD - PCBS W/O LBP
		COST-CAT 52275	RESTORE & MOD - LEAD BASED PAINTS
		COST-CAT 52280	RESTORE & MOD - HOST NATION COMPLIANCE
		COST-CAT 52290	RESTORE & MOD - OTHER POLLUTION PREVENTION
		COST-CAT 52295	RESTORE & MOD - OTHER AS CLASS OF WORK
		COST-CAT 522XT	RESTORE & MOD - ANTI-TERRORISM/FORCE PROTECT
	523	COST-CAT 52300	RENOVATION MAINTENANCE PROJECTS
		COST-CAT 52370	RENOVATION - GRD WATER MONITORING COMPLIANCE
	524	COST-CAT 52390	RENOVATION - OTHER
		COST-CAT 52400	FACILITY SUSTAINMENT MODEL REPAIR PROJECTS
		COST-CAT 52401	FSM REPAIR - ARMY CORPS, NAVFAC, AFCEA
		COST-CAT 52404	FSM REPAIR - SABER
		COST-CAT 52416	FSM REPAIR - ENGINE SHOP SOLVENT TANK
		COST-CAT 52424	FSM REPAIR - OTHER
		COST-CAT 524XT	FSM REPAIR - ANTI-TERRORISM FORCE PROTECTION
		COST-CAT 52700	FSM REPAIR - IN-HOUSE REPAIR PROJECTS
Minor Const	529	COST-CAT 52800	MINOR CONSTRUCTION - IN-HOUSE
		COST-CAT 52810	MINOR CONSTR -IN-HOUSE - LESS THAN 15K
		COST-CAT 52900	MINOR CONSTRUCTION BY CONTRACT
		COST-CAT 52901	MINOR CONSTR - ARMY CORPS, NAVFAC, AFCEA
		COST-CAT 52904	MINOR CONSTR - SABER
		COST-CAT 52910	MINOR CONSTR - HAZ WASTE MGMT TREATMENT
		COST-CAT 52914	MINOR CONSTR - EPA 17 REDUCTION INITATIVES
		COST-CAT 52915	MINOR CONSTR - SOLID WASTE REDUCTION
		COST-CAT 52920	MINOR CONSTR - UNDERGROUND STORAGE TANK
		COST-CAT 52930	MINOR CONSTR - AIR POLLUTION
		COST-CAT 52950	MINOR CONSTR - WASTE WATER TREATMENT
		COST-CAT 52970	MINOR CONSTR - GROUND WATER MONITORING
		COST-CAT 52971	MINOR CONSTR - PESTICIDES
		COST-CAT 52975	MINOR CONSTR - LEAD BASED PAINT
		COST-CAT 52990	MINOR CONSTR - OTHER POLLUTION PREVENTION
		COST-CAT 52995	MINOR CONSTR - ALL OTHER MC PROJECTS
		COST-CAT 529XT	MINOR CONSTR - ANTI-TERRORISM FORCE PROTECT

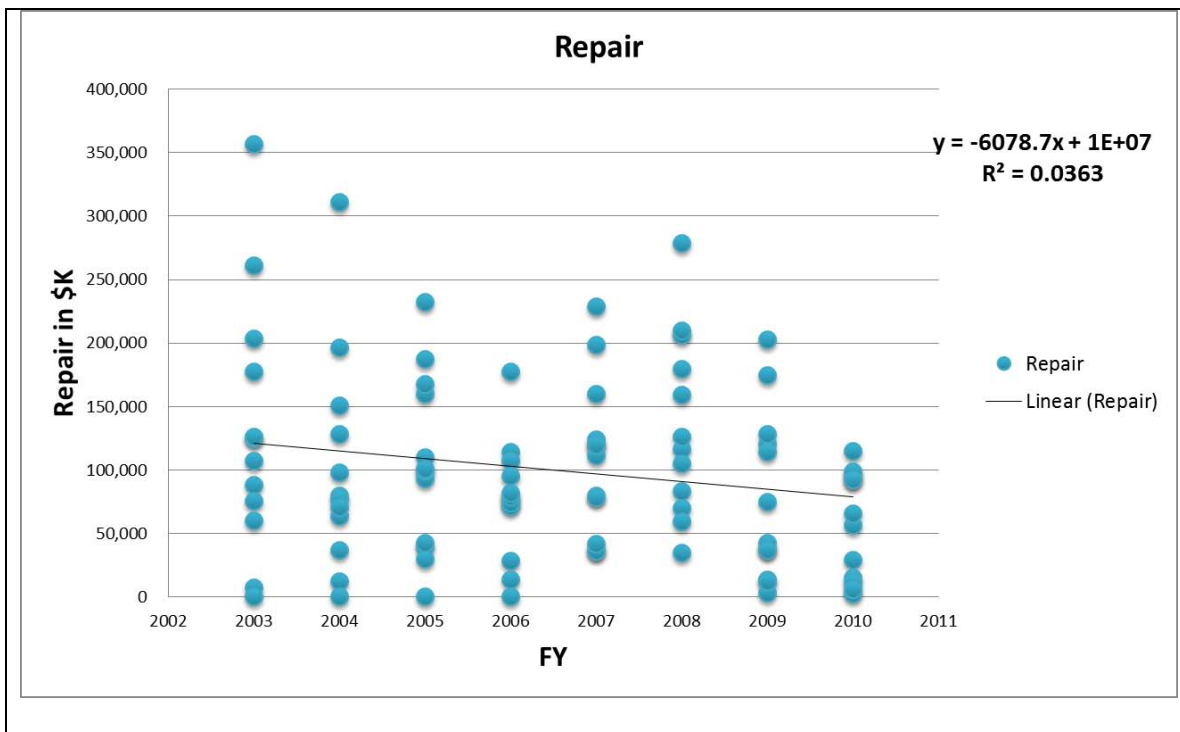


Figure 6. Repair Cost Trend Line

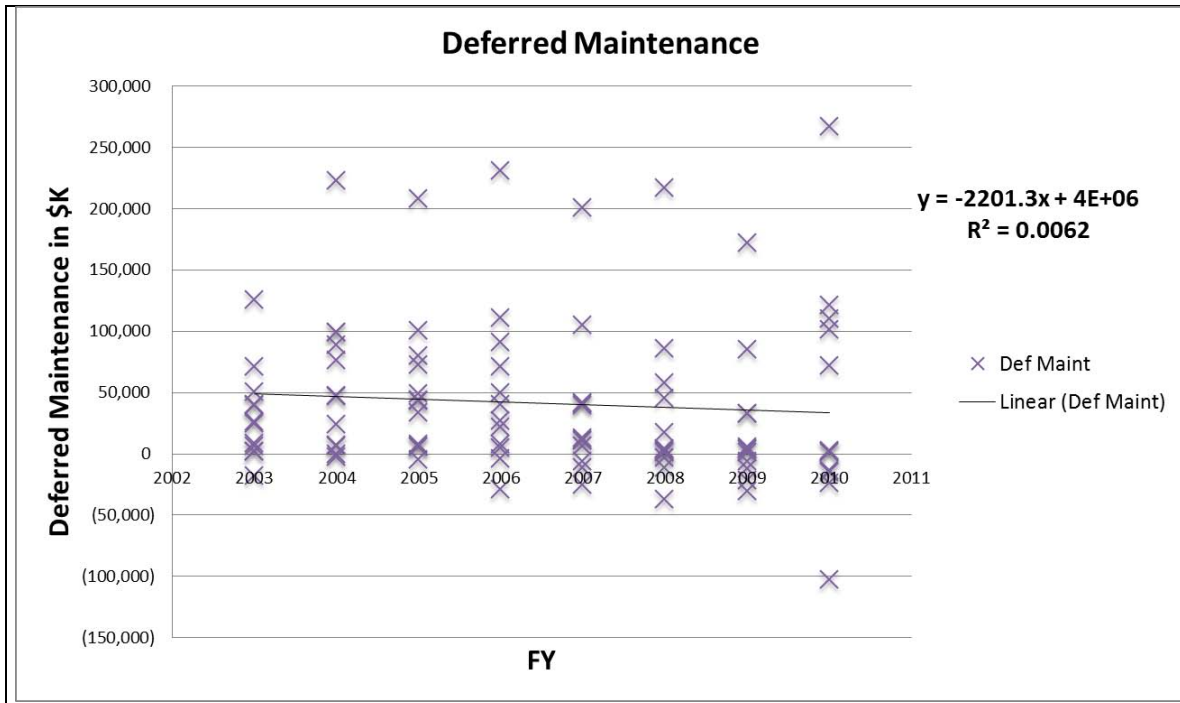


Figure 7. Deferred Maintenance Trend Line

Iterative Process of Modeling

As mentioned in the methodology chapter, multiple linear regression is an iterative process. Because the model attempted to predict future expenditures, a time lag was introduced. For example, the FY03 expenditure data was used to predict the FY04 repair variable for a 1-year lag as depicted in Figure 8. This process was repeated for up to 5 lag years. The purpose of using the time lag was to determine which data has the best relationship to future repair costs. As discussed during the literature review, underfunding maintenance in one year may not lead to an associated repair bill until some number of years into the future.

		Total Obs	Maint	Minor Const	Def Maint	Repair	
FY03	PACAF	782,027	12,070	42,738	125,730	260,890	
	AFMC	756,956	20,664	9,625	26,477	107,106	
	ACC	1,016,803	11,677	63,002	40,037	203,556	
	USAFE	519,166	6,829	51,647	24,752	124,568	
	AFSPC	502,404	10,871	18,787	39,378	88,008	
	AETC	641,147	6,068	29,075	8,656	177,611	
	AMC	740,870	10,193	44,227	71,223	356,884	
	USAFA	117,065	2,361	2,311	(17,739)	60,163	
	AFSOC	39,866	821	5,838	1,500	7,185	
	AFDW	0	0	0	5,940	0	
	ANG	563,627	9,904	34,509	50,142		
	AFR	299,374	2,828	18,295	1,845		
FY04	PACAF	563,473	6,381	8,730	222,997		
	AFMC	724,604	6,823	7,762	76,351		
	ACC	1,025,878	9,539	168,772	88,386		
	USAFE	416,796	4,963	22,600	24,207		
	AFSPC	494,851	7,773	13,429	99,246		
	AETC	520,266	3,164	21,252	47,421		
	AMC	505,007	8,189	23,363	99,026		
	USAFA	95,289	1,811	5,388	6,978		
	AFSOC	69,268	591	5,272	(2,934)		
	AFDW	0	0	0	6,585		
	ANG	540,405	25,619	41,914	46,548		
	AFR	284,821	4,480	26,475	(541)		

FY04 150,765
 79,629
 310,742
 76,897
 63,386
 97,725
 196,683
 37,022
 11,880 0
 128,012

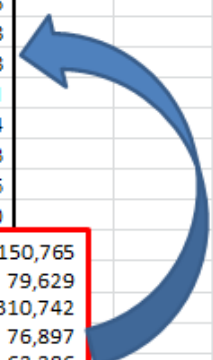


Figure 8. Illustration of 1-Year Lag

This study used the SPSS software package to conduct the multiple regression analysis. During the original model development, the statistical analysis indicated that only the FSM variable contributed significantly to the predictive model during multiple lags. After further evaluation, it was noted that a number of the variables contained portions of other variables causing a multicollinearity issue. As discussed previously, new variables were chosen that did not overlap which were total obligations, maintenance, minor construction, and deferred maintenance. With the new variables, the regression was again performed for each of the lag years, first via the software's enter regression method. The results are summarized in Table 4.

Table 4. Enter Regression Method Results

	Repair									
	1 Year Lag		2 Year Lag		3 Year Lag		4 Year Lag		5 Year Lag	
Regression - Enter	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Constant (\$K)	20,825.79	0.047	21,189.54	0.049	25,409.68	0.026	27,967.75	0.047	21,189.54	0.049
Total Obs	0.108	0.000	0.109	0.000	0.07	0.032	0.065	0.000	0.109	0.000
Maint	0.205	0.684	0.589	0.285	0.707	0.262	1.072	0.684	0.589	0.285
Minor Const	0.388	0.151	0.3	0.270	0.467	0.100	0.625	0.151	0.3	0.270
Def Maint	0.322	0.002	0.255	0.018	0.414	0.001	0.322	0.002	0.255	0.018
R-Squared	0.516		0.525		0.55		0.522		0.525	
Adjusted R-Squared	0.492		0.497		0.517		0.277		0.497	
Durbin-Watson	1.385		1.293		1.382		1.219		1.271	

From the regression results, maintenance and minor construction do not appear to be significant predictors of repair in all five lag years, as indicated by p-values greater than 0.05. However, both total obligations and deferred maintenance have p-values of less than 0.05 for all five lag years. For the next step, the regression was conducted again using the software's stepwise regression method, where the software will analyze the significance of the predictability of each variable and exclude variables which do not

contribute significantly. The stepwise regression model results are provided in Table 5. As expected, the two insignificant variables were eliminated during the regression, leaving total obligations and deferred maintenance as the two significant predictors of repair.

Table 5. Stepwise Regression Method Results

	Repair									
	1 Year Lag		2 Year Lag		3 Year Lag		4 Year Lag		5 Year Lag	
Regression - Stepwise	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value	Coefficient	p-value
Constant (\$K)	20,307.98	0.053	21,128.77	0.049	24,366.76	0.032	26,433.11	0.063	22,042.81	0.194
Total Obs	0.132	0.000	0.136	0.000	0.111	0.000	0.154	0.000	0.149	0.000
Maint										
Minor Const										
Def Maint	0.299	0.003	0.229	0.030	0.376	0.002				
R-Squared	0.503		0.509		0.519		0.432		0.414	
Adjusted R-Squared	0.491		0.495		0.502		0.42		0.397	
Durbin-Watson	1.5		1.293		1.355		1.365		1.174	
VIF	1.232		1.278		1.296		1		1	

Proposed Model

This study used SPSS's stepwise regression to determine the best linear predictor given the input variables. The software selected the most statistically significant independent variables and assigned a coefficient to each. The final model in equation form is (in thousands of dollars):

$$\text{Repair} = 24,366.76 + 0.111x_{1(t-3)} + 0.376x_{2(t-3)}$$

where $x_{1(t-3)}$ is the Total Obligations (CE O&M Only) and $x_{2(t-3)}$ is the Deferred Maintenance, with both variables being measured in the FY from 3 years ago.

Test the Proposed Model

As described in the methodology section, multiple linear regression models must meet three assumptions for the model to be considered valid. The first assumption is that the random error must be normally distributed with a mean of zero. This assumption was satisfied based on the histogram of the random error as illustrated in Figure 9. The second assumption is that the error component has a constant variance. A scatter plot of the residuals shows that generally there is generally constant variance of the error component as depicted in Figure 10.

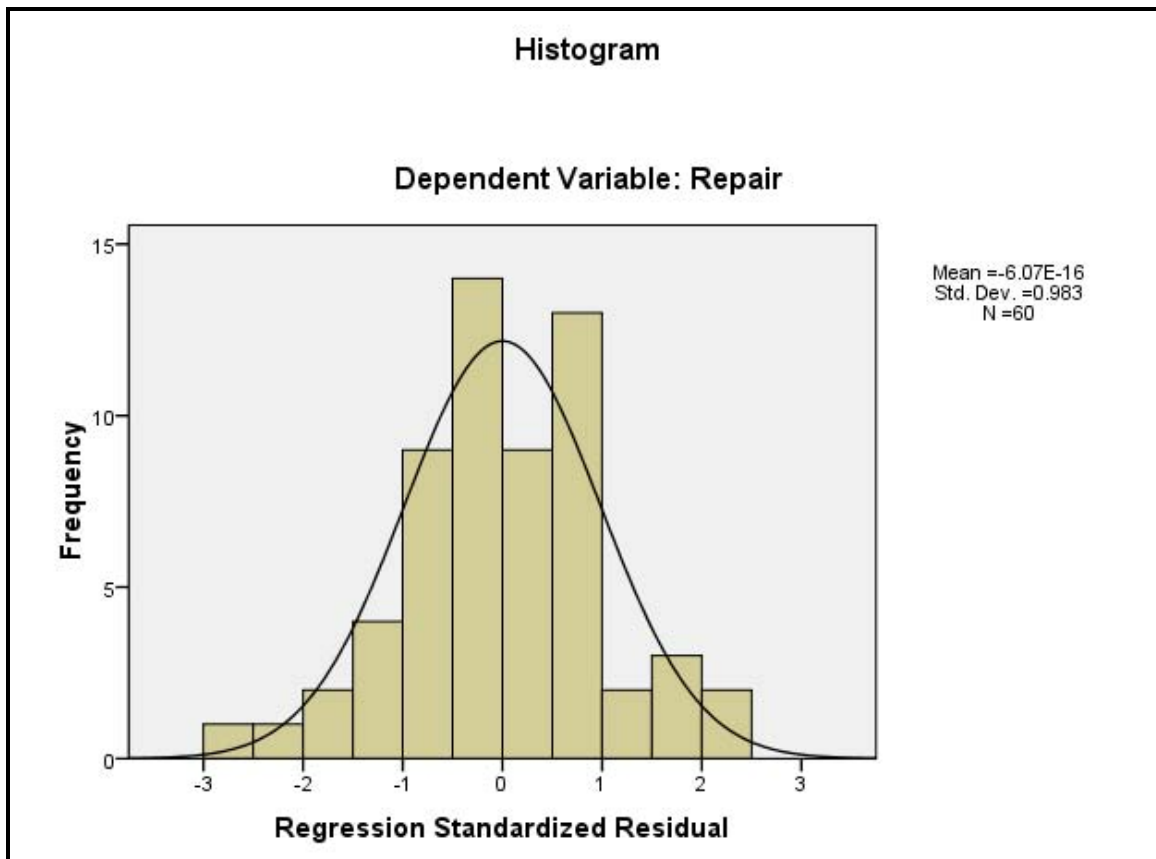


Figure 9. Regression Standardized Residual

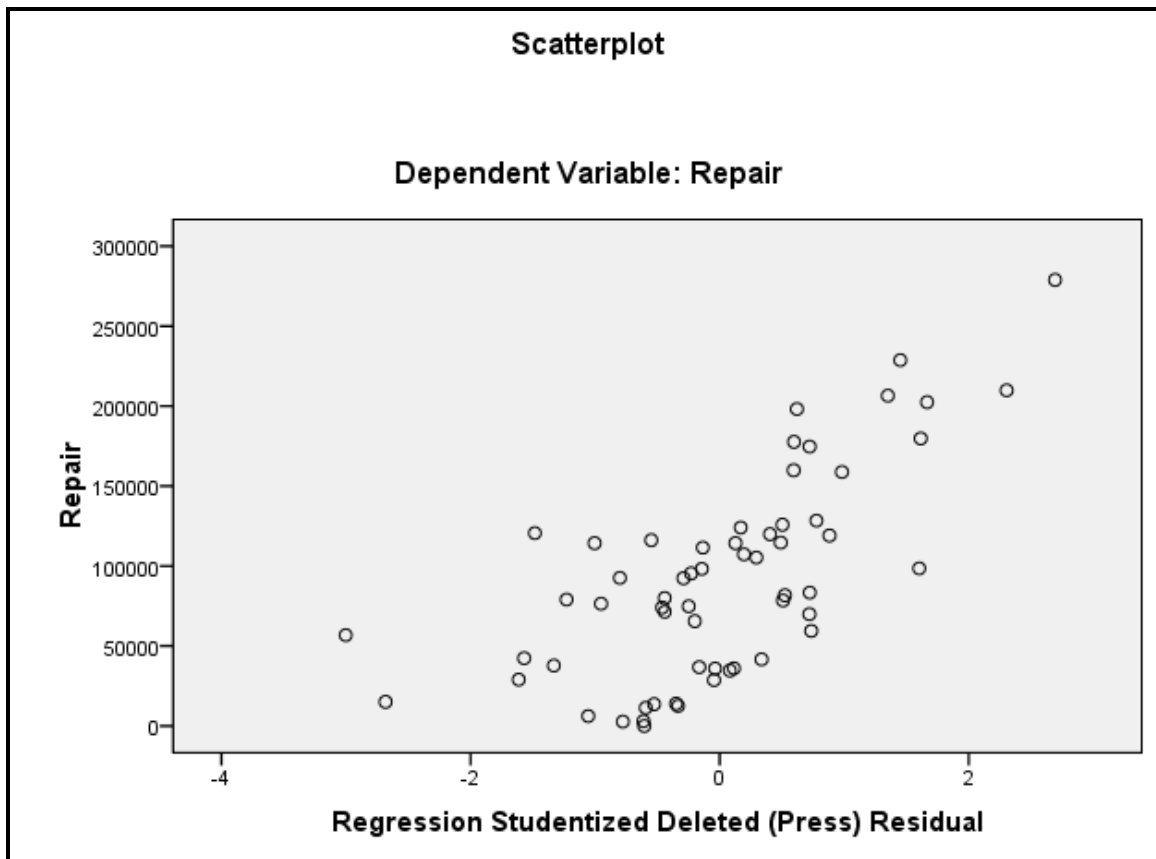


Figure 10. Regression Studentized Residual

The third of the primary assumptions is that the error be probabilistically independent or that the errors are uncorrelated. Due to the lagging effect of using prior year funding data, there was a concern of autocorrelation (Neter, Kutner, Wasserman, & Nachtsheim, 1996). To check for correlation between the error terms, the model used the Durbin Watson test. According to Neter et al. (1996),

A major cause of positively auto correlated error terms in business and economic regression applications involving time series data is the omission of one or several key variables from the model. When time-ordered effects of such mission key variables are positively correlated, the error terms in the regression model will tend to be positively auto-correlated since the error terms include effects of missing variables.

The Durbin-Watson test checks the null hypothesis ($H_0: \rho = 0$) that autocorrelation does not exist against the alternative hypothesis ($H_a: \rho > 0$) that autocorrelation does exist. In this case, ρ is the autocorrelation parameter. The Durbin Waston test statistic formula is:

$$d_{pd} = \frac{\sum_{i=1}^N \sum_{t=2}^T e_{i,t} - e_{i,t-1}^2}{\sum_{i=1}^N \sum_{t=1}^T e_{i,t}^2}$$

The value for d_{pd} is compared against a table of upper and lower bounds based on the number of regressors, excluding the intercept. If d_{pd} is less than the lower bound, then the alternative hypothesis is accepted. If d_{pd} is greater than the upper bound, then the null hypothesis is accepted. Lastly, if d_{pd} is between the lower and upper bounds, then the test is inconclusive (Montgomery, Peck, & Vining, 2001).

At the 99% confidence interval ($\alpha = 0.01$), for two regressor variables and $n = 60$, the lower limit is 1.351 and the upper limit is 1.484. Based on the 3-year lag, the d_{pd} was 1.355. Because this value is between the lower and upper limits, the test is inconclusive. The next stage of analysis in the case of possible autocorrelation is to determine if there are any other important regressor variables. In this particular case, all of the predictors have been exhausted. Because of the inconclusive results, it is possible that the model is not the best linear unbiased estimator of the dependent variable. It is likely, but not able to be determined that the time series data has created the possible autocorrelation.

Given the possibility of autocorrelation, the model was further examined for multicollinearity. According to Montgomery, Peck, & Vining (2001), there are four primary sources of multicollinearity: 1) data collection method employed, 2) constraints

on the model or in the population, 3) model specification, and 4) an overdefined model. From previous analysis of the raw data in Figures 6 and 7, the data collection does not appear to be a concern. Secondly, a check of the relationship between the variables determined to be significant in the model is necessary to ensure they are not causing multicollinearity. In Figure 11, the repair costs are plotted based on the deferred maintenance values. The scatter plot shows that there is no general linear relationship between the raw data. Additionally, in Figure 12, the repair costs were compared to total obligations. For this comparison, there is a general relationship, but the values do not appear in a straight line which would be an indication of multicollinearity. This was also checked using the Durbin-Watson tests in the assumptions verification step. Lastly, for the second step, a scatter plot was conducted, Figure 13, for the two regressor variables (total obligations and deferred maintenance). These two variables do not have a straight line relationship.

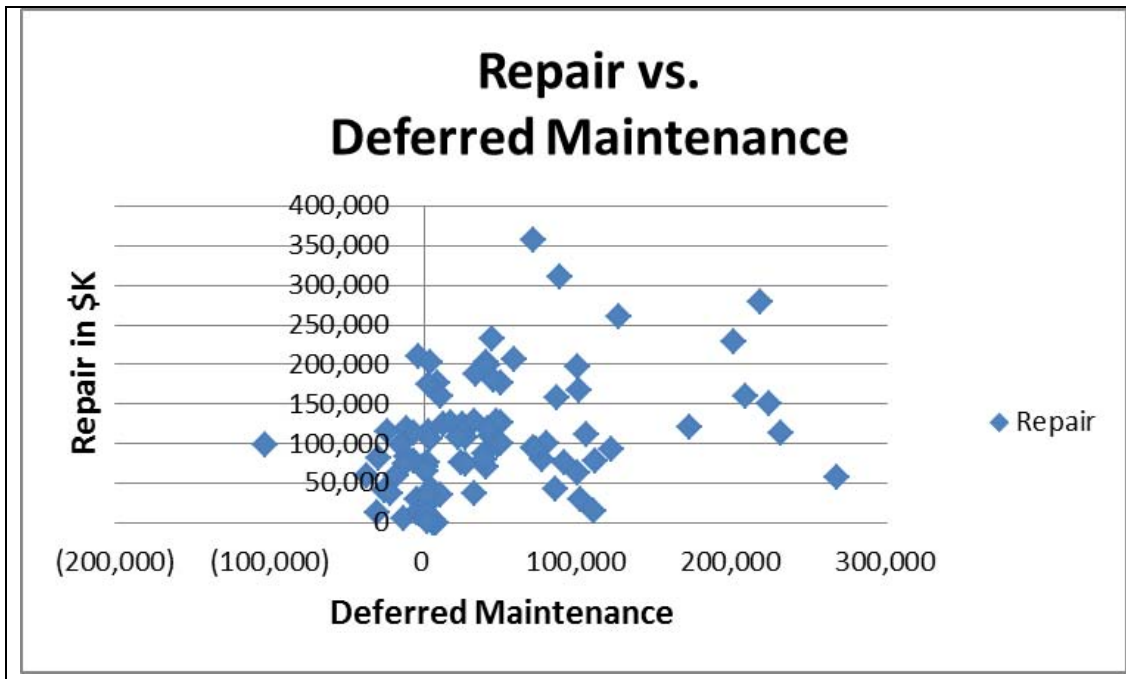


Figure 11. Repair vs. Deferred Maintenance

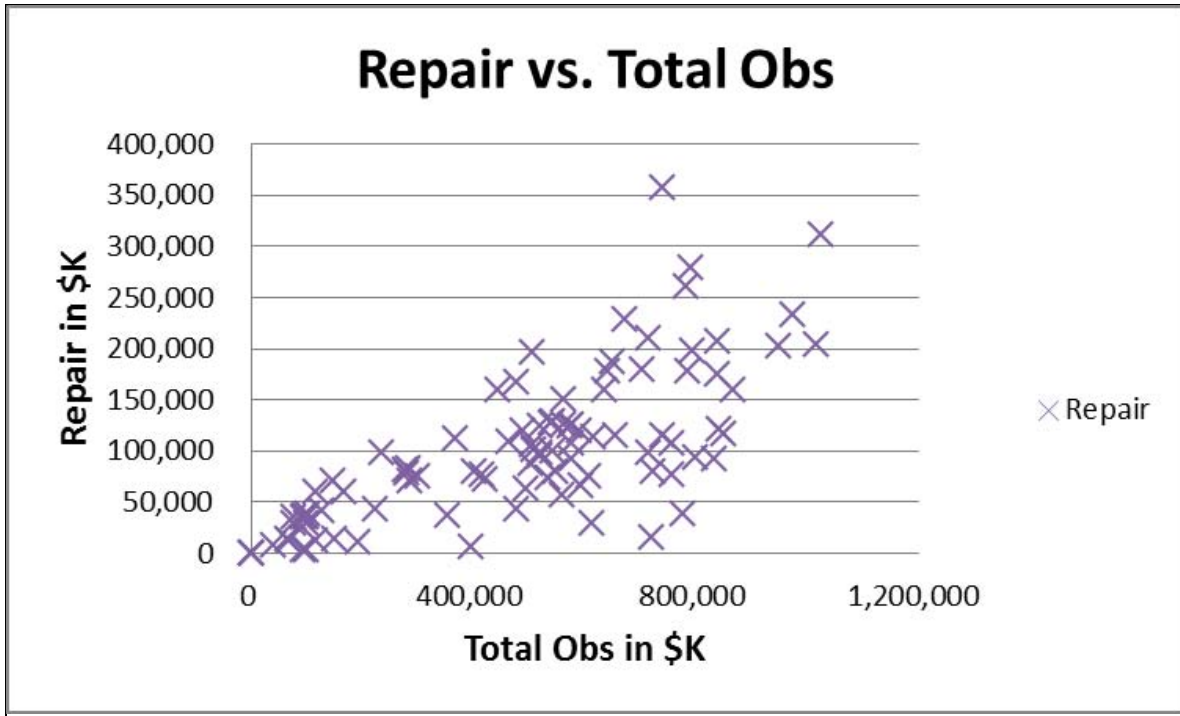


Figure 12. Repair vs. Total Obligations

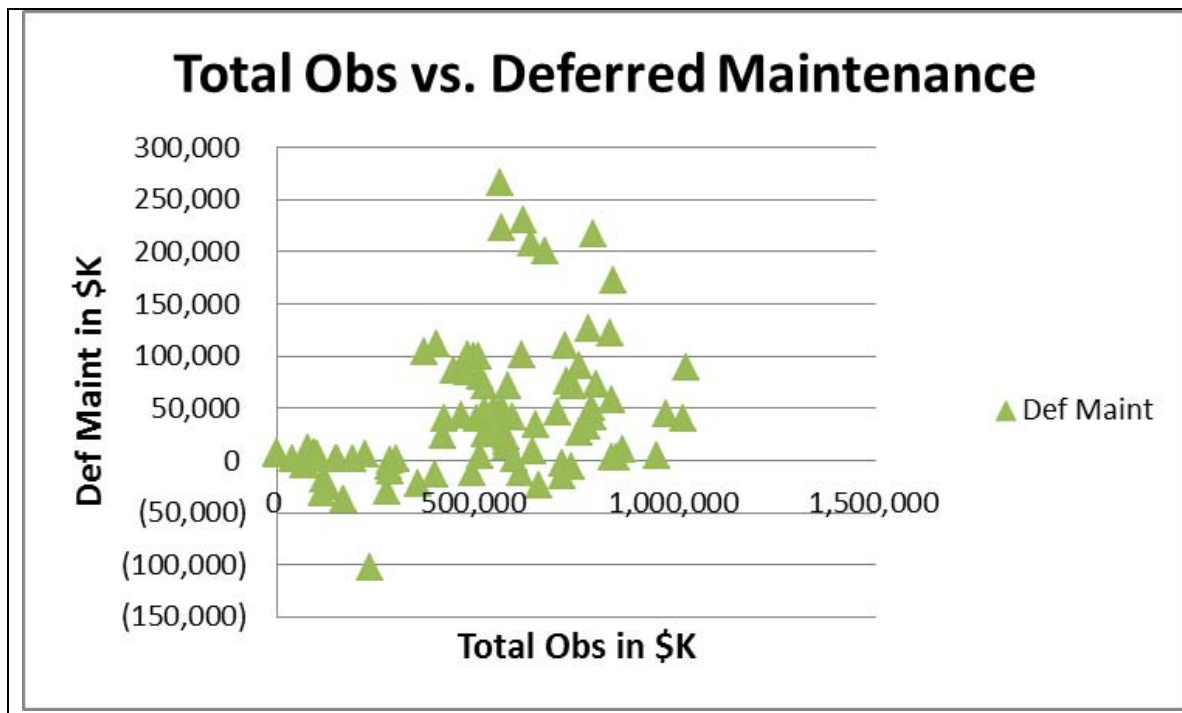


Figure 13. Total Obligations vs. Deferred Maintenance

Now that the model has passed the first two primary sources of multicollinearity, the model was tested for the third primary source. Montgomery, Peck, & Vining (2001) indicate that polynomial variables, especially within a small range, can cause significant multicollinearity. Since this model does not use polynomial variables, it passes this step. The last test was to determine if the model was overdefined, i.e., had more regressor variables than observations. Since there were 60 observations and only 2 regressor variables at a 3-year lag, the model also passed this test. One further check can be conducted by examining the variance inflation factor (VIF). The VIF for the independent variables was 1.296, well below the value of 5.0 for which practical experience indicates multicollinearity issues. The proposed model thus passed all three assumptions, did not

show positive signs of autocorrelation, and passed all the tests for multicollinearity. With the estimates of the regression coefficients stable, the next stage was to apply the model.

Use the Model for Prediction

Given the previous discussion of inconclusive autocorrelation results and the impacts of large variations in budgetary conditions, it is reasonable to assume that application of the proposed model may or may not be accurate depending on funding environment and political factors that could not be replicated in the model. According to McClave, Benson, & Sincich (2008, p. 13-37), regression with time series data “may adequately describe the secular trend of the sales, we have not attempted to build any cyclical effects into the model. Thus, the effect of inflationary and recessionary periods will be to increase the error of the forecasts because the model does not anticipate such periods.” Assuming that the budgetary climate remains fairly stable, the proposed model is reported to be able to predict about 51.9% of the variance in the future repair costs.

Using the model, the FY10 repair costs were estimated as follows:

$$\begin{aligned} \text{FY10 Repair} &= 24,366.76 + 0.111(\text{FY07 Total Obs}) + 0.376(\text{FY07 Def Maint}) \\ &= 24,366.76 + 0.111(5,491,962) + 0.376(424,481) \\ &= \$793,579K \end{aligned}$$

Comparing this with the actual repair expenditures for FY10 of \$682,996K, there is an error of 16.2%. Using the model to predict the FY11 repair costs results in:

$$\begin{aligned} \text{FY11 Repair} &= 24,366.76 + 0.111(\text{FY08 Total Obs}) + 0.376(\text{FY08 Def Maint}) \\ &= \$847,181K \end{aligned}$$

Given that FY11 will not be finished until September 30, 2011, an error cannot yet be determined, but will likely be similar to that of FY10.

V. Conclusions and Recommendations

This chapter discusses the implications and relevance of this research effort along with addressing some of the limitations associated with the model. Additionally, this section presents some recommendations for future research.

Implications for Theory and Practice

This proposed study comes at a very important crossroads of deep DoD budget cuts for FY11 as well as aging infrastructure at the 166 Air Force installations worldwide (Air Force Civil Engineer Support Agency, 2009). The research focus was primarily to advise Air Force leadership of expected future repair costs as a result of underfunding facility maintenance requirements. This information can be used by decision makers to enable the best possible use of limited DoD budgetary resources.

This predictive model is relevant to making sound financial decisions at the corporate Air Force level. Making resource decisions without such a model simply increases the risk of the future impact of those decisions. The Installation Support Panel, which provides budget defense for Air Force Civil Engineers, Air Force Security Forces, and Air Force Office of Special Investigations, will be better prepared to explain to the Air Force Corporate Structure at the Pentagon the long-term ramifications of cuts to the facility sustainment program from the future year budgets.

This predictive model should be transferrable to the civilian sector, although the model would have to be replicated based on other organizations' financial data.

Specifically, city public works offices could use such a model to help defend their maintenance budget in a time where government budget cuts are getting deeper. Additionally, companies with large amounts of infrastructure could also benefit from a similar model. It could help to ensure they invest the appropriate amount of maintenance funding into their facilities and infrastructure to prevent unnecessary deterioration and potentially larger repair costs.

Relevance of Research

Civil Engineers are constantly looking for additional ways to help defend funding requirements to ensure Air Force infrastructure can be properly maintained and, where necessary, repaired. This research effort set out to establish a predictive model for Air Force facility repair costs. The final regression model includes two independent variables that have a significant relationship to repair costs. The original variable of interest, deferred maintenance, proved to contribute toward the model estimation but to a much lesser extent than originally expected. The larger predictor in the model was the overall CE total obligations. This indicates that the overall budget climate has a larger impact on repair expenditures than any of the other variables evaluated. While this limits the applicability of the model, it does help explain large variances in spending within these key maintenance and repair areas.

During the course of this research, some key findings were discovered that civil engineer leaders should consider.

- 1) There is very limited information concerning deferred maintenance within the Air Force. The only data that was able to be obtained for this research, with some difficulty, was the FSM data from previous fiscal years. While the civil engineer community does not seem to dwell on the lack of maintenance resources and instead looks forward to what needs to get done, there may be some benefit of conducting an analysis of the amount of maintenance that is not being funded at an installation, MAJCOM, and Air Force levels.
- 2) While this study could not confirm a very significant impact of deferred maintenance on the overall repair costs, it was very alarming to find that the Air Force has changed its FSM requirement and is now only budgeting for 80% of the model requirement. Given past history that the MAJCOMs typically under obligate the sustainment program, the Air Force may be on a path to spend 70% or less of the actual model requirement. This is great cause for concern as costs for facility repairs are significantly higher than the costs associated with sustaining the facility.

Limitations

While the R^2 value of 51.9% indicated a relatively good predictor of variance, it may also be an indication that there may be other variables not considered in this research that are contributing to the variance. The approach to this analysis greatly differs from the majority of previous research in that this effort focused only on actual financial expenditures. Any large changes in spending can adversely affect this model, thereby

causing the need for a new regression analysis. This is evidenced by the comparison of the predicted values with the actual Air Force facility repair expenditures from FY06 to FY13 in Table 6. When rolled up to total Air Force obligations, the error ranged from 9.74 to 46.37%. Should the Air Force adopt this model, it is recommended that the regression analysis be redone at least every two fiscal years to improve the model's accuracy. Another limitation was due to the deferred maintenance data that was limited to FY03 to FY10. Given this short timeframe, there was not an opportunity to assess the long term impact that deferred maintenance has on the facilities and future costs.

Table 6. Prediction Summary

FY	Repair Costs		
	Predicted	Actual	Error
FY06	830,175	919,801	9.74%
FY07	874,645	1,333,336	34.40%
FY08	873,393	1,628,427	46.37%
FY09	819,101	961,351	14.80%
FY10	793,579	682,996	16.19%
FY11	847,181	TBD	
FY12	845,507	TBD	
FY13	907,391	TBD	

Recommended Future Research

As with any research effort, several opportunities were identified for additional exploration. Specifically, the following three areas are recommended for future study.

- 1) While it was proven in this model that deferred maintenance is not specifically a large predictor of repair costs, the topic is worthy of additional study to determine if a relationship exists to future facility life-cycle costs. With the

current development of the NexGen IT system to track all CE requirements, there is a unique opportunity to include some data fields to start collecting specific data on the subject for future analysis of the long term impact of deferring maintenance.

- 2) Another opportunity would be to include some non-expenditure related variables in the model such as PRV, facility square footage by installation, or facility type and age. A hybrid approach to developing a model with both cost data and other facility information may be the right balance for a better predictive model.
- 3) One last research opportunity would be re-examine the prediction of repair costs using a different methodology. The regression analysis provided varying results which indicates that this approach may not be the best method of establishing a prediction. Other statistical methods may be able to provide more accurate predictions.

Conclusion

Maintaining Air Force facilities remains a challenge, but one that the Civil Engineering community takes on with pride. With upcoming budget constraints, this task will become even more difficult. The recent downward trend on repair obligations should raise some concern over the long term reliability of the Air Force's facilities and their ability to meet mission requirements. Continuing to defer maintenance

requirements could have major consequences on the Air Force's readiness. It is therefore essential to have the tools necessary to defend the sustainment program from further cuts.

The research described in this paper is just one tool in that toolbox. It developed a predictive model for future repair costs with a 3-year outlook. The developed model accounts for 51.9% of the variability of the repair requirements. Given the environmental, political, and economic factors that affect financial decisions, the model provides a solid basis for predicting future costs based on previous expenditures. This could be improved by further research and the introduction of additional variables or continued study, given that this research was limited to just eight fiscal years of data under the FSM.

Overall, this effort has provided insight on the topic and highlighted the need for additional research into the concept of deferred maintenance and the long term impacts it may have for Air Force facilities. Air Force Civil Engineers have a shared goal of ensuring facilities do not deteriorate below the acceptable level to meet mission requirements. The model developed by this research is just one method of helping in that endeavor.

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Vita

Major Gregory A. Morissette graduated from O’Fallon Township High School in O’Fallon, Illinois in 1994. After graduation, he attended Southern Illinois University in Carbondale, Illinois, graduating with a Bachelors of Science in Civil Engineering in 1998. During his time at Southern Illinois University, Major Morissette also conducted officer training through the Detachment 205, Air Force Reserve Officer Training Corps program, earning his commission also in 1998. Major Morissette earned a Master of Science in Management from Troy State University in Troy, Alabama in 2004.

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14. ABSTRACT The Air Force Civil Engineering community spends significant effort maintaining and repairing their infrastructure and facilities at their installations worldwide. They continually search for ways to better illustrate the impact of funding decisions on future infrastructure and facility conditions. The purpose of this research was to develop a predictive model for determining future facility repair costs. The research analyzed current and past funding levels as a possible predictor of future repair costs by way of a multiple linear regression. During the research, one variable of specific interest was deferred maintenance. The results provide a predictive model that can be used to forecast repair costs with a 3-year outlook. Given the environmental, political, and economic factors that affect financial decisions, the model provides a solid basis for predicting future costs based on previous expenditures. The model can be used to help support and defend future Air Force funding decisions and can be adapted for use by non-Air Force organizations.					
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