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

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ABSTRACT

The Air Force Civil Engineering community spends significant effort maintaining and repairing their infrastructure and facilities. 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 used multiple linear regression to analyze current and past funding levels as possible predictors of future repair costs. The results provide a predictive model that provides insight into the effects of underfunded maintenance requirements and serves as an advocacy tool to aid Air Force decision-makers in supporting the facility sustainment program.

INTRODUCTION

In 2009, the American Society of Civil Engineers assigned a grade of D to the nation's infrastructure and concluded that "delayed maintenance and chronic underfunding are contributors to the low grades in nearly every (infrastructure) category" [1]. Although the United States (U.S.) needs $2.2 trillion to invest in its infrastructure, it spends only 2.4% of its gross domestic product on the infrastructure, yet Europe spends 5% and China spends 9% on their respective infrastructures [1]. The Department of Defense (DoD) faces similar challenges and has underfunded facility maintenance requirements by more than $3.5 billion in fiscal years (FY) 2005 through 2007 [8]. Therefore, 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 FY2003 to FY2010.

BACKGROUND

Maintaining facilities and infrastructure can be one of the largest investments made in both the public and private sectors [15]. In fact, only 5-10% of the facility costs are the actual construction, with 60-85% of the costs being attributed to operations, maintenance, and upgrades [2]. The DoD is no exception with over 577,000 structures located at more than 5,300 sites worldwide [8]. The Air Force alone has budgeted approximately $2 billion per fiscal year from 2008 to 2010 to maintain its facilities, also referred to as sustainment in this paper, to include buildings, runways, roadways, and other infrastructure (e.g., water/electrical lines). Many 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., [12]); however, the DoD implemented the facilities sustainment model (FSM) in 2003 as the standard for maintenance funding [8]. The adoption of the FSM has greatly improved the Air Force's budgeting consistency over the past several years. However, the financial expenditures for facility sustainment are not quite to the level recommended by the FSM. This delta between the obligation amounts and the FSM represents what the Government Accountability Office (GAO) refers to as "deferred maintenance" [8]. The remainder of this section provides additional information regarding facility maintenance.

Facility Deterioration

Choate and Walter [3] first highlighted the declining condition of the U.S. infrastructure in 1981. Since then, studies [e.g., 10] have cited evidence that "infrastructure systems in industrialized nations have been deteriorating" [20]. More specific to the DoD, "United States military installations' infrastructure has reached an alarming state of deterioration" [11]. To counter deterioration, Christian and Pandeya [4] define maintenance as "the effort to keep a device or system in working condition" and note that the deterioration process can be reduced by timely maintenance. For this reason, numerous models have been constructed by corporate and military sectors to provide maintenance schedules and representative cost predictions. However, corporate executives often overlook the long-term impact of maintenance budget decisions in an effort to improve the company's short-term bottom line [4]. This short-mindedness could have a lasting and potentially unfortunate impact on the company's facilities.

Budget Estimation Models

Neely and Neathammer [18] reviewed five types of facility maintenance prediction models: average of actual expenditures, resources by facility age, facility component description, facility age, and life-cycle cost models. They concluded that the best model is the facility component description but emphasize that it requires the most detailed inputs. The Air Force's budget estimation models were similarly developed for specific purposes. For sustainment, the Air Force uses the Facility Sustainment Model (FSM) mandated by the DoD in FY 2003. Under the FSM, sustainment budget requests increased by $600 million from 1% to 1.3% of the plant replacement value even though facility sustainment funds were often redirected to pay for restoration and modernization projects [5]. The DoD has since adjusted their requirements and currently requires services to budget for at least 90% of the FSM. However, "the Air Force will drive additional efficiencies by funding Facility Sustainment to 80 percent of the FSM" in FY 2012 [7]. 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, which leads to a discussion on deferred maintenance.

The term "deferred maintenance" came about in the 1970s when facility managers recognized the deteriorated state of their facilities. Hutson and Biedenweg [13] 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.*

Another definition of deferred maintenance is, "maintenance work that has been deferred on a planned or unplanned basis to a future budget cycle or postponed until funds are available" [14]. One major problem with deferring maintenance is the compounding effect or backlog it creates. If funds are not used to eliminate the backlog, portions of the facilities will not reach their design life expectancy, thereby causing additional repairs [14]. These definitions are consistent with findings by the GAO regarding the risks taken by the DoD when maintaining their facilities [8, 9]. One of the foundational diagrams to highlight the impacts of underfunding facility maintenance is shown in Figure 1. The figure conceptually illustrates the thought that funding the facility sustainment program at less than 100% of the requirement will result in a "lost capability or cost to restore." The difficult part of this theoretical model is to quantify the "lost capability or cost to restore" or "deferred maintenance."

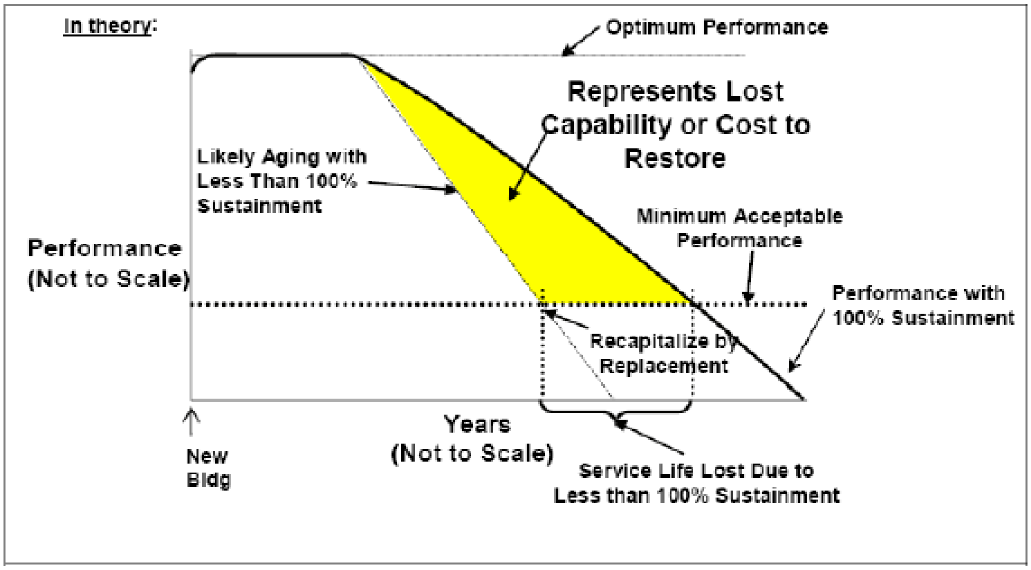

Figure 1. Lost Service Life Due to Inadequate Sustainment [17]

The underlying theme is that there is a relationship between underfunding sustainment and increased future repair costs. An area "that is under-researched is the amount of future cost that could be avoided by execution of properly timed maintenance or recapitalization projects" [12]. With the exception of the "Law of Fives" [6], there does not appear to be any common methods to determine the long-term effects of deferring maintenance. By focusing on this funding gap as a primary variable, our intent is to develop an easy to use model that offers facility managers and organizations a tool to predict future repair costs that could be avoided by fully funding their maintenance requirements.

RESULTS AND ANALYSIS

Data Collection

Models developed to predict future Air Force maintenance and repair costs often rely on data from the Automated Civil Engineer System. Since this data has a tendency to be outdated and incorrect due to manual entry, we gathered our data from two financial data systems, the Automated Budget Interactive Data Environment System and the Commander's Resource Information System. Focusing on maintenance and minor repair activities, the data were categorized by fiscal year, major command, and direct or contingency funding. While the data could be considered a pooled data set due to its time component, it was analyzed as a cross-sectional data set to ensure the number of cases was large enough to provide meaningful results. The dependent variable was the repair cost and the independent variables were sustainment obligations, FSM, deferred maintenance, maintenance, and minor construction. The deferred maintenance variable was defined as the FSM minus sustainment obligations.

Since multicollinearity might be an issue due to the related nature of the financial variables, we categorized the data for the independent variables into three groups: maintenance, minor construction, and deferred maintenance. We also added a variable to analyze the impact of the overall budget; this variable was called “total obligations” and represented the sum of all O&M expenditures. Because the model attempted to predict future expenditures, a time lag was introduced. For example, FY 2003 expenditure data was used to predict FY 2004 repair costs for a 1-year lag. This process was repeated for up to 5 lag years. The purpose of the time lag was to determine which data has the best relationship to future repair costs since underfunding maintenance may not lead to an associated repair bill until some number of years into the future. The regression results, conducted using the stepwise method via forward selection and backward elimination, are summarized in Table 1. As indicated in the table, both total obligations and deferred maintenance have p-values of less than 0.05 for all five lag years. We also performed a multiple regression on the data set with the fiscal years as independent variables with no conclusive results. The final model, based on the 3-year lag, in equation form is thus:

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

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

Table 1. 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	

For linear regression models to be considered valid, the random error term must meet three assumptions: normal distribution with a mean of zero, constant variance, and independence (i.e., uncorrelated). Due to the use of prior year funding, the model was also tested for autocorrelation [19] and multicollinearity [16]. Additionally, the variance inflation factor for the independent variables was 1.296, well below the value of 5.0 for which practical experience indicates collinearity issues. The proposed model thus met all assumptions, did not show signs of autocorrelation, and passed all tests for collinearity. Given the large variation in budgetary conditions, application of the model may or may not be accurate depending on the funding environment and political factors. Assuming the budgetary climate remains fairly stable, the proposed model predicts about 51.9% of the variance in future repair costs.

CONCULSIONS AND RECOMMENDATIONS

The final regression model includes two independent variables having a significant relationship to repair costs. The original variable of interest, deferred maintenance, contributed to the model but to a lesser extent than expected. The larger predictor, overall total obligations, indicates that the budget climate has a larger impact on repair expenditures than any of the other variables evaluated. While the resulting R^2 value of 51.9% indicates a relatively good predictor of variance, it may also be an indication that there are other variables not considered contributing to the variance. Since we focused on actual financial expenditures, any large changes in spending can adversely affect the model. This is evidenced by the comparison of predicted values with actual expenditures shown in Table 2, with the error ranging from 9.74% to 46.37%. Therefore, we recommend that the analysis be accomplished every two fiscal years to improve the model's accuracy. Additionally, given the 8-year timeframe for the data, there was not an opportunity to assess the long-term impact of deferred maintenance on the facilities and future costs.

Table 2. Prediction Summary

	Repair Costs		
FY	**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	

As with most research, several opportunities were identified for additional exploration. Specifically, three areas are recommended for future study. First, while deferred maintenance was not found to be a large predictor of repair costs, it is worthy of additional study as there is limited information concerning deferred maintenance in the Air Force. The only data we could obtain was FSM data from previous fiscal years. Therefore, there may be some benefit to conducting an analysis of unfunded maintenance. Additionally, with the development of the NexGen IT system, there is a unique opportunity to start collecting specific data related to the long-term impact of deferred maintenance. Another opportunity would be to include non-expenditure related variables in the model (e.g., PRV, facility square footage, and facility type and age). A hybrid approach with cost data and other facility information may be the right balance for a better predictive model. Finally, one last research opportunity would be to conduct the analysis 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.

The declining trend for repair obligations may diminish the long-term reliability of the Air Force's facilities. This is compounded by the fact that the Air Force is now budgeting for 80% of the FSM requirement. This is a concern as costs for facility repairs are significantly higher than the costs associated with sustaining the facility. Continuing to defer maintenance could have major consequences on the Air Force's readiness and its ability to meet mission needs. Therefore, it is essential to have 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. This could be improved by further research and the introduction of additional variables or continued study.

REFERENCES

[1] American Society of Civil Engineers. (2009). *2009 Report Card for America's Infrastructure.* Reston: American Society of Civil Engineers.

[2] Building Research Board. (1998). Stewardship of Federal facilities: A proactive strategy for managing the nation's public assets. *National Research Council (Ed.)*. Washington DC: National Academy of Sciences.

[3] Choate, P., & Walter, S. (1981). *America in ruins: Beyond the public works pork barrel.* Washington DC: Council of State Planning Agencies.

[4] Christian, J., & Pandeya, A. (1997, January/February). Cost predictions of facilities. *Journal of Management in Engineering*, 52-61.

[5] Cole, R. C. (2003, March). Analyze the Air Force methods for facility sustainment and restoration. *MS Thesis, Air Force Institute of Technology*. Wright-Patterson AFB, OH: School of Engineering and Management.

[6] De Sitter, W. R. (1984). Costs for service life optimization: The "Law of Fives". *Durability of Concrete Structures Workshop Report* (pp. 131-134). Copenhagen, Denmark: Ed. Steen Rostam.

[7] Department of the Air Force. (Feb 2011). *Fiscal Year (FY) 2012 Budget Estimates, Operations & Maintenance, Air Force.* Washington DC: Secretary of the Air Force, Financial Management.

[8] GAO. (2008). *Defense infrastructure: Continued management attention is needed to support installation facilities and operations (GAO-08-502).* Washington DC: U.S. Government Accountability Office.

[9] GAO. (2009). *Defense infrastructure. DOD needs to periodically review support standards and costs at joint bases and better inform congress of facility sustainment funding issues (GAO-09-336).* Washington DC: U.S. Government Accountability Office.

[10] Grant, A. A. (1995). Civil infrastructure systems: The big picture. *Journal of Infrastructure Systems*, 78-81.

[11] Hamner, R. T. (2002). Installations modernization, quelling the "quiet crisis". *Strategy Research Project, US Army War College*.

[12] Hickman, K. M. (2008, March). A Decision Tool to Evaluate Budgeting Methodologies for Estimating Facility Recapitalization Requirements. *MS Thesis. Air Force Institute of Technology*. Wright-Patterson AFB, OH: School of Engineering and Management.

[13] Hutson, R. E., & Biedenweg, F. M. (1989). Before the roof caves in: A predictive model for physical plant renewal. *Critical Issues in Faciliities Management*, 12-29.

[14] Kaiser, H. H. (1995, September/October). Preventing deferred maintenance. *AIPE Facilities*, 24-31.

[15] Lufkin, P. S., Desai, A., & Janke, J. (2005). Estimating the restoration and modernization costs of infrastructure and facilities. *Public Works Management & Policy, 10*(1), 40-52.

[16] Montgomery, D. C., Peck, E. A., & Vining, G. G. (2001). *Introduction to linear regression analysis* (3rd ed.). New York: John Wiley & Sons, Inc.

[17] National Research Council (U.S.). Committee on Facility Design to Minimize Premature Obsolescence, Donald G. Iselin, Andrew C. Lemer. (1993). *The Fourth Dimension in Building Strategies for Minimizing Obsolescence.* Washington DC: National Academy Press.
[18] Neely, E., & Neathammer, R. (1991). Life-cycle maintenance costs by facility use. *Journal of Construction Engineering and Management, 117*(2), 310-321.
[19] Neter, J., Kutner, M. H., Wasserman, W., & Nachtsheim, C. J. (1996). *Applied Linear Statistical Models* (4th ed.). McGraw-Hill/Erwin.
[20] Okada, N., Fang, L., & Hipel, K. W. (2001). Infrastructure management: New challenges. *IEEE International Conference on Systems, Man, and Cybernetics* (pp. 1211-1217). Tucson: IEEE.