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# EXPEDITIOUS METHOD FOR ESTIMATING CLEANUP COSTS AT DEPARTMENT OF DEFENSE INSTALLATIONS IN KOREA

THESIS

John M. Griffin, Captain

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Presented to the Faculty of the Graduate School of Engineering

Of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the

Requirements for the Degree of

Master of Science in Engineering and Environmental Management

John M. Griffin, Capt

March 1998

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# EXPEDITIOUS METHOD FOR ESTIMATING CLEAN-UP COSTS AT DEPARTMENT OF DEFENSE HAZARDOUS WASTE SITES IN KOREA

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To my wife, Misty, and children, John and Jenna, -- There are no words which can adequately convey my heartfelt appreciation for your endless support, understanding and patience. As you know Dear, I continued to put our family times on the back burner while placing my classes, thesis, and career in front. However, you have given me the encouragement and drive to make it though this program. Thanks.

Last, but not least, recognition goes to my Lord, Jesus Christ. You are "my shield, and the horn of my salvation, my high tower, and my refuge," 2 Samuel 22:3.

John M. Griffin

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## *Abstract*

The purpose of this research was to develop and test a method that can be used to expeditiously estimate costs of hazardous waste site remediation at US DoD installations in Korea for use by decision-makers in developing a hazardous waste site remediation strategy. Specifically, this objective was addressed through answering the following interrelated questions: (1) What cost and time constraints do the decision-makers have in developing remediation cost estimates; (2) What degree of accuracy do the decision-makers require in remediation cost estimates; (3) What estimating models are available for determining costs of remediation activities; (4) Have models been used to estimate costs of remediation activities at Korean installations; and (5) Of the methods/models elicited in question (3), which met the needs of decision-makers as defined in questions (1) and (2)?

A combination of literature review (academic journals, and DoD, Air Force, and USFK directives and policies), personal interviews, and field observations were employed to answer the questions. Model selection was accomplished through qualitative analysis, followed by a case study application of the method chosen. Face and concurrent validity measures were administered to ensure the reasonableness of the cost estimates obtained.

This research resulted in selection of the Remedial Action Cost Engineering and Requirements (RACER) system as a model that can be used to obtain expeditious site specific costs. A polynomial regression model was developed for use in obtaining a rough estimate of costs to remediate an entire installation. These models can be applied to our Korean installations to relatively rapidly provide decision-makers with cost

estimates that can be used for formulating a remediation strategy that meets mission requirements while responding to evolving domestic and international conditions.

# EXPEDITIOUS METHOD FOR ESTIMATING CLEANUP COSTS AT DEPARTMENT OF DEFENSE INSTALLATIONS IN KOREA

## I. INTRODUCTION

### A. Motivation

In December 1997, Captain Edwin Oshiba completed an extensive study of issues relevant to Department of Defense (DoD) hazardous waste sites in Korea. This study concluded that the DoD's current policy regarding hazardous waste site issues in Korea should be reviewed since (1) Korean environmental laws are becoming more stringent, (2) the Korean populace is becoming more environmentally aware, (3) there have recently been examples of restoration at US installations overseas that may set a precedent, and (4) groundwater contamination from hazardous waste sites may degrade wartime capabilities in Korea (Oshiba, 1997).

In the Fiscal Year 1997 Annual Defense Environmental Restoration Program (DERP) Report to Congress, Ms Sherri Wasserman Goodman, the Deputy Undersecretary of Defense for Environmental Security – DUSD (ES), portrayed the importance of environmental stewardship for DoD operations:

> The Defense Department must have an environmental program that protects our troops and families; ... that fulfils our obligation to be good citizens; and that sets a good example to other militaries around the world. (DoD, 1998)

It is prudent that the DoD continue to be proactive in environmental remediation efforts at overseas installations to become that role model. DoD currently limits remediation overseas to those cases where there are "known imminent and substantial endangerments to human health and safety due to environmental contamination" (see

Appendix 1-1). This broad and somewhat ill-defined criterion may be inadequate to guide decision-making at US installations in Korea, as it does not account for the rapidly evolving perceptions of, and the value placed upon, the environment in Korea, changing international precedents, and potential impacts on warfighting capabilities. An overseas remediation policy that does not account for these important issues risks DoD access to the land, air, and sea that is needed for mission accomplishment, along with degradation of warfighting capabilities (Oshiba, 1997).

This current research focuses on "... economic issues associated with remediation policy for Korea ... [to] aid DUSD (ES), United States Forces in Korea (USFK), and Pacific Air Force (PACAF) policy makers in mapping out a future requirements strategy to match cleanup policy" (Oshiba, 1997). Captain Dean Hartman is accomplishing a companion study looking at how to expeditiously characterize and assess risk at hazardous waste sites in Korea. It is the goal of this study, along with the companion study of Captain Hartman's, to provide DoD decision-makers with a methodology that can be used to gather risk and cost data on hazardous waste sites in Korea quickly and cheaply. With these data available, better-informed decisions can be made regarding hazardous waste site remediation at DoD installations in Korea.

Estimates of remediation cost are critical to the development of a sound remediation strategy, particularly at overseas installations where resources for site cleanup are severely constrained. While in the Continental US (CONUS), Defense Environmental Restoration Program (DERP) funds that are specifically designated for remediation are provided to DoD by Congress, use of DERP funds to cleanup overseas installations is prohibited (United States Congress, 1994; United States Congress, 1996). Thus, characterization and remediation of hazardous waste sites overseas must be paid for using operation and maintenance (O&M) funds, so that hazardous waste restoration directly competes with other mission requirements (for example fuel for aircraft, installation utility costs, and other mission essential items). In the years 1993-1996, DoD spent $6.5 billion in DERP funds at US installations, while expending $102 million in O&M funds to characterize and cleanup sites overseas (DoD, 1998; GAO, 1997; GAO, 1996). Presumably, these O&M funds were used to remediate sites that posed "...imminent and substantial endangerments to human health and safety" in accordance with current policy. Thus, although approximately 12% of DoD installations and manpower are overseas, only 1.5% of remediation dollars are expended at overseas installations (DoD, 1998). The DERP has brought about substantial cleanup progress at DoD installations in the US, with Ms. Sherri Goodman, Deputy Undersecretary of Defense for Environmental Security (DUSD (ES)) proclaiming in the Fiscal Year 1997 Annual DERP Report to Congress that DoD was "...at the beginning of the end of our cleanup program" (DoD, 1998). However, as noted above, because of Congressional and DoD policy, progress towards cleanup of DoD overseas installations significantly lags that of installations under the DERP. If, indeed, it becomes necessary to change our cleanup policy in Korea to adapt to the evolving domestic and international situation, and meet mission requirements, we must be able to elicit remediation requirements cheaply and quickly.

Characterization of hazardous waste sites at US bases, which includes risk assessment, and development of remediation cost estimates, varies widely by installation. However, looking at Shaw AFB as an Air Combat Command (ACC) base with a flying mission similar to the mission at both Osan and Kunsan Air Bases in Korea, we find that at Shaw site characterizations costs were approximately $15 million over 10 years (Benton, 1996; Battaglia, 1998). In the resource-constrained environment in Korea, such time and money expenditures cannot be sustained, and a cheaper/faster method of determining requirements must be found. This research, along with the companion effort by Captain Hartman, is focussed on eliciting such a method.

## B. Research Objective

The objective of this research is to develop and test a method that can be used to expeditiously estimate costs of hazardous waste site remediation at US DoD installations in Korea for use by decision-makers in developing a hazardous waste site remediation strategy. In order to accomplish this objective, the research will attempt to answer several interrelated questions:

(1) What cost and time constraints do the decision-makers have in developing remediation cost estimates? (i.e. what is "expeditious?")

(2) What degree of accuracy do the decision-makers require for strategy formulation?

(3) What estimating models are available for determining costs of remediation activities? What input parameters are needed to apply these models? What level of effort is required to obtain them? How accurate are the model estimates?

(4) Have models been used to estimate costs of remediation activities at Korean installations? How did estimated costs compare to actual costs of completed projects?

(5) Of the methods/models elicited in question (3), which meet the needs of decision-makers as defined in questions' (1) and (2)?

## C. Scope and Limitation

In order to meet the research objective it is essential to first determine the constraints established by decision-makers for cost, time, and accuracy. These constraints will be elicited through interviews with management level personnel at the United States Forces in Korea (USFK) who are responsible for setting environmental policy for US installations on the Korean peninsula. Secondly, a literature review will be accomplished to identify methods and models that may be used for cost estimation. Based upon decision-maker's input, a model will be selected or developed that meets identified constraints. It is important to note that there will not be an attempt to select or develop the "best" model. Instead any model that meets the constraints established by USFK will be considered adequate. The model will be validated using actual remediation data from hazardous waste sites in the United States and Korea.

# II. LITERATURE REVIEW

## A. Overview

The purpose of this chapter is to review the literature relevant to application of cost estimating models to hazardous waste site remediation. Also, statistical analysis tools that may be used to estimate cleanup costs will be explored. Initially, remediation cost estimating models that are currently being used or are being developed in both the federal and civilian communities will be reviewed. A model that meets decision-maker's criteria for cost, speed and accuracy will subsequently be selected from this compendium of cost estimating models. After the review of current models, which are useful in estimating cleanup costs at individual sites, statistical tools will be reviewed. These tools may be useful in determining order of magnitude estimates for cleanup of entire installations. This review will focus on regression analysis techniques that may be used to predict remediation costs at DoD installations in Korea based upon hazardous waste remediation costs of installations located in the United States.

## B. Cost Estimating Models

As discussed in earlier chapters, this research effort is focussed on exploring potential cost estimating models for use at DoD installations in Korea. Cost estimating models may be based upon parametric, statistical, historical, work breakdown structure, quantity take-off, or other methods (Rubin, 1995). Cost estimation is a challenge, particularly "...because of unknown, unique, and infeasible activities that ... present themselves in the future" (Tyborowski, 1996). As an introduction to the chapter, cost estimating will be defined along with the general classifications of cost estimating models and tools. We will then discuss the characteristics of individual models.

## C. Introduction

Cost estimating is a broad term that means different things to different people. In Life-Cycle Cost and Economic Analysis, the authors describe a cost estimate as "an opinion based on analysis and judgement of the cost of a product, system, or structure" (Fabrycky and Blanchard, 1991). Two key words in this definition are opinion and judgment demonstrating that cost estimation is somewhat subjective, perhaps as much out as severe. Decisions which will commit millions of dollars, determine future use of land, and assign exposure risks for populations often rely on cost estimates prepared during the early stages of a feasibility study for a site (Sellers, 1998). The three classifications of cost estimates described by Ms Sellers are (1) screening-level cost estimate which is accurate to within +100/-50%, (2) order-of-magnitude cost estimate which is within +50/-30%, and (3) final project cost estimate which is within +15/-10% (Sellers, 1998).

Rodney Stewart, in his book Cost Estimating, defines one of the basic tools required for a good cost estimate as "knowledge and data concerning the work activity or work output" (Stewart, 1991). This information provides the foundation for determining remediation costs for hazardous waste sites in Korea. In Environmental Remediation Estimating Methods, Richard Rast describes estimating costs of an environmental remediation action (RA) project as "...a multi-stage process that includes seven basic steps" (Rast, 1997).

1. Develop the project description,
2. Classify project sites,

3. Identify the technology/treatment train,
4. Estimate the quantity of work and direct cost of each technology,
5. Estimate sampling and analysis and professional labor costs required to support the project,
6. Identify miscellaneous costs required to complete the project, and
7. Estimate indirect costs, general conditions, overhead and profit.

The models to be discussed in this chapter may include some, all, or none of these, as it may be possible to skip some of these steps when applying an “expeditious” cost-estimating tool. Due to functional similarities, the models reviewed in this section follow two general categories of cost estimating: the “top-down,” or parametric approach, and the “bottoms-up,” or in-depth approach (Fabrycky and Blanchard, 1991 and Derel, 1998). “When a detailed definition of the work is available, the most credible, supportable, usable, and accurate cost estimate is one where an in-depth analysis of the work and estimation of work elements is accomplished (Fabrycky and Blanchard, 1991). However, the top-down approach has the advantage of rapid preparation from limited information. These two general categories can be further classified into three distinct cost estimating procedures; engineering, analogy, and parametric (Fabrycky and Blanchard, 1991 and Derel, 1998). Figure 1 displays categories and procedures.

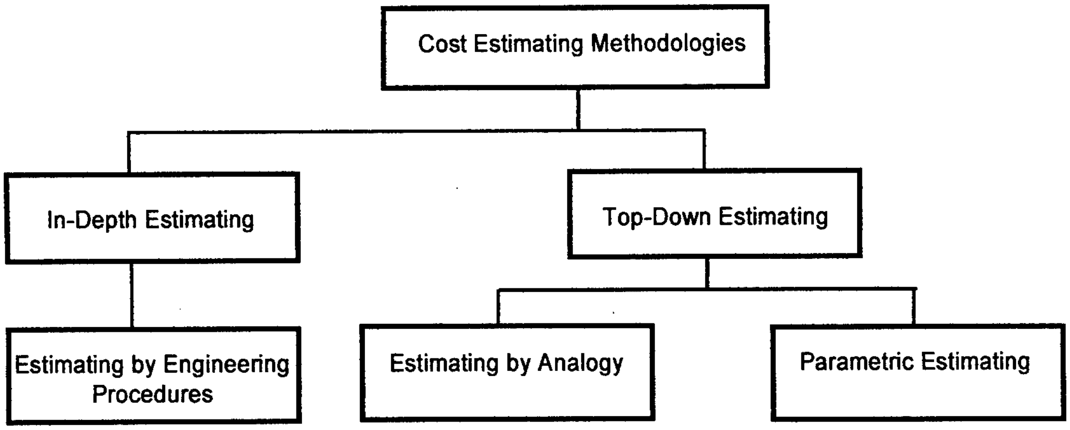


***Figure 1. Cost Estimating Methodology (Derel, 1998)***

"Estimating by engineering procedures involves an examination of separate segments at a low level of data" (Fabrycky and Blanchard, 1991). This methodology works from the bottom in the work breakdown structure (WBS) up to the overall project. These estimating procedures may require an extensive level of effort and large database of information (Fabrycky and Blanchard, 1991). The estimating by analogy procedure requires some level of judgment as it develops cost estimates through comparing similar types of actions. One example of this procedure could be estimating the cost of removing two cubic yards of contaminated soil. If previously a firm had removed one cubic yard of the same type of contaminated soil for $100, the estimator could estimate by analogy that the current project would cost twice the amount or $200. Fabrycky and Blanchard define parametric estimating as finding "a functional relationship between changes in cost and the factor or factors upon which the cost depends, such as output rate, weight, lot size, and so forth" (Fabrycky and Blanchard, 1991). This procedure uses statistical techniques to establish cost estimating relationships (CERs).

This background provides the necessary understanding of cost estimating procedures and methodology. It further depicts the three general types of estimating procedures which are engineering, analogy, and parametric. The study will now focus on specific models used for estimating remediation costs of hazardous waste sites.

## D. Estimating by Engineering Procedures

Estimating an activity's cost through engineering procedures "presumes that a detailed design of the product or project is available" (Stewart, 1991). It further conveys that the estimator knows the material, labor, and skills required in performing each task resulting in the activity's completion.

### 1. Micro-Computer Aided Cost Engineering System (MCACES)

MCACES for Windows, Version 1.2, is a computerized model "used to prepare detailed cost estimates for construction projects" (Building Systems Design, 1996). The US Army Corps of Engineers (ACE) oversees the use of this cost estimating construction tool. "The MCACES database ... provides ... line items for both conventional construction and environmental restoration projects" (Homback and Stanley, 1994). Using MCACES, a multi-stage process consisting of eight steps is followed to provide a detailed cost estimate.

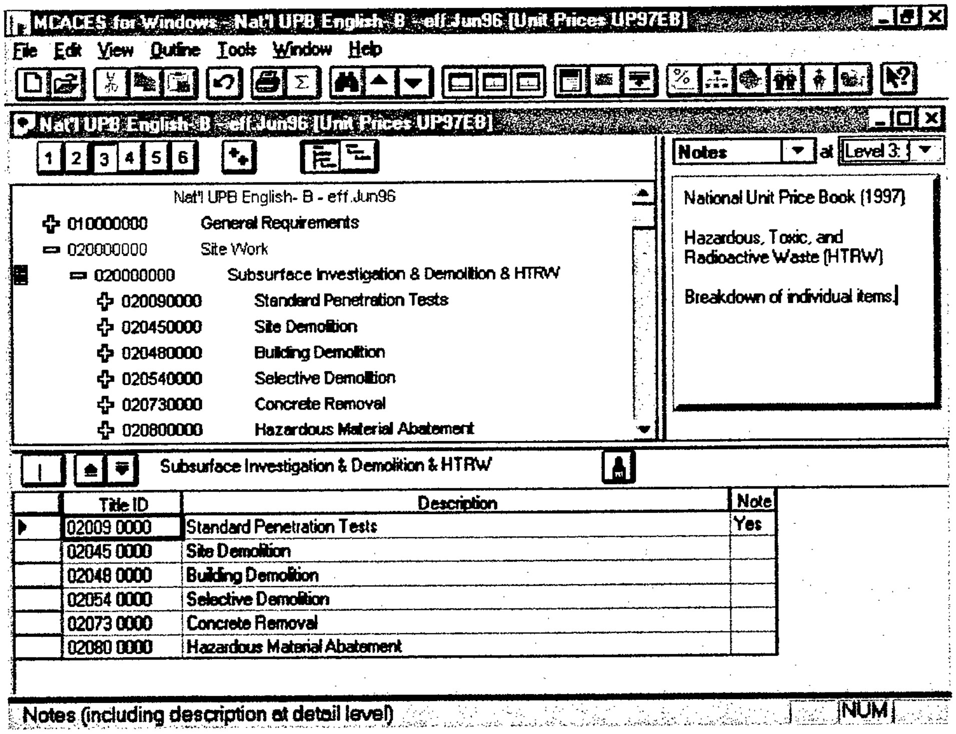
1. Create a specific project identification,
2. Select the applicable template,
3. Establish the database,
4. Determine the type of estimate,
5. Modify project columns
6. Identify work breakdown structures (WBS),
7. Input the quantity of work data, and
8. Estimate direct, indirect, and owner costs.

MCACES provides four selections of templates for the estimator to use. These are (1) military, (2) civil works, (3) hazardous, toxic, and radioactive wastes [HTRW], and (4) other. The HTRW template has 19 primary (or level one) classifications for remedial action, which are displayed in Table 1 (Building Systems Design, 1996). These classifications are divided into hierarchical structures consisting of second and third level categories and specifications. For example, chemical treatment has 13 subdivisions including solvent extraction, chlorination, and ultraviolet photolysis. The HTRW template can best be described as an outline for the cost estimator to use when determining hazardous waste remediation costs.

***Table 1. Level 1 Items for HTRW Template in MCACES, Version 1.2***

Mobilize and Preparatory Work
Monitoring, Sampling, and Testing
Site Work
Surface Water Collect & Control
Groundwater Collect & Control
Air Pollution/Gas Collect & Control
Solids Collect & Containment
Liquid/Sediment/Sludges Collect
Drums/Tanks/Structures/Misc Removal
Biological Treatment
Chemical Treatment
Physical Treatment
Thermal Treatment
Stabilization/Fixation/Encapsulating
Decontamination & Decommissioning
Disposal (Other than Commercial)
Disposal (Commercial)
Site Restoration
Demobilization

Once the desired template is selected, the model requires the estimator to establish a database that has an itemized list of cost details. Databases included with the MCACES model are unit price book, crew, labor rate, equipment, and assembly costs. The estimator can use information from one of these databases or a combination of several. The unit price database (also referred to as the Unit Price Book) details costs for material, labor, shipping weight, and shipping volume of each item described. Figure 2 displays this initial screen. Some examples of unit price book items include slurry wall installation, landfill gas control systems, monitoring well construction, subsurface investigation, and other remedial activities. The labor rates database contains costs of taxes, insurance, fringe benefits, and travel for hazardous waste technicians and supervisors. Equipment cost, including both ownership and operating, are located in the equipment rates database. The assemblies database includes groups of total costs involved in creating a large piece of a project. The final database provided in MCACES is the crew database. This category groups labor and equipment costs into crews for easy access. The program includes several HTRW remediation work crews.



Nat'l UPB English- B - eff.Jun96

| | |
|---|---|
| 010000000 | General Requirements |
| 020000000 | Site Work |
| 020000000 | Subsurface Investigation & Demolition & HTRW |
| 020090000 | Standard Penetration Tests |
| 020450000 | Site Demolition |
| 020480000 | Building Demolition |
| 020540000 | Selective Demolition |
| 020730000 | Concrete Removal |
| 020800000 | Hazardous Material Abatement |

National Unit Price Book (1997)

Hazardous, Toxic, and Radioactive Waste (HTRW)

Breakdown of individual items.

Subsurface Investigation & Demolition & HTRW

| Title ID | Description | Note |
|---|---|---|
| 02009 0000 | Standard Penetration Tests | Yes |
| 02045 0000 | Site Demolition | |
| 02048 0000 | Building Demolition | |
| 02054 0000 | Selective Demolition | |
| 02073 0000 | Concrete Removal | |
| 02080 0000 | Hazardous Material Abatement | |

Notes (including description at detail level)

***Figure 2. MCACES Opening Screen with Unit Price Book Database***

The next three steps involve selecting an estimate type, a project column type, and a work breakdown structure. The estimate type provides different options for pricing and repricing the project. Direct, indirect, and owners cost titles are the generic project columns provided. However, these can be branched into several subtitles including man-hours, labor, equipment, material, shipping, overhead, and profit. The work breakdown structure is simply used to display different levels of detail for the project. These levels represent various divisions and subdivisions of the project being estimated. MCACES allows for seven different levels of detail.

The final stages in the cost estimating process using MCACES involve inputting the detailed information and producing reports. This detailed information is inputted in a bottom-up manner, where the number of labor hours, individual pieces of equipment, and other engineered designed data must be provided. Once listed in the model, the program can then produce a cost estimate of the overall system or project.

William Homback and Wayne Stanley, Survey of Resources Available for Estimating the Environmental Costs of Major Defense Acquisition Programs, described some advantages and disadvantages of MCACES. The key advantage identified was that the estimates were "defensible ... very comprehensive ... based on a significant amount of data" (Homback and Stanley, 1994). The disadvantages identified were (1) MCACES required at least 30% complete design and (2) the "user/estimator must be a professional cost engineer and experienced with MCACES" (Homback and Stanley, 1994). Since limited data are currently available on hazardous waste sites in Korea, MCACES may be inappropriate for estimating remediation costs.

### 2. Other Models or Methods

During this research effort, there were no other software models or standardized methods for accomplishing detailed estimates through engineering procedures found. However, Rodney Stewart in Cost Estimating describes other "bottom-up" cost estimating procedures such as firm quotes, staffing methods, and direct estimates (Stewart, 1991). However, since all these bottom-up methods require detailed data that are not available at our Korean installations, they were not evaluated for this study.

## E. Estimating by Analogy

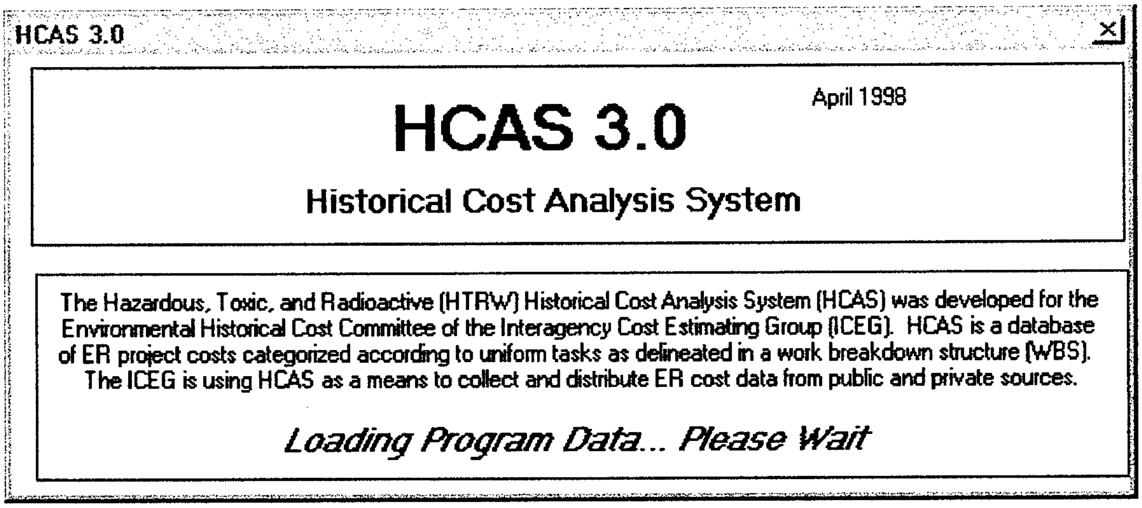
Using analogies for cost estimating requires the estimator to gather resource information about one remediation effort and compare it to a similar or analogous task (Stewart, 1991). This method requires considerable judgement, as the user has to not only identify similarities, but also has to recognize differences between the two activities. It is these differences that may lead to erroneous comparisons of tasks which are really not similar or analogous (Stewart, 1991).

### 1. Historical Cost Analysis System (HCAS)

Under the sponsorship of the Environmental Protection Agency, the Environmental Historical Cost Committee (EHCC) of the Interagency Cost Estimating Group (ICEG) was established in 1989. One of the goals of EHCC is to collect and consolidate environmental costs incurred by the Department of Defense, Department of Energy, and Environmental Protection Agency (ICEG, 1997). HCAS was developed to consolidate those environmental costs (to include studies and designs, operations and maintenance, and remedial actions) and to distribute these cost data to both public and private sources (ICEG, 1997).

This system is simply a compendium of expenses incurred by the three agencies for environmental restoration activities. The program, HCAS, version 3.0, initially loads the project database for use by the cost estimator. Figure 3 displays the initial screen that appears when the user begins the program. As of April 1998, there were only 61 projects loaded in this database. An internet site (http://globe.lmi.org/lmi_hcas/) has been established for both public and private environmental cost data to be added in order to increase the database. This allows for the compilation of information to grow and become a better tool.

Once HCAS loads the data, the program uses a three-tier procedure. The cost estimator begins by viewing the project selection screen (see Figure 4). This screen displays all of the projects for the estimator to view and use. It is recommended that a working copy of the database be made when new projects are being added. Once a remedial project is found that appears similar to the project under construction by the user, the user can view the detail work breakdown structures (WBS) described for the selected project. For purposes of this discussion, the detail WBS comprises the second tier of the procedure. Comparing this information to the task at hand allows the estimator to determine if the two activities are truly similar. The final tier of the HCAS procedure is modifying the historical data to reflect the quantities of the remediation project being evaluated.

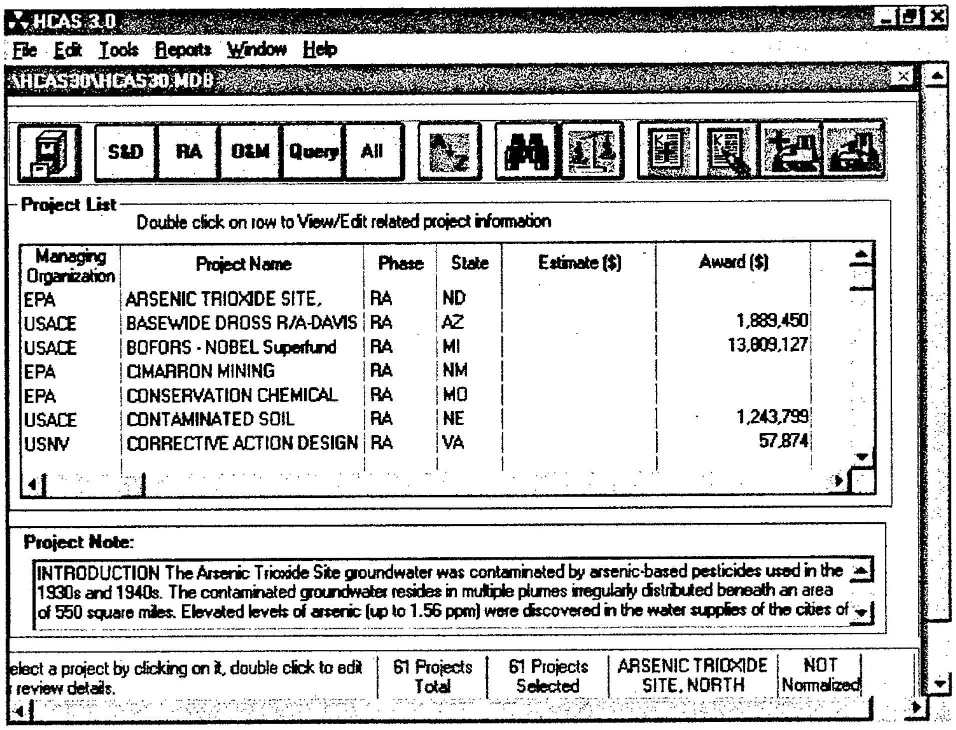


The Hazardous, Toxic, and Radioactive (HTRW) Historical Cost Analysis System (HCAS) was developed for the Environmental Historical Cost Committee of the Interagency Cost Estimating Group (ICEG). HCAS is a database of ER project costs categorized according to uniform tasks as delineated in a work breakdown structure (WBS). The ICEG is using HCAS as a means to collect and distribute ER cost data from public and private sources.

*Loading Program Data... Please Wait*

***Figure 3. Initial Screen for HCAS***

An advantage for HCAS is that its simplistic listing of projects, coupled with its search capability, allows the estimator to expeditiously compare completed projects to the project under consideration. However, having only 61 remediation projects available for review, places limitations on the applicability of HCAS. Hombach and Stanley describe the data contained in HCAS as not having “sufficient definition for direct use” (Hombach and Stanley, 1994). These constraints potentially pose severe limitations on HCAS’s applicability for decision-makers in Korea.



Project List

Double click on row to View/Edit related project information

| Managing Organization | Project Name | Phase | State | Estimate ($) | Award ($) |
|---|---|---|---|---|---|
| EPA | ARSENIC TRIOXIDE SITE, | RA | ND | | |
| USACE | BASEWIDE DROSS R/A-DAVIS | RA | AZ | | 1,889,450 |
| USACE | BOFORS - NOBEL Superfund | RA | MI | | 13,809,127 |
| EPA | CIMARRON MINING | RA | NM | | |
| EPA | CONSERVATION CHEMICAL | RA | MO | | |
| USACE | CONTAMINATED SOIL | RA | NE | | 1,243,799 |
| USNV | CORRECTIVE ACTION DESIGN | RA | VA | | 57,874 |

Project Note:

INTRODUCTION The Arsenic Trioxide Site groundwater was contaminated by arsenic-based pesticides used in the 1930s and 1940s. The contaminated groundwater resides in multiple plumes irregularly distributed beneath an area of 550 square miles. Elevated levels of arsenic (up to 1.56 ppm) were discovered in the water supplies of the cities of

elect a project by clicking on it, double click to edit review details. | 61 Projects Total | 61 Projects Selected | ARSENIC TRIOXIDE SITE, NORTH | NOT Normalized

*Figure 4. Sample of HCAS Database Project Listing*

## 2. Other Analogy Methods

There are several other models and methods that use analogy in order to provide a cost estimate. The Historical Cost Analysis Generator (HAG), version 2.0, is used by the Army, Navy, and Air Force to collect historical costs on awarded military construction projects. HAG is part of the Tri-Service Automated Cost Engineering System (TRACES). This model deals only with construction of facilities, systems, or subsystems. Since there were no references made to environmental remediation projects, this model was not considered for the research effort. Some so-called analogy models actually used parametric relationships and these will be described in the next section.

## F. Parametric Estimating Models/Methods

Parametric or statistical estimating procedures involve consolidating historical data through mathematical techniques and relating this information to the activity being estimated (Stewart, 1991). The cost estimating relationships (CERs) provide a measurement of correlation between the cost of a remedial project and factor(s) of the remediation work. Parametric estimating methods have four advantages over other estimating tools; (1) cost estimates are based on general system characteristics with no detailed information needed, (2) the model is generally fast and easy to use, (3) the model is resistant to user bias, and (4) confidence intervals can be placed on forecasts because of the use of inferential statistics (Habas, 1992). The advantage of not needing detailed information is particularly important for this study, as limited hazardous waste site information is available for the DoD installations in Korea. Also, the advantage of "fast and easy" is important, as decision-makers in Korea require an expeditious methodology.

### 1. Cost of Remedial Action

EPA's Cost of Remedial Action (CORA) model was among the first computerized cost estimating tools (Gleason and Maharrey, 1993). The CORA model was developed in 1985 through a contract with CH2M Hill to obtain estimates for budget submissions. The CORA model "requires minimal design data and other parameters to run and is useful during the conceptual design phases of a project" (Hombach and Stanley, 1994). It consists of two independent subsystems, Expert and Cost. The Expert system recommends a range of remedial response actions based upon a particular site characterization from among 44 technologies. Based on these potential response actions, the Cost system evaluates an order of magnitude cost estimate.

CORA has not been updated since 1987 and does not allow for escalation, engineering design, and other costs (Hombach and Stanley, 1994). The original intent was to provide a mechanism for users to estimate costs of hazardous site remediation under the purview of the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA). However, both federal government agencies and private contractors developed other cost estimating models to meet their needs. Since CORA is not currently in circulation, limited information was available for evaluation.

### 2. LCC Analysis for Radioactive Waste Remediation

At the Air Force Institute of Technology (AFIT) in 1995, a generic life-cycle cost (LCC) model for the Department of Energy (DOE) to compare radioactive waste remediation alternatives (White et al., 1995). The two technologies evaluated by this model were vitrification and cementation.

This LCC model initially required inputs of variables and cost elements. The variables represented characteristics such as power consumed, waste volume, and per unit disposal cost (White et al., 1995). The user provided this information through engineering analysis, previous cost estimates, vendor information, or process simulation results. Cost elements could be generated through Monte Carlo simulation procedures using trapezoidal, percentage, or recurring cost elements (White et al., 1995). Based on this information, the model generated inflated project cash flows "by multiplying the overall project cost by an inflation factor" (White et al., 1995). The costs for alternative technologies were displayed for an infinitely long monitoring period and break-even points were calculated.

The LCC model developed for this study "provide(s) a mechanism for ranking alternatives with varying cost and project life" (White et al., 1995). However, the specific application was for comparing radioactive remediation alternatives of cementation and vitrification for DOE. In order for this model to generate life-cycle costs for other remedial activities, the user must first input the cost estimates, which requires a considerable amount of effort. Therefore, it would not appear that this is an expeditious tool for determining hazardous waste site remediation costs at DoD installations in Korea.

### 3. LCC Model for Innovative Remediation Technologies

In 1997, the LCC model discussed above was applied to evaluate four trichloroethylene (TCE) remediation technologies (Dereli, 1997). The four technologies evaluated were Dynamic Underground Stripping, Two-Phase Extraction, In-Situ Chemical Oxidation, and Six Phase Soil Heating. Using historical data to establish the cost estimating relationships, along with statistical simulation, the author compared the life-cycle costs of the alternative technologies by varying costs and quantity to obtain break-even curves.

As in the previous discussion, the life-cycle costs generated by this model required initial estimates provided by the user. Since installations in Korea do not have the detailed information required to select alternatives, decision-makers could not easily compare technologies for hazardous waste sites using this model. This model could potentially be used in the future when more information is available on these sites.

## 4. Remedial Action Cost Engineering and Requirements (RACER)

The US Air Force, through Delta Research Corporation, developed the Remedial Action Cost Engineering and Requirements System specifically to estimate costs associated with environmental cleanup. The unique parametric cost-estimating technology used in RACER was first designed by the Air Force for the Construction Cost Management Analysis System (CCMAS). CCMAS was designed to evaluate a project's life cost through an "integrated system of multiple cost-estimating techniques, construction criteria, construction methodologies, and worldwide bases" (Page, 1990). However, it was this parametric cost estimating technology that was later patented in 1992 by the US Air Force and used to develop the RACER system.

The RACER system provides military analysts a tool to estimate the cost of Resource Conservation and Recovery Act (RCRA) and Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) investigation, design, and cleanup (Burns, 1995). Figure 5 displays the uses of the RACER system at various stages of the CERCLA and RCRA remediation processes.

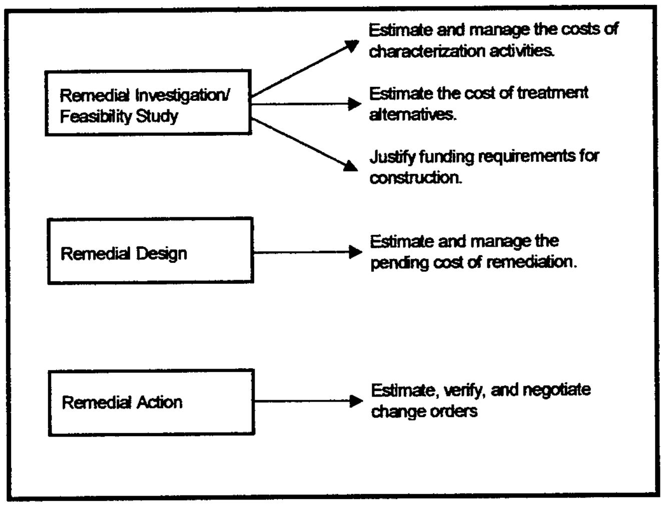


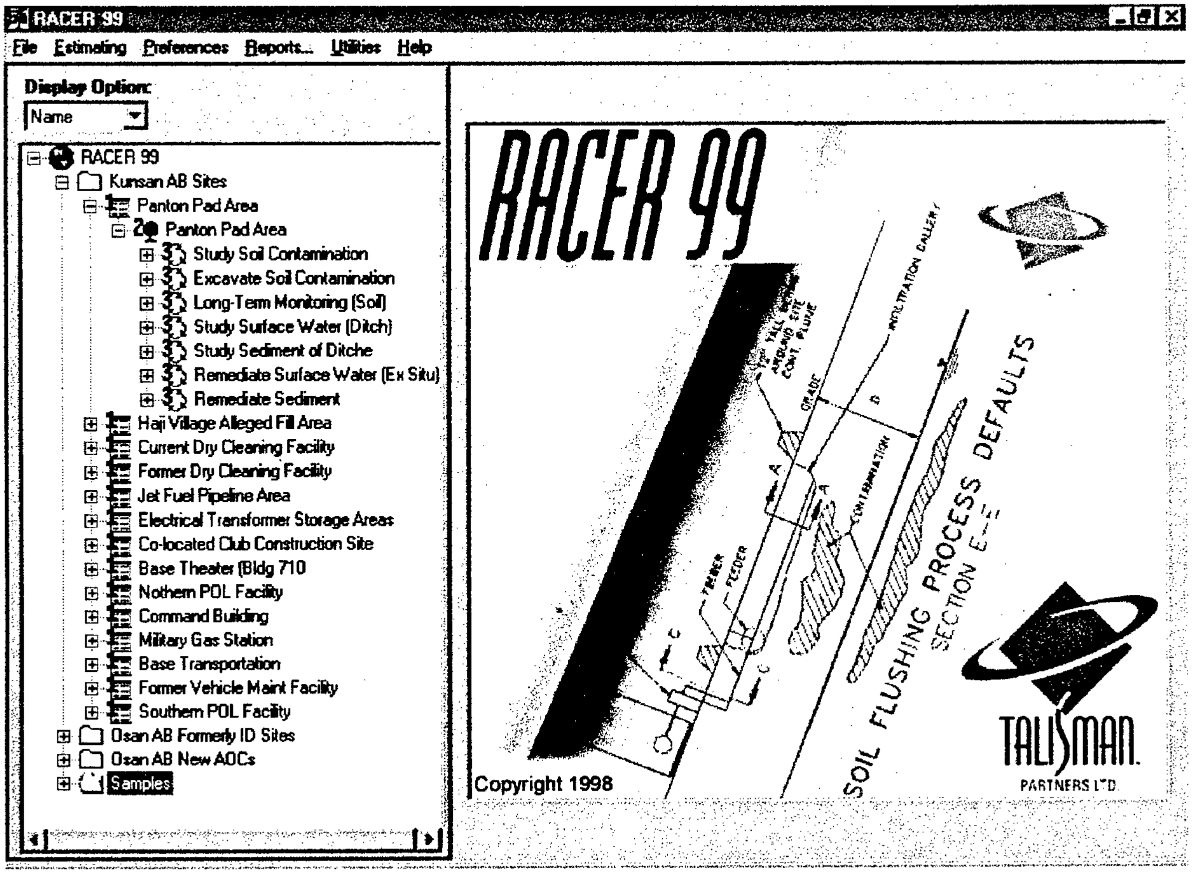
***Figure 5. RACER Activities (Burns, 1995)***

RACER 99, Version 1.1.1, is a Windows-based cost estimating system (see Figure 6) that will accurately estimate costs during all phases of remediation (Talisman Partners, 1998). The objective of the overall RACER system is to:

> "... provide automated tools and data to characterize sites, consider alternative remediation methods, document the decision process, accurately predict remediation costs, and manage them throughout the design." (Gregory and Rast, 1992)

The estimating process consists of six basic steps; (1) create a folder to contain projects, (2) create an active project, (3) create sites within the project, (4) add/update site phase elements, (5) select and run remediation technologies for each site phase element, and (6) run and print reports (Talisman Partners, 1998). To start using RACER, the user inputs information identifying the project. The user is also afforded the opportunity to subdivide this project into several sites. At this point, the user is required to decide which of five stages to consider during remediation. These stages are interim action, studies, remedial action, long term monitoring, and site closeout.

The next step involves selecting the media to be remediated at the site. This involves selecting from surface water, free product, groundwater, soil, sediment/sludge, or air. Also, the user must define the contaminant present from a list of eleven categories including volatile organic compounds, semi-volatile organic compounds, fuels, and metals. Finally, the user must classify the remediation approach to be pursued as in-situ, ex-situ, or natural attenuation. RACER 99 then has the capability of using a "Remedial Action Wizard" to suggest possible treatment options. Once the technologies are selected, RACER will determine the associated costs of each technology. To accomplish this, the user will be required to input some additional information, depending on the technology.



Display Option: Name

- RACER 99
  - Kunsan AB Sites
    - Panton Pad Area
      - Panton Pad Area
        - Study Soil Contamination
        - Excavate Soil Contamination
        - Long-Term Monitoring (Soil)
        - Study Surface Water (Ditch)
        - Study Sediment of Ditche
        - Remediate Surface Water (Ex Situ)
        - Remediate Sediment
    - Haji Village Alleged Fill Area
    - Current Dry Cleaning Facility
    - Former Dry Cleaning Facility
    - Jet Fuel Pipeline Area
    - Electrical Transformer Storage Areas
    - Co-located Club Construction Site
    - Base Theater (Bldg 710
    - Nothern POL Facility
    - Command Building
    - Military Gas Station
    - Base Transportation
    - Former Vehicle Maint Facility
    - Southern POL Facility
  - Osan AB Formerly ID Sites
  - Osan AB New AOCs
  - Samples

***Figure 6. RACER 99, Version 1.1.1, Initial Screen Display***

There are seventy-four remediation technologies and twenty-five additional site-work models included in RACER 99. The specific technologies are shown in Table 2. Site-work models include items such as assess roads, bridges, fencing, and other project activities. The Remedial Action Wizard evaluates the media, contaminant, and approach, and displays several treatment train options. A treatment train is considered a series of technologies used for remediation. For example, if the user was to input media equal to soil, contaminant equal to soil, and approach equal to in-situ, the Wizard would present four potential treatment trains. The first option would consist of soil vapor extraction, carbon adsorption (gas), overhead electrical distribution, decontamination facilities, and professional labor. The other options would suggest technologies like capping, bioventing, or in-situ land farming followed by decontamination facilities and professional labor. RACER 99 also allows the user to select a technology or develop a treatment train from past experiences.

***Table 2. Remedial Action Technology Models in RACER, Version 1.1.1***

Air Sparged Hydrocyclone
Air Sparging
Air Stripping
Bioremediation, Water [Ex Situ]
Bulk Material Storage
Capping
Carbon Adsorption [Gas]
Carbon Adsorption [Liquid]
Chemical Precipitation
Coagulation/Flocculation
Commercial Disposal [Incinerator]
Decontamination Facilities
Dewatering [Sludge]
Discharge to POTW*
Drum Removal
Ex Situ Bioreactor
Ex Situ Vapor Extraction
Excavation, Buried Waste
Extraction Wells
Field Sampling/Mobile Laboratory
Free Product Removal [French Drain]
Gas Distribution
Groundwater Monitoring Wells
Heat Enhanced Vapor Extraction
Heating/Cooling Distribution System
In Situ Biodegradation [Saturated Zone]
In Situ Biodegradation [Bioventing]
In Situ Biodegradation [Land Treatment]
In Situ Solidification
In Situ Vitrification
Incineration [On-Site]
Infiltration Gallery
Injection Wells
Land farming [Ex Situ]
Landfill Disposal
Load and Haul
Low Level Rad Soil Treatment
Low Temperature Thermal Desorption
Materials Plant
Media Filtration
Monitoring
Neutralization
Oil/Water Separation
Ordnance and Explosive Waste Remediation
PA/SI
Passive Water Treatment
Permeable Barriers
Petroleum UST Site Assessment
Piping
Pressure Water Treatment
Retaining Wall, CIP Concrete
Sanitary Sewer
Slurry Walls
Soil Flushing
Soil Vapor Extraction
Soil Washing
Solidification/Stabilization
Solvent Extraction
Special Well Installation (Slant/Horizontal)
Sprinkler System
Storage Tank Installation
Storm Sewer
Thermal and Catalytic Oxidation
Transportation
Treatment Plants/Lift Stations
UST Closure
Ultraviolet Oxidation
User Defined Estimate
Water Distribution
Water Storage Tanks
Well Drilling and Installation
RA Professional Labor
Remedial Design
Sampling and Analysis

* Publicly Owned Treatment Works

Once a technology or treatment train is selected, RACER will determine costs. This requires input of additional parameters, and perhaps overrides RACER's default parameters to "fine tune" estimates (Delta Research Corp, 1996). Continuing with the example above, if the estimator was looking at soil vapor extraction, he or she would need to supply the program with the area and depth of contamination along with the average well depth and formation type (consolidated or unconsolidated). The estimator would continue for each technology in the treatment train. The required parameters are dependent upon the chosen technology. Upon completion of each of the technologies, RACER 99 allows the user to calculate the operations and maintenance (O&M) expenses associated with the treatment train for the duration of the remediation.

The final step in running RACER involves compiling and printing reports. This allows the user and decision-maker to view the cost information in a readable format. RACER includes nine types of reports for detailing the estimates. Report descriptions are provided in Table 3.

***Table 3. RACER 99 Report Descriptions***

| REPORT NAME | DESCRIPTION (Talisman Partners, 1998) |
|---|---|
| Project Total Cost Summary Report | Displays "Present Value," including markups, for the Capital Operations and Maintenance by Level 2 (Site) for the selected Level 1 (Project). |
| Project "Cost Over Time" | Displays "Estimated" total costs by year, including mark ups, by Level 2 (Site) for the selected Level 1 (Project). This report displays as an Excel spreadsheet document. |
| Site Total Cost Summary | Displays the "Present Value" of Capital and Operations and Maintenance, including mark ups, by Level 3 for the selected Level 2 (Site). |
| Site "Cost Oover Time" | Displays "Escalated" total costs, including mark ups, by year for the selected level 2 (Site). This report displays as an Excel Spreadsheet document. |
| Phase Direct Cost Summary | Displays the "Present Value" direct costs by technology for the selected Level 3 (Phase Element). This report does not include mark ups. |
| Phase "Cost over Time" | Displays by year, the "present value" and "escalated" total costs by technology or assembly for the selected Level 3 (phase element). This report includes marked up and non-marked up costs. |
| Phase Direct Cost Detail | Displays all assembly detail including assembly number, description, quantity, MLE unit cost, and extended cost for each technology in the selected Level 3 (phase element). |
| Technology Direct Cost Detail | Displays all assembly detail including assembly number, description, quantity, MLE unit cost, and extended cost for the selected technology. |
| Phase Residual Waste Management | Applies only to Interim Action and Remedial Action phases. |

Gleason and Maharrey (1993) validated RACER by comparing RACER estimates with CORA. Based on RACER's validity and ease of use, Air Force Instruction (AFI) 32-7001 states that Air Force installations should "use the Remedial Action Cost Engineering and Requirements system ... to estimate costs for outyear programs" (Department of the Air Force, 1994). A decision by an installation not to use RACER to estimate remedial action costs must be justified.

## 5. Linear Regression Model

Another cost estimating procedure can be developed through linear regression analysis. The linear regression model combines statistical techniques with analogy types of information to estimate parameters. Regression is defined as "a process of fitting an equation to ... data" (Berthouex and Brown, 1994). During the equation fitting procedure, a "relationship between two or more variables" is investigated to determine if any correlation exists (Devore, 1995). In order to estimate hazardous waste remediation costs for an entire installation, the relationship investigated would be that of installation remediation costs to such variables as number of aircraft on the installation, installation size, population, and other installation parameters.

Devore (1995) explains the Simple Linear Regression Model (LRM) as the condition when "there exists parameters $\beta_0$, $\beta_1$, ... (for) any fixed value of the independent variable x, the dependent variable is related to x through the model equation [$Y = \beta_0 + \beta_1 x + \varepsilon$]" (Devore, 1995). In our problem of determining a model to estimate hazardous waste site remediation costs at an installation, the independent variable x may refer to an installation parameter (number of aircraft, square footage of buildings, acreage, number of personnel, etc) and the dependent variable y refers to the remediation costs. The quantity $\varepsilon$ refers to the random deviation or random error term in the model equation (Devore, 1995). This variable accounts for the pairs of variables falling above or below the true regression line. This type of cost estimating method may be useful in predicting remediation costs for entire DoD installations in Korea.

### 6. Other Parametric Models

There are multitudes of other parametric models that have been used for cost estimating. However, most tend to have methodologies similar to those discussed earlier. An example of these "other" models is the Department of the Navy's Cost-To-Complete (CTC) budget system for environmental cleanups. The system is designed to help select feasible cleanup technologies and estimate the life-cycle cost of a site remediation through studies, design, cleanup, operations and maintenance, and long-term monitoring. The disadvantage of CTC is that it is part of a larger system and resides on a central server, so it is not readily amenable for expeditious use in Korea.

# III. METHODOLOGY

## A. Overview

In this chapter we present the approach taken to accomplish the objective of reviewing, developing, selecting and testing a method that can be used to expeditiously estimate hazardous waste site remediation costs at DoD installations in Korea. "The ultimate goals of research are to formulate questions and to find answers to those questions" (Dane, 1990). In the first chapter, questions were formulated focussing on this important problem. The second chapter shifted the attention towards developing answers to those questions, specifically looking at what cost estimating models and methods are available from the literature for application at hazardous waste sites in Korea.

Figure 7 depicts the methodology used to answer the research questions posed earlier. In the introduction chapter, the research objective and questions were established. The literature review chapter categorized cost estimating models and looked at several that have been applied at hazardous waste sites in some detail. The existing models that were found were all designed for estimating site-specific remediation costs. Also discussed was a statistical technique, linear regression, that potentially could be used to estimate remediation costs for an entire installation. A model based upon linear regression was developed and will be discussed in the next chapter of this study. Survey research, which involved a trip to several Korean bases and interviews with key workers and decision-makers, helped answer questions 1, 2, and 4.

The results of the literature review, model development and survey research were then qualitatively analyzed in order to compare constraints imposed by the decision-makers to the various costs estimating models and methods. An answer to question 5 was obtained by selecting a model that met these constraints. The chosen models were then applied to a case study for analysis and validation.

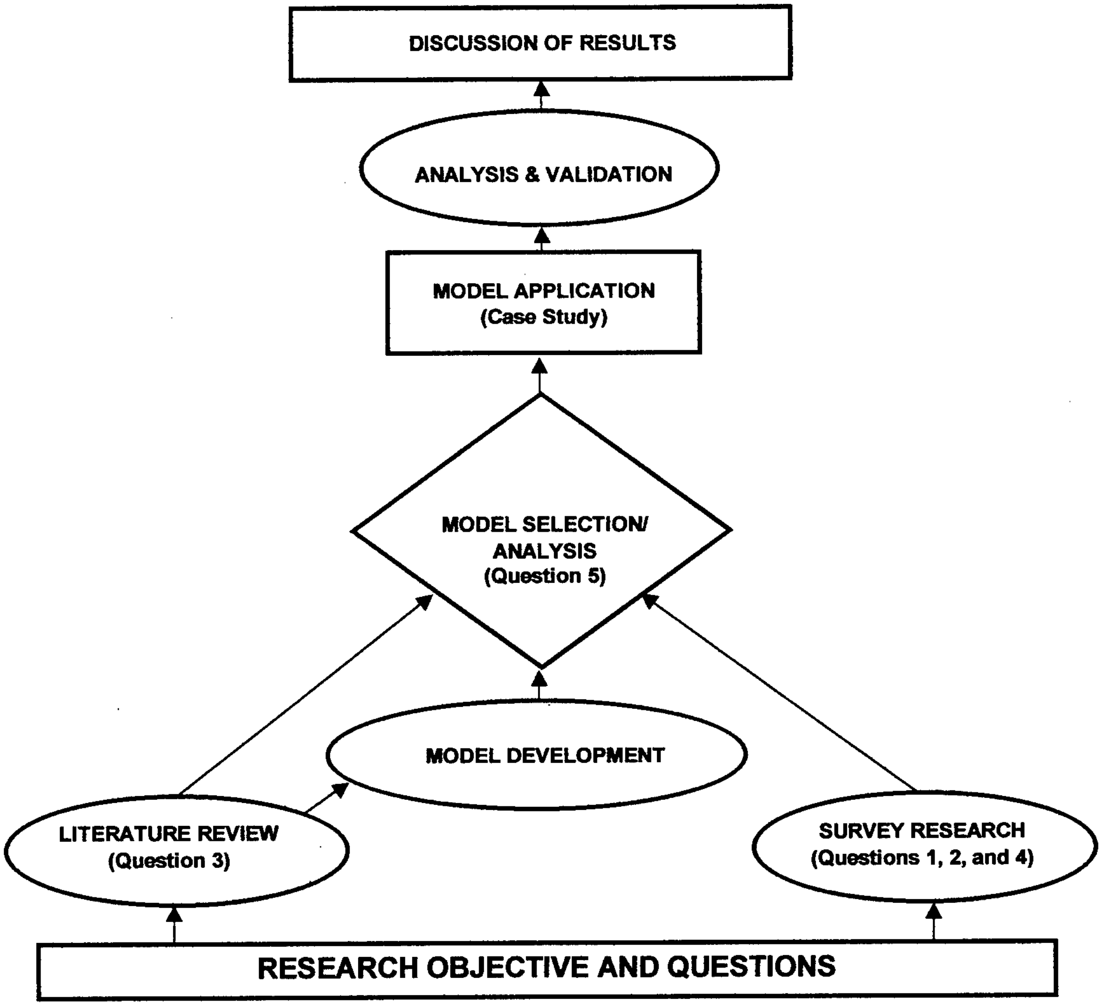


***Figure 7. Methodology Used for Research Effort***

In the next six sections, the methodology applied in this research is described in more detail and related to each of the research questions.

## B. Literature Review

The primary goals of a literature review are to (1) convey the scientific perspective, (2) prevent the duplication of effort, and (3) avoid encountering conceptual or procedural problems (Dane, 1990). Once the research objective and questions are established, the first procedural step was to share with the reader other studies, ongoing dialogue, and importance of the research effort (Creswell, 1994). In this stage of the process, the study was focussed on a review and description of articles, journals, DoD reports and studies, computer model user manuals, and internet sources. The literature review provided information to answer question 3, as described below.

The third question asked, "What estimating models are available for determining costs of remediation activities?" To answer this question, we initially focussed on those estimating tools being used at DoD installations in the US to estimate remediation costs. Existing site-specific models and methods used by the Army, Air Force, Navy, and Marines were evaluated. Also, we viewed models previously or currently used by other government agencies, including the Environmental Protection Agency (EPA), as well as private corporations. A descriptive analysis of how each cost model operates and any underlying assumptions were included for the benefit of the reader. The review further incorporated a description of the parameters required for these models along with a discussion of accuracy, if available.

As described above, the cost estimating models and methods discovered were designed for hazardous waste activities, at specific sites. Providing a cost estimate for an entire installation would require (1) identification of all hazardous waste sites, (2) estimation of individual site remediation costs using available models, and (3) compilation of these costs. Since identification of all hazardous waste sites was not practical as part of an expeditious methodology, we researched the use of a "gross" linear regression model to provide remediation estimates for entire DoD installations.

## C. Linear Regression Model Development

This study first gathered data from Air Combat Command (ACC) bases located in the United States because of the similarity in the flying missions of ACC and the Air Force installations in Korea. Likewise, data from Army installations within the United States could be used to analyze comparable Army installations in Korea. Assuming the bases with the same mission are "similar," the intent of gathering this information is to determine if there is some parameter (number of aircraft, square footage of buildings, acreage, number of personnel, etc) that correlates with remediation cost. Both the population and size of these installations could easily be obtained by using the *Air Force Magazine 1998 USAF Almanac* and *the Guide to Military Installations in the US 1999 Edition* by the Air Force Times. However, the other predictors would be obtained using the above two publications along with internet home pages, telephone interviews, and email conversations.

Once a correlation was established, the study would be able to produce a model to estimate a scope or magnitude of the hazardous waste remediation costs at DoD installations in Korea. This "gross" linear regression model could be used to infer remediation costs (the dependent variable) from installation parameters (the independent variables) resulting in an expeditious cost-estimating model for decision-makers.

## D. Survey Research

Francis Dane, in his book Research Methods, defines survey research as the procurement of information directly from a group of individuals through any mechanism (Dane, 1990). This can include face-to-face interviews, telephone interviews, mail surveys, or any other means to convey questions to people. In this research face-to-face and electronic mail (email) interviews were mainly used. Interview techniques can be divided into (1) schedules, (2) focused interview, and (3) nondirective interview (Dane, 1990). The schedule type of interview provides the most structured as it provides a pre-determined questionnaire for individuals to answer. In comparison, the focused interview has some flexibility as it has a few pre-determined questions but allows for follow-up questions to research particular areas in more detail. The final category of nondirective interview allows the respondent to discuss a topic at his or her own direction.

In this research, we used focused interviews to obtain answers to questions 1, 2, and 4. The nondirective approach was not used because this study (1) required the answers to three specific research questions and (2) allowed limited time for face-to-face discussions during the Korea trip. Flexibility was the deciding factor between focussed and scheduled interviews. By using a focussed interview approach, we could "explore more fully the opinions and behavior of respondents; thus the total collection of responses could contain more and varied detail than would the data from a structured interview" (Dane, 1990).

### 1. Selection of Decision-Maker

For this research effort, the decision-maker refers to the organization, agency, or activity appointed to distribute policy in regards to environmental remediation actions in Korea. DoD Instruction 4715.5 requires the Deputy Under Secretary of Defense for Environmental Security to "designate a DoD Component as the DoD Environmental Executive Agent for environmental matters in foreign countries" (DoD, 1996). An executive agent is an agency assigned by the Department of Defense to oversea specific activities in a foreign country. The area of environmental compliance represents one such activity. In DoD Instruction 4715.5, the Commander-in-Chief of US Forces in Korea (CINCUSFORKOREA) is appointed as the executive agent for the Pacific Command forces in Korea. With US Forces in Korea (USFK) designated as the executive agent, we selected the same office to represent the decision-makers for this research effort.

### 2. Questions Presented to Decision-Makers

The first question posed to personnel at US Forces in Korea (USFK) was aimed at determining what these decision-makers envisioned as "expeditious." USFK was asked, "What cost and time constraints do they have in developing remediation cost estimates?" The purpose of this question was to establish if there were any limitations placed upon or created by USFK.

The next question posed to USFK decision-makers was to determine what accuracy was needed for cost model estimates in order to adequately support mission requirements. The decision-maker was asked, "What degree of accuracy do they require for strategy formulation?" The level of accuracy provided a qualitative measurement to be used to select a cost-estimating model.

The final question was focussed on determining if remediation cost estimating models have been applied at DoD installations in Korea and how the estimates obtained from the models compared to actual costs. Several DoD installations in Korea were visited so we could determine through face-to-face interviews, which, if any, cost estimating methods, had been used to support on-going or planned remediation activities.

## E. Model Selection and Analysis

After obtaining answers to questions 1, 2, 3 and 4, this study proceeded to qualitatively analyze the information and select a cost estimating model which met the constraints of the decision-maker. This step in the process first evaluated whether the model could produce an estimate within the established time and cost constraints. Secondly, we estimated the model's level of accuracy and compared it to the accuracy required by the decision-maker. If the model met these constraints, then it was labeled as potentially applicable. As described in the introduction chapter, there was no attempt to select the "best" model.

## F. Model Application (Case Study)

After model selection, the selected models were applied to a case study of Osan and Kunsan Air Bases. During the Survey Research process, there were several documents gathered detailing limited characterization studies accomplished at hazardous waste sites on DoD installations in Korea. The data were collected through baseline assessments, contractor studies, Air National Guard management action plans, hazardous material spill logs, computer databases, and items accumulated by other researchers. We used this information to determine model parameters for input into the selected models.

## G. Analysis and Validation

Case study results were used to analyze and validate the selected expeditious cost-estimating models. The term validity "refers to the extent to which a measure actually measures what it is supposed to measure" (Dane, 1990). This portion of the study focussed on determining whether the selected cost estimating models really estimated hazardous waste site remediation costs at a DoD installation in Korea. Francis Dane goes further to classify four categories of validity: (1) face, (2) concurrent, (3) predictive, and (4) construct (Dane, 1990). This study focussed on the first two measures of validity.

Face validity is a "consensus that a measure represents a particular concept" (Dane, 1990). Applying this to the study, we accomplished face validity by comparing the cost estimates obtained using the model with the distribution of remediation costs for the ACC bases. Initially, this could only be used for the site-specific model as the ACC bases were used to develop the linear regression model. Ultimately, only five of sixteen ACC bases were used to develop the linear regression model. This enabled use of the remaining eleven ACC bases to establish face validity of the regression model. This type of validation was used to verify that the model provided an estimate that was reasonable. Concurrent validity uses an existing cost estimate as a comparison tool (Dane, 1990). In this study, concurrent validity was determined by contrasting the estimates of more than one model. Both predictive and construct validity tests require a comparison of the evaluated model to a separate, previously validated model. As previously validated models were determined not to have been used in Korea, these validation methods could not be applied in this study.

# IV. LINEAR REGRESSION MODEL DEVELOPMENT

## A. Overview

In this chapter a general linear regression model is developed to define a relationship, if one exists, between the hazardous waste remediation costs of continental United States (CONUS) Air Combat Command bases and various parameters describing these bases. The focus of this research was to develop and test a method that could be used to expeditiously estimate costs of hazardous waste site remediation at US DoD installations in Korea for use by decision-makers in developing a hazardous waste site remediation strategy. Using a linear regression method, this section combines both analogy and parametric cost estimating strategies to apply a statistical tool to Air Force installations in Korea, specifically Osan and Kunsan Air Bases. Once developed, this methodology can be applied to other DoD installations in Korea in a likewise fashion.

## B. Regression Model Assumptions

### 1. Sample of Bases

The first assumption for developing this regression model was that Air Combat Command (ACC) bases located in the United States had similar flying missions to Air Force installations in Korea. We further assumed that this flying mission was a major driver affecting remediation costs of these installations. The effort then focussed on defining a relationship for predicting remediation costs. The population was defined as all the DoD installations, worldwide, having a flying mission. However, the sample used in this study was the sixteen CONUS ACC bases. The specific bases examined were

Barksdale, Beale, Davis-Montham, Dyess, Ellsworth, Holloman, Langley, Minot, Moody, Mountain Home, Nellis, Offutt, Seymour Johnson, Shaw and Whiteman. This sample was explored to decide whether a relationship between parameter(s) describing the bases, and remediation cost could be determined.

### 2. Response and Predictor Variables

In this work, we will refer to response and predictor variables. The response variable, also referred to as the dependent variable, was defined as the total remediation costs for a base. The remediation costs would be obtained through HQ ACC at Langley AFB and verified through discussions with individual bases. However, since each base was at a different stage of its remediation process and located in a different region of the United States, we normalized the remediation costs to negate these effects. In the first step, we determined the percent of the remediation effort that had been completed at each base. The measure we used to define this value was the ratio between the total number of cleaned sites divided by the total number of sites identified at each base. Potentially the easier "no action" sites could have been closed first, resulting in calculated costs for all sites being lower than actual costs. Although this ratio did not take into account the various difficulties of individual cleanup site efforts, we did feel this value provided a relative estimate of how far along the base was in its remediation program. The second step was to apply the area cost factors (ACF) defined by the US Army Corps of Engineers (ACE) for comparing average construction costs at different geographical locations. The predictor variables, also referred to as the independent variables, used in this study included base population, size, annual fuel usage, aircraft inventory, and number of aircraft squadrons.

### 3. Type of Data Collected

There are four classes of data; ratio, interval, ordinal, and nominal (Reynolds, 1997; Kachigan, 1991). Both the predictor and response variables are ratio data. The variables are on a measurement scale with equal intervals and a boundary of zero. The variables were assumed to have normal distributions, which will be evaluated through an aptness test. Finally, we assumed the estimated error associated with the model was normally distributed with a mean of zero.

## C. Regression Model Hypotheses

The objective of this chapter is to investigate whether a relationship exists between the response and the predictors using hypothesis testing. Devore defines a statistical hypothesis as "a claim either about the value of a single population characteristic or about the values of several population characteristics" (Devore, 1995). We want to use sample statistics to support or discredit a speculation about the slope coefficient that defines the relationship. The null hypothesis (written as $\mathbf{H_o{:}\beta_1 = 0}$) simply states that there is no linear relationship or slope of coefficient relating the independent and dependent variables. The alternative hypothesis (written as $\mathbf{H_a{:}\beta_1 \neq 0}$) is that there is a slope and potentially a linear relationship. The objective of hypothesis testing is to statistically demonstrate whether or not the null hypothesis can be rejected. If it can, this provides support for the existence of a relationship between the two parameters.

## D. Regression Model Test Statistic and Decision Rule

During the planning phase of an experiment, the test statistic and the decision rule gives the researcher a means to analyze results. Using the model utility test, we defined the test statistic value (T) to be the ratio of the estimated $\beta_1$ value divided by the standard deviation of the estimated $\beta_1$ value (Devore, 1995). The study looked at a two-tailed test and defined the significance level ($\alpha$) to be .1. With this significance level defined and using a table of critical values for the t-distribution (Devore, 1995), we obtain a decision rule of $T \geq 1.761$ or $T \leq -1.761$. The decision rule shows the rejection region for the null hypothesis. If the calculated test statistic is outside the interval (-1.761, 1.761) then there is statistical evidence that a relationship exists. The significance level translates to a ten percent probability of rejecting the null hypothesis when it is true, commonly referred to as type I error (Devore, 1995). Also, as an added measurement tool, this research effort is seeking a significant coefficient of determination ($r^2$) of at least .8. This calculated value describes the proportion of observed remediation cost variation that can be explained by the simple linear regression model. Devore defines the correlation between the response and predictor variables as strong if between .8 and 1, weak if between 0 and .5, and moderate otherwise (Devore, 1995).

## E. Gathering of Model Data

This section describes the procedures used for gathering the model data and displays the information obtained in tabular format.

### 1. Response Variable (Remediation Costs)

Hazardous waste remediation costs at each of the sixteen identified bases were the first data collected. These data were compiled from a centralized computer database report, and categorized as cleanup, investigation, and management obligations for remediation projects (Battaglia, 1998). The remediation costs are tabulated in Table 4.

*Table 4. Remediation Costs of HQ ACC CONUS Bases*

| | | | | Base Remediation Costs | | | |
|---|---|---|---|---|---|---|---|
| | Base | State | Unit | Cleanup | Invest | Mgmt | Total |
| 1 | Barksdale AFB | LA | 2d BW | $1,615.8 | $3,653.0 | $119.7 | $5,388.5 |
| 2 | Beale AFB | CA | 9th RW | $38,631.3 | $26,587.1 | $258.5 | $65,476.9 |
| 3 | Cannon AFB | NM | 27th FW | $1,498.0 | $8,065.3 | $57.2 | $9,620.5 |
| 4 | Davis-Monthan AFB | AZ | 355th Wing | $5,988.3 | $5,456.7 | $72.9 | $11,517.9 |
| 5 | Dyess AFB | TX | 7th Wing | $4,661.0 | $5,317.3 | $154.3 | $10,132.6 |
| 6 | Ellsworth AFB | SD | 28th BW | $33,863.3 | $18,045.4 | $279.0 | $52,187.7 |
| 7 | Holloman AFB | NM | 49th FW | $20,071.5 | $9,718.2 | $87.4 | $29,877.1 |
| 8 | Langley AFB | VA | 1st FW | $20,772.4 | $11,446.5 | $154.4 | $32,373.3 |
| 9 | Minot AFB | ND | 5th BW | $5,436.1 | $2,232.6 | $65.7 | $7,734.4 |
| 10 | Moody AFB | GA | 347th Wing | $5,763.3 | $4,024.1 | $67.7 | $9,855.1 |
| 11 | Mountain Home AFB | ID | 366th Wing | $275.1 | $7,796.9 | $71.1 | $8,143.1 |
| 12 | Nellis AFB | NV | 57th Wing | $22,295.8 | $7,757.6 | $141.7 | $30,195.1 |
| 13 | Offutt AFB | NE | 55th Wing | $6,260.7 | $10,411.7 | $117.3 | $16,789.7 |
| 14 | Seymour Johnson AFB | NC | 4th FW | $7,091.0 | $2,338.3 | $71.7 | $9,501.0 |
| 15 | Shaw AFB | SC | 20th FW | $27,804.1 | $14,642.1 | $167.3 | $42,613.5 |
| 16 | Whiteman AFB | MO | 509th BW | $9,976.0 | $2,261.3 | $184.7 | $12,422.0 |
| | | | | | | | |
| | TOTALS: | | | $212,003.7 | $139,754.1 | $2,070.6 | $353,828.4 |

These remediation costs were then normalized by first taking into account the actual number of remediated sites compared to the total number of sites requiring remediation. We then used Area Cost Factor 32 – Version 0.9.5 to normalize these remediation costs for geographical locations. Both the raw and normalized data are displayed in Table 5.

*Table 5. Normalized Remediation Costs of CONUS HQ ACC Bases*

| | Base Remediation Costs | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Air Force Base | Cleanup | Invest | Mgmt | Total | Clean | Total | Comp | ACF | Adj Cost |
| | | | | | Sites | Sites | (%) | | (Total) |
| Barksdale | $1,615.8 | $3,653.0 | $119.7 | $5,389 | 17 | 36 | 47.2% | 0.86 | $13,269 |
| Beale | $38,631.3 | $26,587.1 | $258.5 | $65,477 | 19 | 38 | 50.0% | 1.23 | $106,467 |
| Cannon | $1,498.0 | $8,065.3 | $57.2 | $9,621 | 22 | 27 | 81.5% | 1.03 | $11,463 |
| Davis-Monthan | $5,988.3 | $5,456.7 | $72.9 | $11,518 | 46 | 49 | 93.9% | 0.93 | $13,193 |
| Dyess | $4,661.0 | $5,317.3 | $154.3 | $10,133 | 29 | 43 | 67.4% | 0.86 | $17,470 |
| Ellsworth | $33,863.3 | $18,045.4 | $279.0 | $52,188 | 18 | 21 | 85.7% | 1.02 | $59,692 |
| Holloman | $20,071.5 | $9,718.2 | $87.4 | $29,877 | 58 | 63 | 92.1% | 0.98 | $33,115 |
| Langley | $20,772.4 | $11,446.5 | $154.4 | $32,373 | 10 | 48 | 20.8% | 0.91 | $170,760 |
| Minot | $5,436.1 | $2,232.6 | $65.7 | $7,734 | 8 | 11 | 72.7% | 1.08 | $9,847 |
| Moody | $5,763.3 | $4,024.1 | $67.7 | $9,855 | 9 | 36 | 25.0% | 1.00 | $39,420 |
| Mountain Home | $275.1 | $7,796.9 | $71.1 | $8,143 | 31 | 32 | 96.9% | 1.23 | $6,834 |
| Nellis | $22,295.8 | $7,757.6 | $141.7 | $30,195 | 39 | 48 | 81.3% | 1.07 | $34,732 |
| Offutt | $6,260.7 | $10,411.7 | $117.3 | $16,790 | 15 | 27 | 55.6% | 0.97 | $31,156 |
| Seymour Johnson | $7,091.0 | $2,338.3 | $71.7 | $9,501 | 3 | 31 | 9.7% | 0.82 | $119,728 |
| Shaw | $27,804.1 | $14,642.1 | $167.3 | $42,614 | 20 | 33 | 60.6% | 0.86 | $81,758 |
| Whiteman | $9,976.0 | $2,261.3 | $184.7 | $12,422 | 23 | 43 | 53.5% | 1.04 | $22,331 |
| | | | | | | | | | |
| TOTALS: | $212,003.7 | $139,754.1 | $2,070.6 | $353,828 | 367 | 586 | 62.6% | | $771,234 |

## 2. Predictors (Population, Size, Fuel, Squadrons, and Aircraft)

We first obtained the population and size of the identified ACC bases using the *Air Force Magazine USAF Almanac 1998*, dated May 1998. These values are listed in Table 6.

We next collected data about the number of aircraft squadrons and the number of aircraft assigned to the bases. This information was collected through two primary sources. The first source was the *Air Force Magazine USAF Almanac 1998*. We were able to obtain total numbers of aircraft within Air Combat Command. Specific numbers of aircraft were obtained primarily by reviewing each installation's home page and secondarily through estimation using the Almanac's description of aircraft per active duty USAF squadron, which is displayed in Table 7 (Air Force Association, 1998).

### *Table 6. Population and Size of HQ ACC CONUS Bases*

| | | | | Population | | | |
|---|---|---|---|---|---|---|---|
| | Base | State | Unit | Military | Civilian | Total | Acres |
| 1 | Barksdale AFB | LA | 2d BW | 6155 | 1366 | 7521 | 4000 |
| 2 | Beale AFB | CA | 9th RW | 3078 | 492 | 3570 | 22944 |
| 3 | Cannon AFB | NM | 27th FW | 3969 | 724 | 4693 | 25663 |
| 4 | Davis-Monthan AFB | AZ | 355th Wing | 6235 | 1385 | 7620 | 11000 |
| 5 | Dyess AFB | TX | 7th Wing | 5077 | 489 | 5566 | 6437 |
| 6 | Ellsworth AFB | SD | 28th BW | 2884 | 969 | 3853 | 10632 |
| 7 | Holloman AFB | NM | 49th FW | 4150 | 865 | 5015 | 59000 |
| 8 | Langley AFB | VA | 1st FW | 7843 | 1045 | 8888 | 3216 |
| 9 | Minot AFB | ND | 5th BW | 4620 | 589 | 5209 | 5049 |
| 10 | Moody AFB | GA | 347th Wing | 5200 | 800 | 6000 | 6050 |
| 11 | Mountain Home AFB | ID | 366th Wing | 3977 | 427 | 4404 | 9112 |
| 12 | Nellis AFB | NV | 57th Wing | 7338 | 938 | 8276 | 11000 |
| 13 | Offutt AFB | NE | 55th Wing | 9111 | 2660 | 11771 | 4041 |
| 14 | Seymour Johnson AFB | NC | 4th FW | 4354 | 1200 | 5554 | 3233 |
| 15 | Shaw AFB | SC | 20th FW | 5677 | 506 | 6183 | 3363 |
| 16 | Whiteman AFB | MO | 509th BW | 4162 | 1786 | 5948 | 4627 |
| | | | | | | | |
| | TOTALS: | | | 83,830 | 16,241 | 100,071 | 189,367 |

### *Table 7. Number of Aircraft and Flying Squadrons at ACC CONUS Bases*

| | Base | State | Unit | A/C Sqds | A/C |
|---|---|---|---|---|---|
| 1 | Barksdale AFB | LA | 2d BW | 3 | 24 |
| 2 | Beale AFB | CA | 9th RW | 2 | 18 |
| 3 | Cannon AFB | NM | 27th FW | 4 | 66 |
| 4 | Davis-Monthan AFB | AZ | 355th Wing | 6 | 91 |
| 5 | Dyess AFB | TX | 7th Wing | 2 | 56 |
| 6 | Ellsworth AFB | SD | 28th BW | 2 | 12 |
| 7 | Holloman AFB | NM | 49th FW | 5 | 91 |
| 8 | Langley AFB | VA | 1st FW | 3 | 60 |
| 9 | Minot AFB | ND | 5th BW | 1 | 12 |
| 10 | Moody AFB | GA | 347th Wing | 5 | 55 |
| 11 | Mountain Home AFB | ID | 366th Wing | 5 | 70 |
| 12 | Nellis AFB | NV | 57th Wing | 3 | 26 |
| 13 | Offutt AFB | NE | 55th Wing | 6 | 36 |
| 14 | Seymour Johnson AFB | NC | 4th FW | 6 | 100 |
| 15 | Shaw AFB | SC | 20th FW | 4 | 92 |
| 16 | Whiteman AFB | MO | 509th BW | 3 | 37 |
| | | | | | |
| | TOTALS: | | | 60 | 846 |

The final predictor was the annual fuel usage for these bases. These data can be seen in Table 8. The annual fuel quantities represent the total of aircraft, diesel, and unleaded fuel used on each base for the 1997 fiscal year. Fiscal year 1997 data were used since the data for the other independent parameters also as of 1997.

***Table 8. FY 1997 Annual Fuel Usage of ACC CONUS Bases***

| | Base | State | Unit | Annual Fuel Usage (Gallons) |
|---|---|---|---|---|
| 1 | Barksdale AFB | LA | 2d BW | 64,369,977 |
| 2 | Beale AFB | CA | 9th RW | 3,274,050 |
| 3 | Cannon AFB | NM | 27th FW | 18,805,496 |
| 4 | Davis-Monthan AFB | AZ | 355th Wing | 27,812,201 |
| 5 | Dyess AFB | TX | 7th Wing | 41,587,083 |
| 6 | Ellsworth AFB | SD | 28th BW | 20,340,684 |
| 7 | Holloman AFB | NM | 49th FW | 26,906,269 |
| 8 | Langley AFB | VA | 1st FW | 20,685,388 |
| 9 | Minot AFB | ND | 5th BW | 15,572,388 |
| 10 | Moody AFB | GA | 347th Wing | 13,041,539 |
| 11 | Mountain Home AFB | ID | 366th Wing | 24,672,754 |
| 12 | Nellis AFB | NV | 57th Wing | 67,295,710 |
| 13 | Offutt AFB | NE | 55th Wing | 20,247,978 |
| 14 | Seymour Johnson AFB | NC | 4th FW | 39,982,711 |
| 15 | Shaw AFB | SC | 20th FW | 16,764,715 |
| 16 | Whiteman AFB | MO | 509th BW | 9,173,753 |
| | | | | |
| | TOTALS: | | | 430,532,696 |

## F. Analyzing the Collected Data

After collecting these data, we used descriptive statistics for organization and summarization. In order to provide a pictorial representation of the data, a histogram was constructed showing remediation costs for the sample bases (Figure 8). Seventy-five percent of the bases sampled had total remediation costs below $60 million and forty percent of the bases were below $20 million. If our basic assumption that the sampled ACC bases have flying missions similar to the Air Force bases in Korea, and this flying mission is a major factor in determining remediation costs, we can suggest that the remediation costs for Air Force installations in Korea should be in the same range. Similar observations can be made by observing the descriptive statistics of the five other independent parameters obtained from these ACC bases (Table 9).

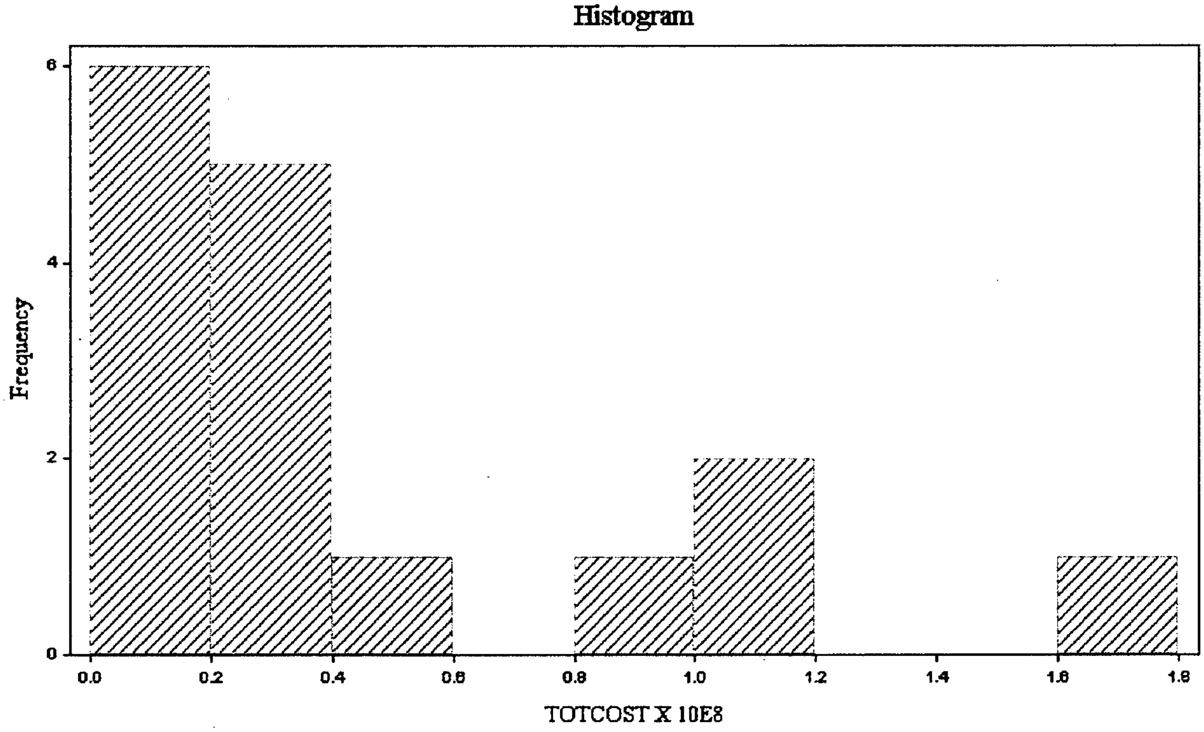


***Figure 8. Histogram Displaying the Distribution of Remediation Costs***

***Table 9. Descriptive Analysis of the Sample of ACC Bases***

| | Parameter | Minimum | Maximum | Mean | Median | Standard Deviation | Variance [Units Squared] |
|---|---|---|---|---|---|---|---|
| 1 | Remediation Cost ($M) | 6.8 | 170.8 | 48.2 | 32.1 | 47.7 | 2278.1 |
| 2 | Size (1K Acres) | 3.2 | 59 | 12.4 | 7.8 | 14.2 | 200.4 |
| 3 | Aircraft (Amount) | 12 | 100 | 53 | 56 | 30.4 | 923.0 |
| 4 | Fuel (1M Gallons) | 3.3 | 67.3 | 26.9 | 20.5 | 18.1 | 328.0 |
| 5 | Population (1K) | 3.6 | 11.8 | 6.3 | 5.8 | 2.1 | 4.5 |
| 6 | Squadrons (Aircraft) | 1 | 6 | 3.75 | 3.5 | 1.6 | 2.6 |

All of the parameters, except aircraft, reflect positively skewed distributions as can be seen from the differences in the medians and the means. This would suggest that the mean value was skewed higher due to the effect of outlying data points. The distribution of remediation costs appears to have a lognormal distribution with eleven of the sixteen bases having total remediation costs below $40 million. Let us now continue to investigate the relationship between these parameters and remediation costs.

## G. Computing Regression Model's Test Statistic and Decision Rule

With the data collected, the next step is to analyze the information to determine the test statistic and to evaluate the decision rule. As mentioned earlier, the test statistic value (T) is the ratio of the estimated $\beta_1$ value divided by the standard deviation of the estimated $\beta_1$ value (Devore, 1995). Appendix 4-1 through 4-5 displays both the calculations (using Mathcad, Version 7.0) and the graphs for each of the parameters in relation to remediation costs. Using linear regression analysis, there does not appear to be a linear relationship between remediation costs and any one of the five independent parameters. The values for the test statistic (T) and coefficient of determination ($r^2$) are displayed in Table 10.

***Table 10. Statistical Values for Simple Linear Regression Model***

| | Parameter | T-Value | $R^2$ |
|---|---|---|---|
| 1 | Population | 0.579 | 0.023 |
| 2 | Size (Acres) | -0.616 | 0.026 |
| 3 | Aircraft | 0.579 | 0.023 |
| 4 | Squadrons (Aircraft) | -0.123 | 0.001 |
| 5 | Fuel (Annual) | -0.716 | 0.035 |

The research then focussed on determining if there was possibly a multiple linear regression model, which would use a combination of the parameters, to describe a relationship with remediation costs.

## H. Multiple Linear Regression Analysis

Multiple regression is simply an extension of the concept of simple regression (Kachigan, 1991). Rather than using values of one predictor value to estimate values of remediation costs, multiple regression uses values of several predictor variables. Since there are many different possible combinations of these five parameters, this research effort used *Student Edition of Statistix*, version 1.0, to determine the best correlation factors that could be obtained to predict remediation costs. The values are tabulated in Table 11. As can be seen, the best correlation obtainable with these values is a value of .2. That requires using all five of the parameters and still does not meet the second part of our decision rule requiring a coefficient of determination ($r^2$) of at least .8.

***Table 11. Best Subset Multiple Regression Models***

| # of Predictors | $R^2$ | Predictors |
|---|---|---|
| 2 | 0.0709 | Acre & Fuel |
| 2 | 0.0645 | Aircraft & Squadrons |
| 2 | 0.0638 | Acre & Aircraft |
| 2 | 0.0579 | Aircraft & Fuel |
| 2 | 0.0515 | Fuel & Population |
| 3 | 0.1202 | Acre, Aircraft, & Squadrons |
| 3 | 0.1093 | Acre, Aircraft, & Fuel |
| 3 | 0.1057 | Aircraft, Population, & Squadrons |
| 3 | 0.0955 | Aircraft, Fuel, & Squadrons |
| 3 | 0.0751 | Acre, Fuel, & Population |
| 4 | 0.1717 | Aircraft, Fuel, Population, & Squadrons |
| 4 | 0.1629 | Acre, Aircraft, Fuel, & Squadrons |
| 4 | 0.1366 | Acre, Aircraft, Population, & Squadrons |
| 4 | 0.112 | Acre, Aircraft, Fuel, & Population |
| 4 | 0.0775 | Acre, Fuel, Population, & Squadrons |
| 5 | 0.2035 | Acre, Aircraft, Fuel, Population, Squadrons |

## I. Subdividing Sample for Analysis

As can be seen from the previous sections, there is no apparent regression describing the relationship between remediation costs and the five independent parameters. We next researched the possibility of subdividing the sample using some intrinsic classification. This was considered because of the large variance annotated in Table 9 of the remediation costs, along with the large range between the minimum costs of approximately $7 million and the maximum costs of $170 million. One means of classifying the bases is by location. Intuitively, it appears likely that bases located in states with very aggressive environmental programs may have different remediation costs than bases located in states with less aggressive programs.

James Lester, in Environmental Politics and Policy: Theories and Evidence, explains a capacity and motivation model for classifying the environmental programs in states by motivation and capacity of resources devoted to their environmental program (Lester, 1995). His first group, the "progressives," is those states with high motivation and high capacity. These states seem to be leaders in the environmental arena and include CA, FL, MD, MA, MI, NJ, NY, OR, WA, and WI. A second group, the "strugglers," has high motivation but low capacity. The states in this group are CO, CT, DE, HI, ID, IA, ME, MN, MT, NV, NH, NC, ND, RI, and VT. The third category was described as the "delayers." These states have the capacity of the "progressive" states, however they lack the motivation to go beyond current environmental standards. AL, AK, AR, GA, IL, LA, MO, OH, OK, PA, SC, TN, TX, VA, and WV fall under this heading. Lester classifies the remaining states as "regressive." They neither have the capability or the motivation to run aggressive environmental programs. This group includes AZ, IN, KS, KY, MS, NE, NM, SD, UT, and WY. James Smith applied these categories to four military installations and confirmed that the Lester model may be used to model the impact of state environmental programs on DoD installations (Smith, 1997).

In this study, we organized the sample of ACC bases under Lester's headings. We then assumed Korea would be similar to a "regressive" state. Comprehensive environmental standards and regulations did not appear in the Republic of Korea until the late 1980s and 1990s. "As of 1996, the Korean Government had established 24 environment-related acts" (Oshiba, 1997). However, to be considered "progressive" or "struggler," Lester describes the constituent to be pursuing options that exceed environmental standards. This suggests that Korea could potentially be categorized as a "delayer" or "regressive" with regard to its environmental role at DoD installations there. As for capacity of resources, Korea's Ministry of Environmental (MOE) was created in the 1990s. However, "MOE can only monitor compliance with environmental regulations and report violations to the police for possible legal prosecution, unlike the EPA in the US which can directly levy fines for non-compliance" (Oshiba, 1998). This suggests that as result of a lack of judicial power, Korea does not have a high capacity of resources devoted to its environmental program. Exploring the 1996 and 1997 budgets, the United States allocated .4 percent for the Environmental Protection Agency while the Republic of Korea allocated .3 percent for overseeing its environmental program to the Ministry of Environment (The Chosun Ilbo, 1996; MOE, 1999; and GPO, 1999). From this evidence, we assumed Korea could reasonably be categorized as "regressive." As an additional note, the DoD installations in Korea are more resource constrained than CONUS installations as the Defense Environmental Restoration Program (DERP) funds can not be expended on overseas installations. This further justifies the proposition that Korean installation environmental expenditures could best be compared with environmental program expenditures at bases in "regressive" states.

The following bases in our sample are located in regressive states: Cannon, Davis-Montham, Ellsworth, Holloman, and Offutt Air Force Bases. Using regression analysis on the sub-sample of five, we explored a potential relationship between remediation costs and the five parameters. As with previous attempts, we first focussed on a simple linear regression model. The decision rule for the T-value changed as a result of the difference in sample size. In order for the relationship to be statistically significant, the decision rule would have to be $T \geq 2.353$ or $T \leq -2.353$. Table 12 lists values for the test statistic (T) and coefficient of determination ($r^2$) for this sample.

***Table 12. Statistical Values for Model Using Regressive States***

| | Parameter | T-Value | $R^2$ |
|---|---|---|---|
| 1 | Population | -0.44 | 0.061 |
| 2 | Size (Acres) | -0.13 | 0.006 |
| 3 | Aircraft | -1.69 | 0.487 |
| 4 | Squadrons (Aircraft) | -1.54 | 0.441 |
| 5 | Fuel (Annual) | -0.4 | 0.015 |

As previously, a linear relationship between these independent parameters and remediation costs could not be inferred. However, it did appear that there might be a curvilinear relationship between remediation costs and the number of aircraft at each base (Figure 9). This relationship was investigated using polynomial regression analysis. The Mathcad template of the calculations is presented in Appendix 4-6 and the graph displaying the relationship between remediation costs and aircraft is seen in Figure 9. A large variance inflation factor (VIF) was originally calculated revealing collinearity problems with the regression equation and the predictor variables. This impact was negated through "centering" the numbers of aircraft by subtracting the mean from each value and plotting them on the x-axis as "normalized over mean." This does not change any of the factors derived from the regression equation. It leads to a lower VIF and eliminates the collinearity problem.

As Appendix 4-6 describes, the test statistic and the correlation improved. We obtained a test statistic of 3.26 and a coefficient of determination of .918. Based on this, we could reject the null hypothesis and hypothesize a polynomial relationship between the remediation costs and number of aircraft. It should be noted that as a result of the sample size being so small, model predictions have a large prediction interval. The next section summarizes the regression model and explains its associated shortcomings.

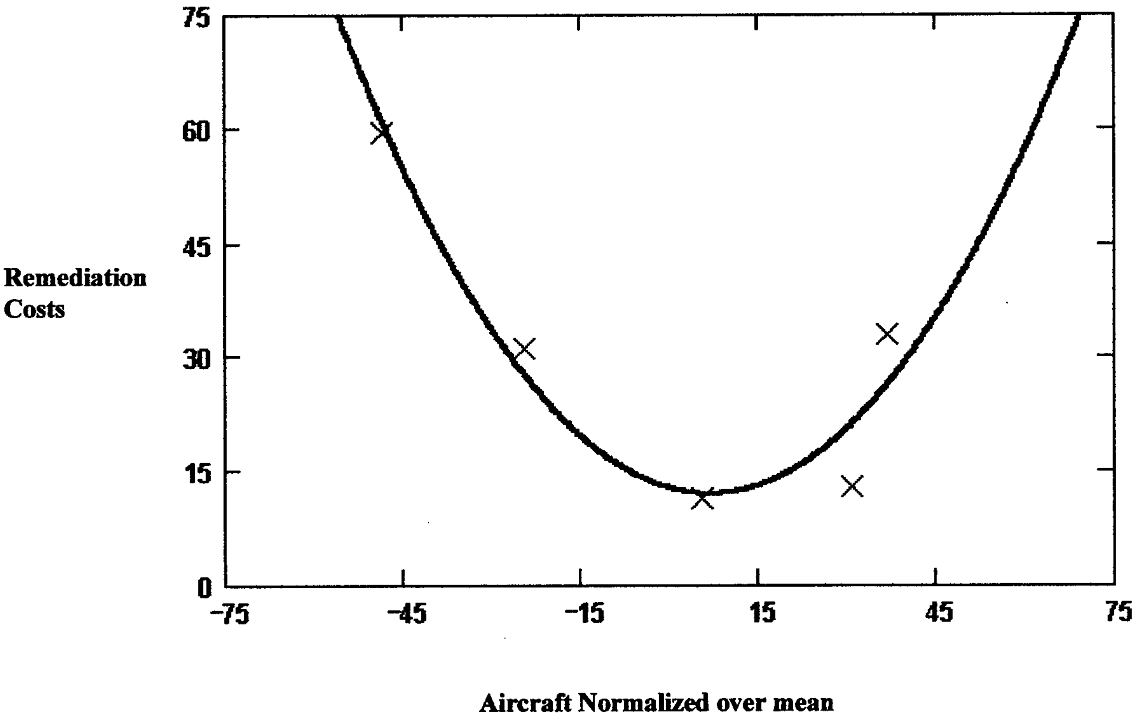


*Figure 9. Plot of Sample Data with Polynomial Regression Model*

## J. Specification of the Regression Model

The purpose of this section is to synopsize the parameters calculated for the polynomial regression model that relates remediation costs to total aircraft at those bases located in regressive states. As previously discussed, the coefficient of determination describes the proportion of observed remediation cost variation that can be explained by the simple linear regression model at a certain significance level. Knowing that everything in nature has a sense of uncertainty and variability associated with it (Lapuma, 1999), it is prudent that the study includes a discussion of the error.

### 1. Polynomial Regression Equation

Polynomial regression techniques are appropriate to use when peaks or valleys occur in a scatter plot of the data (Devore, 1995). Looking at bases in regressive states, we observed a valley in the plot where number of aircraft is used as a predictor. The generic form of a kth degree, polynomial regression model, equation is:

$$Y = \beta_o + \beta_1 x + \beta_2 x^2 + \ldots + \beta_k x^k + \varepsilon$$

Replacing the variables annotated as Y and X with remediation costs (RC) and "centered" number of aircraft (AC), we derived the equation:

$$RC = \beta_o + \beta_1 AC + \beta_2 AC^2 + \varepsilon$$

The final regression equation took the form of:

$$\boxed{RC = 12.825 - 0.223AC + 0.016AC^2}$$

## 2. Polynomial Regression Equation Error

The errors discussed in this section are type 1 and unexplained variation. The effort established a type I error of .1 for the polynomial regression equation. This meant that there was a ten-percent probability of rejecting the null hypothesis suggesting no relationship when it was true. It was stated earlier that the equation had a coefficient of determination equal to .918. This infers that there was 8.2 percent of unexplained variance. Simply stated, the number of aircraft did not fully explain the remediation costs. The intervals of possible β values provide a more account of the polynomial regression equation. Beginning with the βo value, we discover that we are actually 90% confident that the equation will estimate the true remediation costs within the interval of –5.571 and 31.222. This suggests that at the 90% confidence level, we can statistically state that although the value we obtained was 12.825, in fact we only know that the value could be within the range –5.571 and 31.22. Likewise, with the β1 and β2 values, we can state that we are 90% confident that the true value is between (–0.571 and 0.125) and (-18.380 and 18.413) respectively. Table 13 summarizes these data.

***Table 13. Statistical Ranges of the Beta Values at 90% Level***

| | Parameter | Value | Minimum | Maximum |
|---|---|---|---|---|
| 1 | $\text{Beta}_0$ | 12.825 | -5.571 | 31.222 |
| 2 | $\text{Beta}_1$ | -0.223 | -0.571 | 0.125 |
| 3 | $\text{Beta}_2$ | 0.016 | -18.380 | 18.413 |

# V. SURVEY RESEARCH

## A. Overview

The purpose of this chapter is to answer three of the research questions and to gather information concerning hazardous waste contamination sites at DoD installations in Korea. During the last two weeks of September 1998, Dr Goltz, Capt Hartman, and myself visited eleven DoD installations in South Korean. Appendix 5-1 provides the trip report for this visit. During this study, we interviewed twenty-two individuals ranging from senior supervisory personnel to action level employees. We focussed on the USFK staff to answer the research questions dealing with accuracy, cost, and time constraints, while including all the interviewees in discussions dealing with past remediation cost estimation efforts in Korea. During the DoD installation visits, we also obtained information about remediation efforts and specific mission details for later use in model applications (case studies).

This chapter is subdivided into two sections. The first section is focussed on answering research questions (1), (2), and (4). We will simply repeat the question and provide a synopsis of the answer obtained. The second section is geared at gathering site specific information. Since we discovered more remediation data at Kunsan and Osan ABs, these two will be used as case studies. Therefore, the only information presented in the second section of the chapter will relate to those installations.

## B. Answers Elicited from Research Questions

The objective of this research was to develop and test a method that could be used to expeditiously estimate costs of hazardous waste site remediation at US DoD installations in Korea for use by decision-makers in developing a hazardous waste site remediation strategy. In order to accomplish this objective, five interrelated research questions were developed. This section presents the answers elicited by questions (1), (2), and (4). Question (3) was answered during the literature review chapter and question (5) will be answered in the next chapter.

### 1. Question (1)

The first question was "What cost and time constraints do the decision-makers have in developing remediation cost estimates?" During our exploratory sojourn to Korea, we had several discussions with the Eighth US Army (EUSA) Environmental Program Office. As mentioned earlier, Appendix 5-2 provides a list of personnel interviewed. The relevant discussions revolved around the meaning of "expeditious." Mr John Anderson suggested that for USFK, expeditious referred to time measured in days, as compared to weeks or months (Anderson, 1998). Having severely limited economic resources to accomplish environmental projects, US DoD installations could not afford expending funds on long, drawn-out site characterization, risk assessment, and cost estimating studies (Kwon, 1998). For purposes of this research effort, we then defined "expeditious" as providing a cost estimate within the range of several days (potentially a week) which would also serve the purpose of minimizing scarce funds. Colonel Moldenhauer, Eighth Army Engineer, further requested that any tool or methodology provide results that are understandable to the installation commanders (Moldenhauer, 1998). Thus, if the methodology could be accomplished expeditiously and provide easily understood results, as well as meeting the accuracy criteria discussed in the next section, it would be applicable to US installations in Korea.

### 2. Question (2)

The second question was "What degree of accuracy do the decision-makers require for strategy formulation?" This was probably one of the most important areas of interest because of the plethora of cost estimating models available and the various ranges of estimation accuracy. Discussions with EUSA decision-makers elicited that there were two remediation scenarios for which cost estimates were needed. It was important for this study to look cost estimates that are applicable to installation-wide activities as well as for specific projects. The accuracy of a "screening" estimate for an entire installation needed to be within the range of +100% to –50% (Anderson, 1998; Kwon, 1998). This methodology could be used at the decision-maker level for strategy formulation. However, at the same time, the capability was needed for individual bases to expeditiously estimate the costs of individual remediation projects. During the preliminary assessment phases, the accuracy of this estimate needed to be a rough order of magnitude estimate within the range of +50% to –30%. Although models providing more accuracy might be needed as the remediation program progressed, these levels of accuracy were adequate for this early stage of the program.

### 3. Question (4)

The fourth question was "Have models been used to estimate costs of remediation activities at Korean installations?" and "How did estimated costs compare to actual costs of completed projects?" We did not discover any standardized estimating methods being used at DoD installations in Korea. It was apparent that not only each component, but also each installation determined their remediation costs in different fashions. For example, at several installations we were informed that the US

Army Corps of Engineers, Far East District of the Pacific Ocean Division, required $500,000 to accomplish a site characterization (Bliss, 1998; Pak, 1998; Yi, 1998; and Berdugo, 1998). This preliminary estimate seemed to be independent of the extent or type of contamination. We also found that at Osan AB, there had been several site investigation reports published which provided cost estimates (USACE, 1996; USACE, 1995). These estimates were calculated estimates using a spreadsheet because more detailed methods required extensive knowledge of site characteristics that were not available (Schlack, 1998). We concluded from our interviews that there were limited, if any recognized models being used at DoD installations in Korea. Also, there were few, if any, completed remediation projects found. Because of this, we could not compare cost of completed projects to estimated costs.

## C. Installation Specific Information for Model Use

In this section, we attempt to summarize the descriptions and characteristics of sites found at Osan and Kunsan Air Bases. This is important because the information gathered will be input into model(s) as part of our case study analysis in order to determine remediation costs at these two installations. As stated earlier, we focussed on Osan and Kunsan because several studies and site investigation reports had been accomplished describing the areas of concern for hazardous waste contamination. The "Restoration Management Action Plan," developed by the 240 Civil Engineer Flight from Buckley Air National Guard Base Colorado, provided the basic required data to be used in the Osan Air Base case study and cost approximately $25,000 (military travel expenses). The study had to further use several site investigation reports accomplished throughout the past six years, the costs of which were not known. The "Installation

Wide Environmental Baseline and Five Site Investigations of Kunsan Air Base, Republic of Korea," produced by Pacific Environmental Research for Woodward-Clyde Federal Services, provided the information required for the Kunsan AB case study and cost approximately $230,000. It should be noted, the data gathering effort was not extensive, thus the models can be applied without an expensive collection effort. It can further be noted that Captain Dean Hartman's companion study is looking at how to expeditiously (that is, quickly and inexpensively) characterize and assess risk at hazardous waste sites in Korea. Results from the companion study could be used to guide data acquisition from other US DoD installations in Korea.

### 1. Osan Air Base

The operational mission of Osan Air Base is to provide "ready, deployable F-16 and A/OA-10A aircraft, and a responsive support structure for all assigned personnel within the Osan AB family" (Osan AB, 1998). Flying operations began there in 1955 and the installation was named Osan Air Base in 1956 (Air Force Association, 1998). Captain Oshiba described contamination studies in Korea, to include Osan, as being "atypical, as recent remediation policy did not support intensive research efforts for other than immediate and substantial health risks" (Oshiba, 1997). Therefore, this situation limited our ability to obtain site-specific information to input into the model. Although studies at Korean installations were rare, Osan AB had arranged for the 240th Civil Engineer Flight from Buckley Air National Guard, Colorado, to accomplish a characterization study. As a guideline, we were able to use the data from this Restoration Management Action Plan (Buckley ANG, 1997). This study organized the remediation sites into (1) formerly identified restoration projects/activities/sites and (2) new areas of concern.

The study listed twenty-four formerly identified sites that had undergone some type of preliminary assessment, study or investigation. These are summarized in Table 14. Members of the 240th Civil Engineer Flight from Buckley Air National Guard reported that three of the sites had been remediated and closed. We could not determine the level of remedial efforts applied to these sites. During our visit to Osan AB, we actually found some form of assessment for fifteen of the identified sites (Table 14).

***Table 14. Formerly Identified Sites at Osan AB, Korea***

| Site # | Site | Location | Contaminant | Restoration Status |
|---|---|---|---|---|
| FT-001 | * Fire Training Area | South end of base | Fuels, Solvents | Site Investigation Completed |
| ST-001 | * Building 942 | Heating Plant | Diesel | Site Investigation Completed |
| ST-002 | * Building 1073 | Heating Plant | Diesel | Site Investigation Completed |
| SS-001 | * AMC Ramp | Ramp by Doolittle Gate | JP-4 | Site Investigation Completed |
| SS-002 | * POL Tank Farm Area | On Hill North side of base | JP-4 | Site Investigation Completed |
| SS-003 | * POL Railhead Area | NW rail yard | JP-4 | Site Investigation Completed |
| ST-003 | 1700 Jet Fuel Storage | Underground Area | JP-4 | Site Investigation Completed |
| ST-004 | Building 1466 | Dormitory | Diesel | Internal Preliminary Assessment |
| ST-005 | Building 819 | Supply Warehouse | Diesel | Internal Preliminary Assessment |
| ST-006 | Tank 5 (Building 300) | Fuel Farm | Diesel | Internal Preliminary Assessment |
| ST-007 | Building 1363 | Vehicle Maintenance | Diesel | Site Investigation Completed |
| ST-008 | * Tank 8 (Facility 1742) | 3 Million gallon storage | JP-4 | Site Investigation Completed |
| ST-009 | * Tank 9 (Facility 1743) | 3 Million gallon storage | JP-4 | Site Investigation Completed |
| ST-010 | Building 936 | Fuel Spill | Diesel | External Preliminary Assessment |
| ST-011 | Building 371 | Fuel Spill | Diesel | External Preliminary Assessment |
| ST-012 | Building 910 | Officers Club | Diesel | Contracted for Characterization |
| ST-013 | Building 334 | Pump Station | Diesel | 200 Gallons not recovered |
| ST-014 | Building 882 | Base Operations | Diesel | Waiting Excavation |
| ST-015 | Building 1882 | 36th Fighter Squadron | Diesel | Remediated and Closed |
| ST-016 | Building 2011 | Radar Site | Fuel and Oil | Remediated and Closed |
| ST-017 | * Building 1122 | Yard and Ditch | Diesel | Underground fuel line broken |
| ST-018 | * Building 1102 | Ditch | Diesel | Free Product, Sheen |
| ST-019 | * Buildings 1103, 1104 | Ditch | Diesel | Fish Kill, Mar 96 |
| ST-020 | Building 251 | DODDS School | Diesel | Closed as of Dec 94 |

**NOTE: * Indicates a formerly identified site that supporting report was found. (Buckley ANG, 1997)**

Members of the 240th Civil Engineer Flight further identified eighteen additional areas of concern (Buckley ANG, 1997). These sites were determined through interviews with base personnel. Table 15 summarizes the identified areas of concern. No studies had been accomplished on these potential areas of contamination.

***Table 15. Additional Areas of Concern for Osan AB Identified by Buckley ANG***

| Site # | Site | Location | Contaminant |
|---|---|---|---|
| SS-003 | Old LOX Facility | N of Wastewater Treatment | TCE |
| SS-004 | Old Power Production | | PCB Transformers |
| SS-005 | Supply Railhead | Train Car off-loading fuel | Fuel |
| SS-006 | Mini-Mall Area | Cab Maint in parking lot | Oils, cleaners |
| LF-001 | Youth Center (433) | Old Roads & Grounds | |
| SS-007 | Entomology Shop | Pesticide Sprayers washed | Pesticides |
| LF-002 | Landfill, Flightline | Along Perimeter Road | Construction & ??? |
| LF-003 | Landfill, Golf Course | Northwest corner | Construction & ??? |
| LF-004 | Landfill, Small Arms | South of small arms range | Trash & ??? |
| ST-021 | Arts & Crafts Center | leaking tank over ditch | Fuel Oil |
| ST-022 | Bldg 750 & 738 | School impacted by fumes | Heating Oil |
| ST-023 | Bldg 1302 | Fuel Spill Area | Fuel spill |
| ST-024 | Bldg 1210 | Fuel Spill Area | Fuel spill |
| ST-025 | Bldg 511 | Fuel Spill Area | Fuel, cleaners |
| SS-008 | Sand & Gravel Plant | Site Recon | Drums |
| SS-009 | East of Commissary | ROKAF stores drums/tanks | Fuel & ??? |
| OT-001 | Drainage Ditches | Throughout Base | Fuels, Solvents |
| SS-010 | Fence Lines / Runway | 4 to 6 foot around fence | pesticides |

The final information we required for providing decision-makers with an installation-wide cost estimate for strategy formulation was the total number of aircraft. This was determined earlier to be the one base parameter where a statistical correlation might be drawn. Osan AB has F-16, A-10, and C-12 aircraft assigned to the base (Air Force Association, 1998). Using the average aircraft per squadron ratio given in the *Air Force Magazine USAF Almanac 1998*, we estimated there were 24 F-16s, 17 A-10s, and 6 C-12s. This provided us with a total of 47 aircraft to be used in the polynomial model. A site-specific cost-estimating model will be applied to each of these sites, along with the polynomial regression equation to obtain an installation-wide estimate.

## 2. Kunsan Air Base

The operational mission of Kunsan Air Base is "to deliver lethal airpower when and where directed by the Air Component Commander" (Kunsan, 1999). This is accomplished by maintaining two F-16 fighter squadrons. Kunsan AB was originally constructed by the Japanese as a fighter/interceptor base in 1938 and occupied by the United States in September 1950 (Woodward-Clyde Federal Services, 1997). The 8th Tactical Fighter Wing, the Wolf Pack, began operations at Kunsan in 1971. There are approximately 54 aircraft currently located at Kunsan AB (Johnson, 1999). This research effort used data from two studies conducted by Woodward-Clyde Federal Services. The first study's objective was to "identify areas within the air base that may have soil or groundwater contamination that represents a significant human health risk or potentially threatens the environment" (Woodward-Clyde Federal Services, 1997). The second study's purpose was to "evaluate the nature and extent of contamination at five facilities at Kunsan Air Base which were identified by base personnel as being areas of potential environmental concern" (Woodward-Clyde Federal Services, 1997). Using these two assessments, we focussed on fourteen hazardous waste sites, summarized in Table 16. In the Woodward-Clyde reports, preliminary site assessments were only conducted on the first five sites. There were no recommendations for remediation technologies or cost estimates proposed.

A site-specific cost-estimating model will be applied to each of these 14 sites, along with the polynomial regression equation to obtain an installation-wide estimate.

## *Table 16. Areas of Environmental Concern for Remediation Efforts*

| Site # | Site | Contaminant | Description of Reasons for Contamination |
|---|---|---|---|
| 1 | Base Theater, Building 710 | Fuel Release | Potentially leaking UST or Piping |
| 2 | Northern POL Facility, Tank 3234 | Fuel Release | Fuel Spills and No Secondary Containment |
| 3 | Command Building, Building 1305 | Diesel, Fuel | Unknown Cause, No USTs in area |
| 4 | Military Gas Station, Building 816 | Diesel, Fuel | Leaking UST and general spills |
| 5 | Base Transportation, Building 960 | Fuels, Solvents | Approx 5 years old, stained surface soil |
| 6 | Former Vehicle Maintenance Facility, Building 810 | Fuel Release | Damaged UST |
| 7 | Southern POL Facility | Fuel Release | Fuel Spills and No Secondary Containment |
| 8 | Panton Pad Area | Fuels, Solvents | Refuel, minor maintenance, run-off to ditch |
| 9 | Haji Village Alleged Fill Area | Unknown | Area was filled in with unknown debris from base |
| 10 | Current Dry Cleaning Facility, Building 1360 | PCE, Solvents | PCE stored in open yard and used in operations |
| 11 | Former Dry Cleaning Facility, Building 508 | PCE, Solvents | PCE stored in open yard and used in operations |
| 12 | Jet Fuel Pipeline Area (bldg 960 & T/W 624) | JP-4 | Equipment valves have had seal failures |
| 13 | Electrical Transformer Storage Areas | PCB | Document release at scrap metal storage yard |
| 14 | Co-Located Club Construction Site | Fuel Release | Petroleum contaminated soil encountered |

# VI. MODEL SELECTION AND APPLICATION (CASE STUDY)

## A. Overview

The objective of this chapter is to select a model or method that meets the constraints of the decision-maker, as elicited from the answer to the first and second questions, and to apply this model using a case study. It is important to note that there will not be an attempt to select or develop the "best" model. Instead any model that meets the constraints established by USFK will be considered adequate. The model will be validated using actual remediation data from hazardous waste sites at Osan and Kunsan Air Bases in Korea.

## B. Model Selection

The fifth question posed to accomplish the objective of this research was "Of the methods/models elicited in question (3), which meet the needs of decision-makers as defined in questions' (1) and (2)?" During this section, we focus on choosing the appropriate model(s) for the decision-makers to use for environmental strategy formulation. We first compared the models obtained during the literature review to the cost and time constraints described by the decision-makers. In order to obtain an "expeditious" cost estimate, the decision-maker would have to be able to compile data and input the information over several days. The models which met this constraint were the Historical Cost Analysis System (HCAS), Cost of Remedial Action (CORA), Remedial Action Cost Engineering and Requirements (RACER) system, and the regression analysis method. Micro-Computer Aided Cost Engineer System (MCACES) required an extensive amount of detailed information about the site, which would require in-depth characterization before estimating. In order for the life-cycle cost estimating models to generate life-cycle costs for other remedial activities, the user would have to first input the cost estimates, which requires a considerable amount of effort. This would not provide the decision-makers with an appropriate cost-estimating tool. Although HCAS and CORA models both met the cost and time constraints, HCAS only had a limited database for comparisons and CORA was no longer in publication. This left us with using RACER and/or polynomial regression analysis as adequate models that met the cost and time constraints.

The second constraint required a certain level of accuracy of the cost estimate. Polynomial regression analysis and RACER were the only remaining models to be compared to this standard. Accuracy for regression analysis would depend upon the number of aircraft used in the case study. As previously displayed in Figure 9, we assumed that the prediction intervals associated with the cost estimate would be with the screening level accuracy of +100% to –50%. This assumption would be validated after applying the case studies to the regression model. There are no known studies describing the accuracy of the RACER system. The only indication of RACER's accuracy was a user cost engineering and analysis tool questionnaire distributed by CAPSTONE Corporation in 1994 with replies indicating +/- 25% and +/- 15% (Hombach and Stanley, 1994). With this information, we assumed that the RACER model met the decision-maker's constraint for site-specific cost estimates. We note at this point in the study that future efforts should be concentrated on validating and determining the accuracy of RACER. We decided to apply these two models to Osan and Kunsan Air

Base in order to expeditiously estimate the remediation costs resulting in a technique for decision-makers to use in strategy formulation.

## C. Osan Air Base Case Study

The objective of this section is to determine cost estimates for Osan Air Base using both polynomial regression and RACER models. For the polynomial regression, we will also include prediction intervals in order to quantify error.

### 1. Cost Estimate from Polynomial Regression Model

Earlier we discovered that approximately forty-seven aircraft were assigned to Osan Air Base. In Chapter 4 we presented a polynomial regression equation for use in determining remediation costs. This equation characterized the relationship between the number of aircraft (centered by subtracting the mean number of aircraft) and the installation-wide hazardous waste cleanup costs. The final formula was:

$$\boxed{RC = 12.825 - 0.223AC + 0.016AC^2}$$

We first took the 47 aircraft and subtracted the previously established mean of 60.4 from it. Using the result, –19.7, in the regression equation, we calculate an estimate of the total remediation costs for Osan AB to be **$23.5 million**. We also need to provide the decision-maker with an estimate of this result's variability. Applying the software program *Statistic* to calculate the prediction intervals, we are 90% confident that the polynomial regression model will estimate the remediation cost for Osan AB in the interval of **$6.3 to $40.6 million**.

## 2. Cost Estimate from RACER Model

The polynomial regression methodology provided an expeditious tool for estimating total installation remediation costs. A second way to estimate total costs is to apply the RACER model to each of the sites identified on an installation. We applied RACER to the formerly identified sites and new areas of concern at Osan AB (Buckley ANG, 1997). The information input into RACER was either available from a prior study, or it had to be assumed. For 12 of the 42 sites at Osan AB, various amounts of information were available. The US Army Corps of Engineers (USACE) previously accomplished site investigation reports on the AMC ramp area (USACE, 1996), tanks 8 and 9 (USACE, 1996), buildings 942 (USACE, 1996), 1073 (USACE, 1996), 1122 (USACE, 1996), and 1363 (USACE, 1997), the fire-training pit (USACE, 1997), and the ditches near buildings 1102, 1103, 1104 (USACE, 1996). These reports included a general site description and background, groundwater sampling, field observations, analytical results, conclusions and recommendations, and other basic assessment information. The USACE also completed a groundwater fuel-contaminant study on the petroleum, oils, and lubricants (POL) tank farm and the railhead facility (USACE, 1990). Through further research, we found preliminary assessments on building 1073 (AFCEE, 1993) and building 1466 (Osan BES, 1996).

Information that was not available, and that was needed by RACER, had to be assumed. There were several generic assumptions that were made:

1. Studies would have to be accomplished on sites evaluating groundwater, free product, and soil contamination,
2. The studies were classified as moderate and would provide a report in the format of a remedial investigation/feasibility study,
3. The remediation technologies of soil vapor extraction, bioventing, free product removal, or extraction were selected for cleanup,

4. Third-party engineering support would be minimal (on a scale of none to high),
5. Groundwater remediation projects were not evaluated,
6. Long term monitoring for groundwater (10 years) and soil contamination (5 years) was required,
7. 3-phase electricity had to be brought to the site from approximately 1000 feet away,
8. pumped water or free product would be disposed of in a sewer at 500' distance, and
9. Five wells per site were to be used for characterization and monitoring.

We also had to make several site-specific assumptions. For example, most of the reports did not include an estimated surface area of the contamination zone. Through examining the size of the building and type of contamination, estimates were inputted ranging from 1000 SF to 100,000 SF. A majority of these assumptions were made for the new areas of concern. When no assessments were available, the assumptions were made conservatively. Estimated remediation costs for individual sites can be seen in Tables 17 and 18.

***Table 17. Formerly ID Site Cost Estimation Using RACER for Osan AB***

| | | Project Remediation Costs | | | | | |
|---|---|---|---|---|---|---|---|
| **Site #** | **Site** | **Study** | **Design** | **Cleanup** | **O&M** | **Monitoring** | **Total** |
| FT-001 | Fire Training Area | $281,143 | $53,113 | $508,108 | $200,745 | $83,729 | $1,126,838 |
| ST-001 | Building 942 | $284,479 | $32,704 | $291,881 | $345,037 | $105,719 | $1,059,820 |
| ST-002 | Building 1073 | $524,529 | $87,057 | $860,569 | $397,420 | $179,553 | $2,049,128 |
| SS-001 | AMC Ramp | $379,984 | $41,551 | $402,234 | $297,987 | $239,656 | $1,361,412 |
| SS-002 | POL Tank Farm Area | $379,984 | $41,451 | $402,234 | $297,987 | $239,656 | $1,361,312 |
| SS-003 | POL Railhead Area | $379,984 | $37,663 | $342,400 | $258,241 | $242,332 | $1,260,620 |
| ST-003 | 1700 Jet Fuel Storage | $313,590 | $45,710 | $439,253 | $250,092 | $123,887 | $1,172,532 |
| ST-004 | Building 1466 | $310,024 | $37,393 | $330,955 | $171,307 | $82,089 | $931,768 |
| ST-005 | Building 819 | $207,969 | $38,546 | $350,417 | $117,873 | $82,089 | $796,894 |
| ST-006 | Tank 5 (Building 300) | $207,969 | $38,546 | $350,417 | $117,873 | $82,089 | $796,894 |
| ST-007 | Building 1363 | $174,233 | $28,022 | $245,711 | $94,583 | $81,319 | $623,868 |
| ST-008/9 | Tank 8 and 9 | $313,590 | $64,738 | $647,382 | $296,447 | $123,887 | $1,446,044 |
| ST-010 | Building 936 | $207,969 | $38,546 | $350,417 | $117,873 | $82,089 | $796,894 |
| ST-011 | Building 371 | $207,969 | $38,546 | $350,417 | $117,873 | $82,089 | $796,894 |
| ST-012 | Building 910 | $207,969 | $38,546 | $350,417 | $117,873 | $82,089 | $796,894 |
| ST-013 | Building 334 | $207,969 | $38,546 | $350,417 | $117,873 | $82,089 | $796,894 |
| ST-014 | Building 882 | $66,844 | $7,289 | $60,745 | $20,431 | $31,807 | $187,116 |
| ST-017 | Building 1122 | $200,527 | $32,953 | $285,541 | $27,499 | $47,304 | $593,824 |
| ST-018 | Building 1102,03,04 | $147,785 | $32,143 | $281,290 | $29,832 | $68,321 | $559,371 |
| | **TOTAL:** | **$5,004,510** | **$773,063** | **$7,200,805** | **$3,394,846** | **$2,141,793** | **$18,515,017** |
| | **PERCENT:** | **27.0%** | **4.2%** | **38.9%** | **18.3%** | **11.6%** | **100.0%** |

*Table 18. New AOC Site Cost Estimation Using RACER for Osan AB*

| | | Project Remediation Costs | | | | | |
|---|---|---|---|---|---|---|---|
| **Site #** | **Site** | **Study** | **Design** | **Cleanup** | **O&M** | **Monitoring** | **Total** |
| SS-003 | Old LOX Facility | $281,163 | $6,366 | $48,970 | $29,426 | $93,313 | $459,238 |
| SS-004 | Old Power Production | $160,229 | $43,047 | $430,466 | $0 | $19,585 | $653,327 |
| SS-005 | Supply Railhead | $217,374 | $11,146 | $101,334 | $32,120 | $60,846 | $422,820 |
| SS-006 | Mini-Mall Area | $84,063 | $33,362 | $333,616 | $0 | $21,214 | $472,255 |
| LF-001 | Youth Center (433) | $281,163 | $87,268 | $918,544 | $127,414 | $83,729 | $1,498,118 |
| SS-007 | Entomology Shop | $181,278 | $28,702 | $287,018 | $0 | $32,915 | $529,913 |
| LF-002 | Landfill, Flightline | $281,163 | $119,616 | $1,408,958 | $152,103 | $83,729 | $2,045,569 |
| LF-003 | Landfill, Golf Course | $281,163 | $119,616 | $1,408,958 | $152,103 | $83,729 | $2,045,569 |
| LF-004 | Landfill, Small Arms | $281,163 | $119,616 | $1,408,958 | $152,103 | $83,729 | $2,045,569 |
| ST-021 | Arts & Crafts Center | $269,724 | $32,549 | $289,530 | $73,778 | $31,807 | $697,388 |
| ST-022 | Bldg 750 & 738 | $186,218 | $8,415 | $70,128 | $23,846 | $31,807 | $320,414 |
| ST-023 | Bldg 1302 | $207,969 | $38,546 | $350,417 | $117,873 | $82,089 | $796,894 |
| ST-024 | Bldg 1210 | $207,969 | $38,546 | $350,417 | $117,873 | $82,089 | $796,894 |
| ST-025 | Bldg 511 | $207,969 | $38,546 | $350,417 | $117,873 | $82,089 | $796,894 |
| SS-008 | Sand & Gravel Plant | $281,163 | $87,268 | $918,544 | $127,414 | $83,729 | $1,498,118 |
| SS-009 | East of Commissary | $207,969 | $38,546 | $350,417 | $117,873 | $82,089 | $796,894 |
| OT-001 | Drainage Ditches | $341,133 | $45,870 | $441,702 | $348,953 | $31,807 | $1,209,465 |
| SS-010 | Fence Lines / Runway | $343,170 | $218,142 | $2,726,779 | $172,967 | $47,304 | $3,508,362 |
| | **TOTAL:** | **$4,302,043** | **$1,115,167** | **$12,195,173** | **$1,863,719** | **$1,117,599** | **$20,593,701** |
| | **PERCENT:** | **20.9%** | **5.4%** | **59.2%** | **9.0%** | **5.4%** | **100.0%** |
| | **GRAND TOTAL:** | **$9,306,553** | **$1,888,230** | **$19,395,978** | **$5,258,565** | **$3,259,392** | **$39,108,718** |
| | **GRAND PERCENT:** | **23.8%** | **4.8%** | **49.6%** | **13.4%** | **8.3%** | **100.0%** |

Tables 17 and 18 classify the project remediation costs into five categories. Study describes the cost associated with accomplishing preliminary assessments and site investigations. This cost includes monitoring wells, written reports, sampling and analysis, and professional labor. The design and cleanup costs reflect remedial design and action occurring at the site. Operations and Maintenance (O&M) costs include utilities, maintenance of equipment, and replacement of parts. The final category represents long-term monitoring. This cost accounts for sampling and analysis of the project site five to ten years post-remediation.

As can be seen from Tables 17 and 18, adding individual site estimates gives a total cost estimate of $39 million for Osan AB. Of this estimate, investigations and assessments comprised nearly twenty-five percent. As previously noted, some of these studies have already been completed although there was no description of the cost of these studies. Also, we excluded three of the sites because documentation suggested these areas had been completed and closed (Buckley ANG, 1997). Our research did not discover any indication of the remediation accomplished at these sites or any associated cost. Potentially, only surface remediation was accomplished leaving below ground contamination still present.

## D. Kunsan Air Base Case Study

The objective of this section is to determine cost estimates for Kunsan Air Base using both polynomial regression and RACER models. For the polynomial regression, we will also include prediction intervals in order to express a measurement of the error. As at Osan, RACER will be applied conservatively.

### 1. Cost Estimate from Polynomial Regression Model

There were approximately fifty-four aircraft assigned to Kunsan Air Base (Johnson, 1998). By subtracting the mean of 60.4 aircraft from 54, we obtain for input into the regression equation a value of –6.4. Applying the equation, we calculated the overall remediation cost for Kunsan Air Base to be **$14.9 million**. In the same fashion as calculations for Osan AB, we are 90% confident that the polynomial regression model will estimate the remediation cost for Kunsan AB in the interval of **$0 to $33.6 million**.

### 2. Cost Estimate from RACER Model

We followed a similar methodology for applying RACER at Kunsan AB as was done for Osan AB. Data was available from two reports (Woodward-Clyde, 1997a and 1997b). These reports contained data relating on the area (square footage) and depth of contamination of the base theater, northern POL facility, command building, military gas station, and base transportation facility. The same conservative assumptions that were made at Osan AB were made for the sites at Kunsan AB where information was not available. Table 19 provides the estimated remediation cost for each of the fourteen identified sites at Kunsan Air Base.

***Table 19. Site Cost Estimation Using RACER for Kunsan AB***

| | | Project Remediation Costs | | | | | |
|---|---|---|---|---|---|---|---|
| **Site #** | **Site** | **Study** | **Design** | **Cleanup** | **O&M** | **Monitoring** | **Total** |
| 1 | Base Theater | $283,375 | $32,076 | $284,301 | $106,177 | $105,954 | $811,883 |
| 2 | Northern POL Facility | $296,601 | $90,942 | $960,146 | $314,073 | $84,526 | $1,746,288 |
| 3 | Command Building | $174,741 | $34,418 | $310,167 | $111,102 | $82,253 | $712,681 |
| 4 | Military Gas Station | $206,131 | $32,724 | $288,888 | $134,489 | $82,253 | $744,485 |
| 5 | Base Transportation | $206,131 | $24,709 | $219,958 | $97,031 | $82,253 | $630,082 |
| 6 | Fmr Veh Maint Facility | $174,998 | $30,323 | $268,708 | $117,939 | $82,253 | $674,221 |
| 7 | Southern POL Facility | $296,601 | $90,942 | $960,146 | $314,073 | $84,526 | $1,746,288 |
| 8 | Panton Pad Area | $220,272 | $60,109 | $568,211 | $18,661 | $21,262 | $888,515 |
| 9 | Haji Village Fill Area | $346,479 | $117,755 | $1,395,714 | $127,554 | $83,903 | $2,071,405 |
| 10 | Current Dry Cleaning | $284,340 | $6,421 | $49,391 | $29,682 | $93,493 | $463,327 |
| 11 | Former Dry Cleaning | $284,340 | $11,710 | $97,580 | $51,605 | $93,493 | $538,728 |
| 12 | Jet Fuel Pipeline Area | $316,502 | $42,284 | $384,404 | $171,337 | $124,154 | $1,038,681 |
| 13 | Elec Transformer Area | $162,228 | $43,181 | $431,812 | $0 | $19,626 | $656,847 |
| 14 | Co-located Club Site | $210,082 | $38,890 | $353,547 | $118,648 | $82,253 | $803,420 |
| | **TOTAL:** | **$3,462,821** | **$656,484** | **$6,572,973** | **$1,712,371** | **$1,122,202** | **$13,526,851** |
| | **PERCENT:** | **25.6%** | **4.9%** | **48.6%** | **12.7%** | **8.3%** | **100.0%** |

Through the RACER model we obtained an estimate of **$13.6 million**. As at Osan AB, investigations and assessments comprised twenty-five percent of the total estimate. Again note that some of these studies had already been accomplished.

# VII. ANALYSIS AND VALIDATION

## A. Overview

The objective of this chapter is to analyze and validate the results obtained from the case studies of Osan and Kunsan Air Bases. As discussed earlier, a measure is valid if the measurement tool measured what it was supposed to measure. In this chapter, we attempt to determine whether the selected cost estimating models estimated hazardous waste site remediation costs at DoD installations in Korea. Specifically, did the estimates represent remediation costs at Osan and Kunsan?

We simultaneously analyzed face and concurrent validity. The face validity reflects a comparison between the estimates for Korea and those of the ACC bases, while concurrent validity compares the results of the RACER and regression models.

## B. Validating Remediation Cost Estimates

Let us look first at face validity. From Table 20, the regression model suggests a cost of $23.5 million for Osan and $14.9 million for Kunsan. How does this compare to the remediation costs estimated for the ACC bases? Previously, the remediation costs were described as appearing to have a lognormal distribution with eleven of the sixteen bases having total remediation costs below $40 million. The regression model was developed from five of these bases. Therefore, these five bases should not be used for validation purposes. Of the eleven remaining bases however, which can be used for validation, we note that seven had remediation costs below $40 million. It is prudent to reiterate that the ACC bases' total remediation costs are estimates. Ideally, applying it to a base where actual costs were available would validate the model.

The regression model, when applied to Osan and Kunsan Air Bases, also produced estimates below $40 million. Thus, it appears, at least "on the surface," that the estimated remediation costs of the Korean installations are in the same range as remediation costs obtained at ACC installations in the continental United States (CONUS).

***Table 20. Estimated Remediation Costs for Kunsan and Osan***

| Installation | Regression Model | | | RACER |
|---|---|---|---|---|
| | Lower Range | Predicted Value | Upper Range | Predicted Value |
| **Osan AB** | $6.3 | $23.5 | $40.6 | $39.0 |
| **Kunsan AB** | $0.0 | $14.9 | $33.6 | $13.6 |
| TOTAL: | **$6.3** | **$38.4** | **$74.2** | **$52.6** |

We next examined the cost estimates obtained using RACER. Osan and Kunsan AB remediation costs were calculated using RACER as $39 and $13.6 million, respectively, again within the range of the estimated remediation costs of ACC bases. It should be noted that the Osan estimate is on the upper end of the range. This perhaps is a result of the conservative assumptions that went into estimating costs for many of the unstudied sites, especially the landfills, fence lines, and ditches.

Let us now look at concurrent validity. Did the two models predict similar estimates? Looking at Osan AB, the RACER model predicted $39 million would be needed to remediate all sites. This estimate was calculated by summing the costs of remediating individual contamination sites. The regression model predicted a value of $23.5 million with a range of $6.3 to $40.6 million. The RACER estimate is close to the upper end of the regression model's interval. However, as mentioned earlier, this RACER estimate was conservative so it is not surprising it is on the high end of the regression model estimate. Unfortunately, quantifying the error of the RACER estimate is difficult.

Looking at Kunsan AB, the RACER estimate was $13.6 and the regression model estimate was $14.9 million for remediation of all sites. The agreement between the two estimates is surely somewhat fortuitous. The reason the RACER estimate for Osan appears more conservative than the Kunsan estimate perhaps has to do with the data upon which the estimates were based. The Osan estimate is based on information gathered from the Buckley Air National Guard report (Buckley ANG, 1997) while the Kunsan estimate is based on the Woodward-Clyde report (Woodward-Clyde, 1997a and 1997b). The Osan report provided more data applicable to the RACER model. Contamination characteristics such as dimensions, area, and volume were annotated for easy input into RACER. The Woodward-Clyde study, although providing extensive information, did not provide easily identifiable parameters for the RACER model. This resulted in more inaccurate data being input for Kunsan AB and possible underestimation. However, there is also a real reason that the Kunsan AB estimate could be lower than Osan AB's. Note from the history of the two installations that Osan AB has been operational for a significantly longer time than Kunsan AB.

Concurrent validity of both the Osan and Kunsan AB estimates suggests that the RACER and regression model are valid methods for remediation cost estimation.

## C. Discussion of Error

A study such as this would be incomplete without a discussion of source of error.

### 1. Sample of ACC Bases

One major source of error derives from the use of our sample of bases to represent US installations in Korea. We are implicitly assuming that ACC bases that were remediated in the 1990s in the US under the DERA program can be used to predict cleanup costs of DoD installations in Korea in the 2000s. This, combined with using estimated versus actual base remediation costs of the ACC bases, results in a major source of error.

### 2. RACER Model

Another major source of error is the application of RACER and having to make large, conservative assumptions while knowing very little about the sites. Project managers on site could better estimate parameters for input to RACER. Assumptions dealing with dimensions, type of cover (soil, gravel, or asphalt), distance to utilities, and other site characteristics would be more accurate if made by on-site managers. Much better values could be obtained using the results of Captain Dean Hartman's companion study to expeditiously characterize and assess risk at hazardous waste sites in Korea. Gathering this site information allows for improved accuracy of the cost estimates along with reduction of error.

Also note that the inherent error of remediation cost estimates using RACER has not been quantified. The cost estimate generated by RACER, a parametric estimating tool, is obtained by analysis of previous costs. This process in and of itself has some level of error associated with it. Although this study did not attempt to quantify the error with the RACER system, it certainly is a source of error.

# VIII. CONCLUSIONS AND RECOMMENDATIONS

This chapter presents the conclusions for this research effort and details several recommendations for future investigative studies. The objective of this study was to develop and test a method that can be used to expeditiously estimate costs of hazardous waste site remediation at US DoD installations in Korea for use by decision-makers in developing a hazardous waste site remediation strategy. Through the use of regression analysis techniques and the RACER 99 system, we determined an estimate for the scope of cleanup costs of Osan and Kunsan Air Bases. This study provides a tool that decision-makers can use to evaluate and formulate strategic policy.

## A. Conclusions

We pursued five interrelated research questions in the course of the study. Let us now revisit these questions and the answers we elicited. The first two questions asked the USFK decision-makers to provide constraints on cost, time, and accuracy for any expeditious model to be selected. The goal of this study, along with the companion study of Captain Hartman's, was to provide DoD decision-makers with a methodology that can be used to gather risk and cost data on hazardous waste sites in Korea quickly and cheaply. With these data available, better-informed decisions can be made regarding hazardous waste site remediation at DoD installations in Korea. "Expeditious" was defined as within the range of several days (potentially a week). Although RACER could be applied "expeditiously," the required information to input into RACER needed more effort to gather. The Woodward-Clyde studies of Kunsan AB took several months and only developed specific site investigation data on five sites. The Buckley ANG report provided a majority of the required data and required only two weeks to complete.

However, this study compiled data from several site investigation reports that had been accomplished over many years. If using RACER at an installation, we would recommend a study similar to the one accomplished by the Buckley ANG effort. Using that level of data, the estimates are screening level estimates with a range between +100 % and –50 % of the "actual" remediation cost and are adequate to provide decision-makers with needed information for strategy formulation.

The linear regression approach has the greater potential as an expeditious tool though the complexity of the remediation process, and the number of factors that impact the cost of remediation, create great difficulties in developing a simple regression equation to describe these remediation costs. Certainly, any estimate obtained using the regression model should be used with caution.

## B. Recommendations

There are several areas in which further study might be fruitful. The first area is simply to research other factors that may be related to remediation costs. This study only looked at five parameters (population, size, fuel usage, aircraft, and aircraft squadrons). However, there are many other potential parameters that may be relevant to costs. Parameters such as environmental flight size, flying squadron size, hazardous waste/material generation, number of vehicles, average age of military/civilian population, state environmental regulations, or even the number of contracts awarded each year may be related to installation remediation costs.

The second recommendation focuses on a more extensive validation and evaluation of the RACER 99 system. In the literature review, only one validation of RACER was found (Gleason and MaHarrey, 1993). Since RACER is used throughout the Air Force, it would be prudent to validate the estimates provided by this model. This may be accomplished through application of RACER 99 and MCACES on several completed projects. These results should be published in order to provide future users with the data required to apply these models with confidence.

Another area for future research is to apply this regression methodology to other branches of the military. We evaluated remediation costs specifically at Osan and Kunsan Air Bases. However, through our visit, we discovered that there were several Army installations in Korea with extensive contamination problems requiring evaluation. Methods applied in this study to estimate remediation costs at Air Force installations can be extended to Army and Navy installations without difficulty. A tool that can be applied to all installations on the Korean peninsula will provide decision-makers with the data they need to formulate future remediation strategy. Recall the quote in Chapter 1 from Ms Sherri Wasserman Goodman DUSD (ES):

> The Defense Department must have an environmental program that protects our troops and families; ... that fulfils our obligation to be good citizens; and that sets a good example to other militaries around the world. (DoD, 1998)

Becoming that role model requires the US military to be proactive in its strategy formulation. It insists we establish our environmental goals and objectives to meet mission requirements.

The Defense Environmental Restoration Program (DERP) has brought about substantial cleanup progress at DoD installations in the US, with Ms. Sherri Goodman, Deputy Undersecretary of Defense for Environmental Security (DUSD (ES)) proclaiming in the Fiscal Year 1997 Annual DERP Report to Congress that DoD was "...at the beginning of the end of our cleanup program" (DoD, 1998). However, as noted in

Chapter 1, because of Congressional and DoD policy, progress towards cleanup of DoD overseas installations significantly lags that of installations under the DERP. An expeditious model for estimating the scope of remediation at our installations in Korea is a needed tool for use by our decision-makers in formulating a strategy that meets our mission requirements and is protective of the health and well-being of our personnel, and those who live near our installations.

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## APPENDIX 1-1: Evolution of DoD Overseas Remediation Policy

This appendix discusses the evolution of remediation policy for DoD overseas installations. The first executive direction dealing with environmental issues at United States' overseas facilities was signed into effect by President Richard Nixon on 17 December 1973 (Phelps, 1998). Executive Order 11752 stated that:

> Heads of Federal agencies responsible for the construction and operations of Federal facilities outside the United States shall assure that such facilities are operated so as to comply with the environmental pollution standards of general applicability in the host country or jurisdictions concerned. (Nixon, 1973)

Executive Order (EO) 12088, which was signed by President Jimmy Carter on 13 October 1978, superseded EO 11752. Although EO 12088 had a significant impact on federal agencies within the US, requiring compliance with the most stringent federal, state, or local laws, the provision of EO 11752 regarding overseas installations was essentially unchanged. At the end of his tenure, President Carter signed EO 12114 that required environmental impact statements at DoD installations located within foreign countries. Executive Orders 12088 and 12114 are the only current orders that specifically relate to environmental issues at foreign installations. To implement these directives, DoD issued several instructions and regulations to provide guidance to DoD installations in foreign countries.

DoD Directive 6050.7, *Environmental Effects Abroad of Major Department of Defense Actions* issued in 1979, described key terms, review procedures, and detailed documentation requirements for the environmental impact analysis process overseas (Phelps, 1998). "It ... designated DoD Environmental Executive Agents (EEA) for nations with a significant DoD presence, and directed them to prepare 'final governing standards' (FGS) based essentially . . . [on] host-nation environmental standards" (Phelps, 1998). During the next fifteen years, several Secretary of Defense messages addressed environmental remediation at overseas facilities that were being returned to host nations. On 18 October 1995 the Department of Defense implemented the memorandum *Environmental Remediation Policy for DoD Activities Overseas.* Table 21 lists some of the important directives, instructions, and guidance documents issued by the Department of Defense dealing with environmental issues in general, and environmental remediation specifically, at overseas installations.

***Table 21. DoD Overseas Installations' Directives and Instructions***

| NUMBER | TITLE | DATE |
|---|---|---|
| DoD Directive 6050.7 | Environmental Effects Abroad of Major Department of Defense Actions | 31-Mar-79 |
| DoD Directive 6050.16 | DoD Policy for Establishing and Implementing Environmental Standards at Overseas Installations | 20-Sep-91 |
| Policy Memorandum | DoD Policy and Procedures for the Return to Host Governments of Overseas Sites and Facilities | 13-Jan-92 |
| Policy Memorandum | DoD Policy and Procedures for the Realignment of Overseas Sites | 14-Dec-93 |
| Memorandum | Environmental Remediation Policy for DoD Activities Overseas | 18-Oct-95 |
| DoD Directive 4715.1 | Environmental Security | 24-Feb-96 |
| DoD Instruction 4615.5 | Management of Environmental Compliance at Overseas Installations | 22-Apr-96 |
| DoD Instruction 4715.8 | Environmental Remediation for DoD Activities Overseas | 02-Feb-98 |

The October 1995 memorandum provided an avenue for overseas commanders to remediate hazardous waste sites if they posed "known imminent and substantial endangerments to human health and safety due to environmental contamination caused by DoD operations" (DoD, 1995). Also, commanders, after consultation with the environmental executive agent, could remediate hazardous waste sites if "required to maintain operations ... to protect human health and safety ... [or required by] ...

international agreements" (DoD, 1995). On 2 February 1998, the 1995 memorandum was formalized when DoD issued DoDI 4715.8 (DoD, 1998).

## APPENDIX 4-1: Mathcad Template of Costs Versus Population

**1.** Initially, Mathcad requires the researcher to establish a starting point for matrix operation.

$$\mathbf{ORIGIN \equiv 1}$$

**2.** The second step is inputting the variables, in matrix form, to be used....

**Y = Remediation Cost** **X = Aircraft on Base**

$$Y := \begin{bmatrix} 13.3 \\ 106.5 \\ 11.5 \\ 13.1 \\ 17.5 \\ 59.7 \\ 33.1 \\ 170.8 \\ 9.8 \\ 39.4 \\ 6.8 \\ 34.7 \\ 31.2 \\ 119.7 \\ 81.8 \\ 22.3 \end{bmatrix} \qquad X := \begin{bmatrix} 1 & 24 \\ 1 & 18 \\ 1 & 66 \\ 1 & 91 \\ 1 & 56 \\ 1 & 12 \\ 1 & 97 \\ 1 & 60 \\ 1 & 12 \\ 1 & 55 \\ 1 & 70 \\ 1 & 26 \\ 1 & 36 \\ 1 & 100 \\ 1 & 92 \\ 1 & 37 \end{bmatrix}$$

Display the CROSS PRODUCT MATRIX and its INVERSE...

$$X^T \cdot X = \begin{bmatrix} 16 & 852 \\ 852 & 5.97 \cdot 10^4 \end{bmatrix}$$

Where, n = 16 and total aircraft = 58,570.

$$X^T \cdot Y = \begin{bmatrix} 771.2 \\ 4.445 \cdot 10^4 \end{bmatrix}$$

**3.** We next checked for singularity....

$$\left| X^T \cdot X \right| = 2.293 \cdot 10^5$$

If determinant had been equal to zero than it would not have been invertible.

**4.** We obtain the values for Beta Estimates and the Estimate of $\sigma^2$. During this time we also determine values for SSTO, SSR, SSE, MSR, MSE, and relevant Degrees of Freedom.

**SSTO** is the total sum of squares relating to the predictor variable.
**SSR** is the treatment sum of squares relating to the predictor variable.
**SSE** is the error sum of squares relating to the predictor variable.
**MSR** is the mean square for treatments relating to the predictor variable.
**MSE** is the mean square for error relating to the predictor variable.

$n := \text{rows}(Y) \qquad p := \text{cols}(X)$

$\beta_{hat} := \left(X^T \cdot X\right)^{-1} \cdot X^T \cdot Y \qquad \beta_{hat} = \begin{bmatrix} 39.2 \\ 0.001 \end{bmatrix}$ Known as $\beta hat_0$ Known as $\beta hat_1$

$Y_{bar} := \text{mean}(Y)$ The remediation cost mean... $Y_{bar} = 48.2$

$Y_{hat} := X \cdot \beta_{hat} \qquad e := Y - Y_{hat}$ ...Residual Values

$SSE := e^T \cdot e \qquad SSE = 3.404 \cdot 10^4$ ...Error Sum of Squares

$SSTO := \left(Y - Y_{bar}\right)^T \cdot \left(Y - Y_{bar}\right) \qquad SSTO = 3.418 \cdot 10^4$

$SSR := SSTO - SSE \qquad SSR = 139.793$

$df_{SSTO} := n - 1 \qquad df_{SSR} := p - 1 \qquad df_{SSE} := n - p$

$df_{SSTO} = 15 \qquad df_{SSR} = 1 \qquad df_{SSE} = 14$

$MSR := \dfrac{SSR}{df_{SSR}} \qquad MSR = 139.793$

$MSE := \dfrac{SSE}{df_{SSE}} \qquad MSE = 2431.339$

**5.** We now display the vectors from the Y (Remediation Costs), Yhat (Model depiction of Remediation Costs), and e (Resulting error matrix).

$$Y = \begin{array}{c|c} & 1 \\ \hline 1 & 13.3 \\ 2 & 106.5 \\ 3 & 11.5 \\ 4 & 13.1 \\ 5 & 17.5 \\ 6 & 59.7 \\ 7 & 33.1 \\ 8 & 170.8 \\ 9 & 9.8 \\ 10 & 39.4 \\ 11 & 6.8 \\ 12 & 34.7 \\ 13 & 31.2 \\ 14 & 119.7 \\ 15 & 81.8 \\ 16 & 22.3 \end{array} \qquad Y_{hat} = \begin{array}{c|c} & 1 \\ \hline 1 & 41.296 \\ 2 & 39.88 \\ 3 & 51.21 \\ 4 & 57.111 \\ 5 & 48.849 \\ 6 & 38.463 \\ 7 & 58.527 \\ 8 & 49.793 \\ 9 & 38.463 \\ 10 & 48.613 \\ 11 & 52.154 \\ 12 & 41.768 \\ 13 & 44.128 \\ 14 & 59.235 \\ 15 & 57.347 \\ 16 & 44.364 \end{array} \qquad e = \begin{array}{c|c} & 1 \\ \hline 1 & -27.996 \\ 2 & 66.62 \\ 3 & -39.71 \\ 4 & -44.011 \\ 5 & -31.349 \\ 6 & 21.237 \\ 7 & -25.427 \\ 8 & 121.007 \\ 9 & -28.663 \\ 10 & -9.213 \\ 11 & -45.354 \\ 12 & -7.068 \\ 13 & -12.928 \\ 14 & 60.465 \\ 15 & 24.453 \\ 16 & -22.064 \end{array}$$

Residual
Matrix
<---------

**6.** The next step involves calculating the values for the Tstar (test statistic).

$$\mathrm{Var}_{betahat} := \mathrm{MSE}_1 \cdot \left(X^T \cdot X\right)^{-1} \qquad \mathrm{Var}_{betahat} = \begin{bmatrix} 620.779 & -8.859 \\ -8.859 & 0.166 \end{bmatrix}$$

$$\mathrm{Var}_{yhat} := \mathrm{MSE}_1 \cdot \left[ X \cdot \left(X^T \cdot X\right)^{-1} \cdot X^T \right]$$

MSE is the estimate of $\sigma^2$.

$$s_{\beta o} := \sqrt{\mathrm{Var}_{betahat_{1,1}}} \qquad s_{\beta o} = 24.915$$

$$s_{\beta 1} := \sqrt{\mathrm{Var}_{betahat_{2,2}}} \qquad s_{\beta 1} = 0.408$$

$$\mathrm{Tstar} := \frac{\beta\, hat_2}{s_{\beta 1}} \qquad \mathrm{Tstar} = 0.579$$

**7.** Next we determine values for Fstar and p-value as additional test.

$$F_{star} := \frac{MSR}{MSE_1} \qquad F_{star} = 0.335$$

$$Prob := 1 - pF\left(F_{star_1}, df_{SSR}, df_{SSE}\right) \qquad Prob = 0.572$$

**8.** With this information, we can display the data in an Analysis of Variance (ANOVA) table (Devore, 1995).

***Table 22. ANOVA Table for Remediation Costs Vs Population***

| Source | SS | df | MS | F & Prob Value |
|---|---|---|---|---|
| **Regression** | $SSR = 139.793$ | $df_{SSR} = 1$ | $MSR = 139.8$ | $F_{star} = 0.057$ |
| **Error** | $SSE = 34038.7$ | $df_{SSE} = 14$ | $MSE = 2431.3$ | $Prob = 0.814$ |
|  | $SSTO = 34178.5$ | $df_{SSTO} = 15$ |  |  |

**9.** Additional information we can calculate is a 100(1-$\alpha$)% Confidence Interval for $\beta 1$ and the Correlation Coefficient.

$\alpha := .1$ Assuming an a value of .1 which defines a Type I error of 10%.

$$LB := \beta\ hat_2 - \left|qt\left(\frac{\alpha}{2}, n - p\right)\right| \cdot s_{\beta 1} \qquad LB = -0.009$$

...Lower Bound

$$\beta\ hat_2 = 0.001$$

$$UB := \beta\ hat_2 + \left|qt\left(\frac{\alpha}{2}, n - p\right)\right| \cdot s_{\beta 1} \qquad UB = 0.012$$

...Upper Bound

This summarizes as we are 90% confident that the process will hook the true value of $\beta 1$ with the interval:

$$\{\ LB = -0.009 \quad , \quad UB = 0.012\ \}$$

The sample correlation coefficient is calculated as follows (Devore, 1995)...

$$X_{bar} := \frac{\sum_{i=1}^{n} X_{i,2}}{n}$$

$X_{bar} = 53.25$ Mean value for the predictor values

$Y_{bar} = 48.2$ Mean value for the predicand values

$$s_{xy} := \sum_{i=1}^{n} \left(X_{i,2} - X_{bar}\right)\cdot\left(Y_i - Y_{bar}\right)$$

**R is equal to the sample correlation coefficient...**

$$R := \frac{s_{xy}}{\sqrt{\sum_{i=1}^{n} \left(X_{i,2} - X_{bar}\right)^2} \cdot \sqrt{\sum_{i=1}^{n} \left(Y_i - Y_{bar}\right)^2}}$$

R squared is the measure of correlation $R^2 = 0.023$

## APPENDIX 4-2: Mathcad Template of Costs Versus Size

**1.** Initially, Mathcad requires the researcher to establish a starting point for matrix operation.

$$\mathrm{ORIGIN} \equiv 1$$

**2.** The second step is inputting the variables, in matrix form, to be used....

**Y = Remediation Cost** **X = Size of Base**

$$Y := \begin{bmatrix} 13.3 \\ 106.5 \\ 11.5 \\ 13.1 \\ 17.5 \\ 59.7 \\ 33.1 \\ 170.8 \\ 9.8 \\ 39.4 \\ 6.8 \\ 34.7 \\ 31.2 \\ 119.7 \\ 81.8 \\ 22.3 \end{bmatrix} \qquad X := \begin{bmatrix} 1 & 4000 \\ 1 & 22944 \\ 1 & 25663 \\ 1 & 11000 \\ 1 & 6437 \\ 1 & 10632 \\ 1 & 59000 \\ 1 & 3216 \\ 1 & 13549 \\ 1 & 6050 \\ 1 & 9112 \\ 1 & 11000 \\ 1 & 4041 \\ 1 & 3233 \\ 1 & 3363 \\ 1 & 4627 \end{bmatrix}$$

Display the CROSS PRODUCT MATRIX and its INVERSE...

$$X^T \cdot X = \begin{bmatrix} 16 & 1.979 \cdot 10^5 \\ 1.979 \cdot 10^5 & 5.452 \cdot 10^9 \end{bmatrix}$$

Where, n = 16 and total size of bases = 5,452,000,000.

$$X^T \cdot Y = \begin{bmatrix} 771.2 \\ 7.892 \cdot 10^6 \end{bmatrix}$$

**3.** We next checked for singularity....

$$\left| X^T \cdot X \right| = 4.807 \cdot 10^{10}$$

If determinant had been equal to zero than it would not have been invertible.

**4.** We obtain the values for Beta Estimates and the Estimate of $\sigma^2$. During this time we also determine values for SSTO, SSR, SSE, MSR, MSE, and relevant Degrees of Freedom.

**SSTO** is the total sum of squares relating to the predictor variable.
**SSR** is the treatment sum of squares relating to the predictor variable.
**SSE** is the error sum of squares relating to the predictor variable.
**MSR** is the mean square for treatments relating to the predictor variable.
**MSE** is the mean square for error relating to the predictor variable.

$n := \mathrm{rows}(Y) \qquad p := \mathrm{cols}(X)$

$\beta_{hat} := \left(X^T \cdot X\right)^{-1} \cdot X^T \cdot Y \qquad \beta_{hat} = \begin{bmatrix} 54.973 \\ -5.477 \cdot 10^{-4} \end{bmatrix}$ Known as $\beta hat_0$ Known as $\beta hat_1$

$Y_{bar} := \mathrm{mean}(Y)$ The remediation cost mean... $Y_{bar} = 48.2$

$Y_{hat} := X \cdot \beta_{hat} \qquad e := Y - Y_{hat}$ ... Residual Values

$SSE := e^T \cdot e \qquad SSE = 3.328 \cdot 10^4$ ... Error Sum of Squares

$SSTO := \left(Y - Y_{bar}\right)^T \cdot \left(Y - Y_{bar}\right) \qquad SSTO = 3.418 \cdot 10^4$

$SSR := SSTO - SSE \qquad SSR = 901.182$

$df_{SSTO} := n - 1 \qquad df_{SSR} := p - 1 \qquad df_{SSE} := n - p$

$df_{SSTO} = 15 \qquad df_{SSR} = 1 \qquad df_{SSE} = 14$

$MSR := \frac{SSR}{df_{SSR}} \qquad MSR = 901.182$

$MSE := \frac{SSE}{df_{SSE}} \qquad MSE = 2376.954$

**5.** We now display the vectors from the Y (Remediation Costs), Yhat (Model depiction of Remediation Costs), and e (Resulting error matrix).

$$Y = \begin{array}{c|c} & 1 \\ \hline 1 & 13.3 \\ 2 & 106.5 \\ 3 & 11.5 \\ 4 & 13.1 \\ 5 & 17.5 \\ 6 & 59.7 \\ 7 & 33.1 \\ 8 & 170.8 \\ 9 & 9.8 \\ 10 & 39.4 \\ 11 & 6.8 \\ 12 & 34.7 \\ 13 & 31.2 \\ 14 & 119.7 \\ 15 & 81.8 \\ 16 & 22.3 \end{array} \qquad Y_{hat} = \begin{array}{c|c} & 1 \\ \hline 1 & 52.782 \\ 2 & 42.407 \\ 3 & 40.918 \\ 4 & 48.948 \\ 5 & 51.447 \\ 6 & 49.15 \\ 7 & 22.661 \\ 8 & 53.212 \\ 9 & 47.552 \\ 10 & 51.659 \\ 11 & 49.982 \\ 12 & 48.948 \\ 13 & 52.76 \\ 14 & 53.202 \\ 15 & 53.131 \\ 16 & 52.439 \end{array} \qquad e = \begin{array}{c|c} & 1 \\ \hline 1 & -39.482 \\ 2 & 64.093 \\ 3 & -29.418 \\ 4 & -35.848 \\ 5 & -33.947 \\ 6 & 10.55 \\ 7 & 10.439 \\ 8 & 117.588 \\ 9 & -37.752 \\ 10 & -12.259 \\ 11 & -43.182 \\ 12 & -14.248 \\ 13 & -21.56 \\ 14 & 66.498 \\ 15 & 28.669 \\ 16 & -30.139 \end{array}$$

Residual Matrix
<----------

**6.** The next step involves calculating the values for the Tstar (test statistic).

$$Var_{betahat} := MSE_1 \cdot \left(X^T \cdot X\right)^{-1} \qquad Var_{betahat} = \begin{bmatrix} 269.548 & -0.01 \\ -0.01 & 7.911 \cdot 10^{-7} \end{bmatrix}$$

$$Var_{yhat} := MSE_1 \cdot \left[X \cdot \left(X^T \cdot X\right)^{-1} \cdot X^T\right]$$

MSE is the estimate of $\sigma^2$.

$$s_{\beta o} := \sqrt{Var_{betahat_{1,1}}} \qquad s_{\beta o} = 16.418$$

$$s_{\beta 1} := \sqrt{Var_{betahat_{2,2}}} \qquad s_{\beta 1} = 8.894 \cdot 10^{-4}$$

$$Tstar := \frac{\beta\,hat_2}{s_{\beta 1}} \qquad Tstar = -0.616$$

**7.** Next we determine values for Fstar and p-value as additional test.

$$F_{star} := \frac{MSR}{MSE_1} \qquad F_{star} = 0.379$$

$$Prob := 1 - pF\left(F_{star_1}, df_{SSR}, df_{SSE}\right) \qquad Prob = 0.548$$

**8.** With this information, we can display the data in an Analysis of Variance (ANOVA) table (Devore, 1995).

***Table 23. ANOVA Table for Remediation Costs Vs Size (Acres)***

| Source | SS | df | MS | F & Prob Value |
|---|---|---|---|---|
| Regression | $SSR = 901.182$ | $df_{SSR} = 1$ | $MSR = 901.2$ | $F_{star} = 0.379$ |
| Error | $SSE = 33277.4$ | $df_{SSE} = 14$ | $MSE = 2377$ | $Prob = 0.548$ |
| | $SSTO = 34178.5$ | $df_{SSTO} = 15$ | | |

**9.** Additional information we can calculate is a 100(1-α)% Confidence Interval for β1 and the Correlation Coefficient.

$\alpha := .1$ Assuming an a value of .1 which defines a Type I error of 10%.

$$LB := \beta\ hat_2 - \left|qt\left(\frac{\alpha}{2}, n - p\right)\right| \cdot s_{\beta 1} \qquad LB = -0.002$$ ...Lower Bound

$$\beta\ hat_2 = -5.477 \cdot 10^{-4}$$

$$UB := \beta\ hat_2 + \left|qt\left(\frac{\alpha}{2}, n - p\right)\right| \cdot s_{\beta 1} \qquad UB = 0.001$$ ...Upper Bound

This summarizes as we are 90% confident that the process will hook the true value of β1 with the interval:

$$(\quad LB = -0.002 \quad , \quad UB = 0.001 \quad )$$

The sample correlation coefficient is calculated as follows (Devore, 1995)...

$$X_{bar} := \frac{\sum_{i=1}^{n} X_{i,2}}{n} \qquad X_{bar} = 1.237 \cdot 10^{4}$$ Mean value for the predictor values

$$Y_{bar} = 48.2$$ Mean value for the predicand values

$$s_{xy} := \sum_{i=1}^{n} \left(X_{i,2} - X_{bar}\right) \cdot \left(Y_i - Y_{bar}\right)$$

**R is equal to the sample correlation coefficient...**

$$R := \frac{s_{xy}}{\sqrt{\sum_{i=1}^{n} \left(X_{i,2} - X_{bar}\right)^2} \cdot \sqrt{\sum_{i=1}^{n} \left(Y_i - Y_{bar}\right)^2}}$$

R squared is the measure of correlation $R^2 = 0.026$

## APPENDIX 4-3: Mathcad Template of Costs Versus Aircraft

**1.** Initially, Mathcad requires the researcher to establish a starting point for matrix operation.

$$\mathrm{ORIGIN} \equiv 1$$

**2.** The second step is inputting the variables, in matrix form, to be used....

**Y = Remediation Cost** **X = Aircraft on Base**

$$Y := \begin{bmatrix} 13.3 \\ 106.5 \\ 11.5 \\ 13.1 \\ 17.5 \\ 59.7 \\ 33.1 \\ 170.8 \\ 9.8 \\ 39.4 \\ 6.8 \\ 34.7 \\ 31.2 \\ 119.7 \\ 81.8 \\ 22.3 \end{bmatrix} \qquad X := \begin{bmatrix} 1 & 24 \\ 1 & 18 \\ 1 & 66 \\ 1 & 91 \\ 1 & 56 \\ 1 & 12 \\ 1 & 97 \\ 1 & 60 \\ 1 & 12 \\ 1 & 55 \\ 1 & 70 \\ 1 & 26 \\ 1 & 36 \\ 1 & 100 \\ 1 & 92 \\ 1 & 37 \end{bmatrix}$$

Display the CROSS PRODUCT MATRIX and its INVERSE...

$$X^T \cdot X = \begin{bmatrix} 16 & 852 \\ 852 & 5.97 \cdot 10^4 \end{bmatrix}$$

Where, n = 16 and total aircraft = 58,570.

$$X^T \cdot Y = \begin{bmatrix} 771.2 \\ 4.445 \cdot 10^4 \end{bmatrix}$$

**3.** We next checked for singularity....

$$\left| X^T \cdot X \right| = 2.293 \cdot 10^5$$

If determinant had been equal to zero than it would not have been invertible.

**4.** We obtain the values for Beta Estimates and the Estimate of $\sigma^2$. During this time we also determine values for SSTO, SSR, SSE, MSR, MSE, and relevant Degrees of Freedom.

**SSTO** is the total sum of squares relating to the predictor variable.
**SSR** is the treatment sum of squares relating to the predictor variable.
**SSE** is the error sum of squares relating to the predictor variable.
**MSR** is the mean square for treatments relating to the predictor variable.
**MSE** is the mean square for error relating to the predictor variable.

$n := \mathrm{rows}(Y) \qquad p := \mathrm{cols}(X)$

$\beta_{hat} := \left(X^T \cdot X\right)^{-1} \cdot X^T \cdot Y \qquad \beta_{hat} = \begin{bmatrix} 35.631 \\ 0.236 \end{bmatrix}$ Known as $\beta hat_0$ Known as $\beta hat_1$

$Y_{bar} := \mathrm{mean}(Y)$ The remediation cost mean... $Y_{bar} = 48.2$

$Y_{hat} := X \cdot \beta_{hat} \qquad e := Y - Y_{hat}$ ... Residual Values

$SSE := e^T \cdot e \qquad SSE = 3.338 \cdot 10^4$ ... Error Sum of Squares

$SSTO := \left(Y - Y_{bar}\right)^T \cdot \left(Y - Y_{bar}\right) \qquad SSTO = 3.418 \cdot 10^4$

$SSR := SSTO - SSE \qquad SSR = 798.455$

$df_{SSTO} := n - 1 \qquad df_{SSR} := p - 1 \qquad df_{SSE} := n - p$

$df_{SSTO} = 15 \qquad df_{SSR} = 1 \qquad df_{SSE} = 14$

$MSR := \frac{SSR}{df_{SSR}} \qquad MSR = 798.455$

$MSE := \frac{SSE}{df_{SSE}} \qquad MSE = 2384.292$

**5.** We now display the vectors from the Y (Remediation Costs), Yhat (Model depiction of Remediation Costs), and e (Resulting error matrix).

$$Y = \begin{array}{c|c} & 1 \\ \hline 1 & 13.3 \\ 2 & 106.5 \\ 3 & 11.5 \\ 4 & 13.1 \\ 5 & 17.5 \\ 6 & 59.7 \\ 7 & 33.1 \\ 8 & 170.8 \\ 9 & 9.8 \\ 10 & 39.4 \\ 11 & 6.8 \\ 12 & 34.7 \\ 13 & 31.2 \\ 14 & 119.7 \\ 15 & 81.8 \\ 16 & 22.3 \end{array} \qquad Y_{hat} = \begin{array}{c|c} & 1 \\ \hline 1 & 41.296 \\ 2 & 39.88 \\ 3 & 51.21 \\ 4 & 57.111 \\ 5 & 48.849 \\ 6 & 38.463 \\ 7 & 58.527 \\ 8 & 49.793 \\ 9 & 38.463 \\ 10 & 48.613 \\ 11 & 52.154 \\ 12 & 41.768 \\ 13 & 44.128 \\ 14 & 59.235 \\ 15 & 57.347 \\ 16 & 44.364 \end{array} \qquad e = \begin{array}{c|c} & 1 \\ \hline 1 & -27.996 \\ 2 & 66.62 \\ 3 & -39.71 \\ 4 & -44.011 \\ 5 & -31.349 \\ 6 & 21.237 \\ 7 & -25.427 \\ 8 & 121.007 \\ 9 & -28.663 \\ 10 & -9.213 \\ 11 & -45.354 \\ 12 & -7.068 \\ 13 & -12.928 \\ 14 & 60.465 \\ 15 & 24.453 \\ 16 & -22.064 \end{array}$$

Residual
Matrix
<----------

**6.** The next step involves calculating the values for the Tstar (test statistic).

$$\mathrm{Var}_{betahat} := \mathrm{MSE}_1 \cdot \left(X^T \cdot X\right)^{-1} \qquad \mathrm{Var}_{betahat} = \begin{bmatrix} 620.779 & -8.859 \\ -8.859 & 0.166 \end{bmatrix}$$

$$\mathrm{Var}_{yhat} := \mathrm{MSE}_1 \cdot \left[ X \cdot \left(X^T \cdot X\right)^{-1} \cdot X^T \right]$$

MSE is the estimate of $\sigma^2$.

$$s_{\beta o} := \sqrt{\mathrm{Var}_{betahat_{1,1}}} \qquad s_{\beta o} = 24.915$$

$$s_{\beta 1} := \sqrt{\mathrm{Var}_{betahat_{2,2}}} \qquad s_{\beta 1} = 0.408$$

$$\mathrm{Tstar} := \frac{\beta\, hat_2}{s_{\beta 1}} \qquad \mathrm{Tstar} = 0.579$$

**7.** Next we determine values for Fstar and p-value as additional test.

$$F_{star} := \frac{MSR}{MSE_1} \qquad F_{star} = 0.335$$

$$Prob := 1 - pF\left(F_{star_1}, df_{SSR}, df_{SSE}\right) \qquad Prob = 0.572$$

**8.** With this information, we can display the data in an Analysis of Variance (ANOVA) table (Devore, 1995).

***Table 24. ANOVA Table for Remediation Costs Vs Aircraft***

| Source | SS | df | MS | F & Prob Value |
|---|---|---|---|---|
| **Regression** | $SSR = 798.455$ | $df_{SSR} = 1$ | $MSR = 798.5$ | $F_{star} = 0.335$ |
| **Error** | $SSE = 33380.1$ | $df_{SSE} = 14$ | $MSE = 2384.3$ | $Prob = 0.572$ |
|  | $SSTO = 34178.5$ | $df_{SSTO} = 15$ |  |  |

**9.** Additional information we can calculate is a 100(1-$\alpha$)% Confidence Interval for $\beta 1$ and the Correlation Coefficient.

$\alpha := .1$ Assuming an a value of .1 which defines a Type I error of 10%.

$$LB := \beta\,hat_2 - \left| qt\left(\frac{\alpha}{2}, n - p\right) \right| \cdot s_{\beta 1} \qquad LB = -0.482 \qquad \text{...Lower Bound}$$

$$\beta\,hat_2 = 0.236$$

$$UB := \beta\,hat_2 + \left| qt\left(\frac{\alpha}{2}, n - p\right) \right| \cdot s_{\beta 1} \qquad UB = 0.954 \qquad \text{...Upper Bound}$$

This summarizes as we are 90% confident that the process will hook the true value of $\beta 1$ with the interval:

$$\{\ LB = -0.482 \quad , \quad UB = 0.954\ \}$$

The sample correlation coefficient is calculated as follows (Devore, 1995)...

$$X_{bar} := \frac{\sum_{i=1}^{n} X_{i,2}}{n}$$

$X_{bar} = 53.25$ Mean value for the predictor values

$Y_{bar} = 48.2$ Mean value for the predicand values

$$s_{xy} := \sum_{i=1}^{n} \left(X_{i,2} - X_{bar}\right)\cdot\left(Y_i - Y_{bar}\right)$$

**R is equal to the sample correlation coefficient...**

$$R := \frac{s_{xy}}{\sqrt{\sum_{i=1}^{n} \left(X_{i,2} - X_{bar}\right)^2} \cdot \sqrt{\sum_{i=1}^{n} \left(Y_i - Y_{bar}\right)^2}}$$

R squared is the measure of correlation $R^2 = 0.023$

## APPENDIX 4-4: Mathcad Template of Costs Versus Squadrons

**1.** Initially, Mathcad requires the researcher to establish a starting point for matrix operation.

$$\mathrm{ORIGIN} \equiv 1$$

**2.** The second step is inputting the variables, in matrix form, to be used....

**Y = Remediation Cost** **X = Squadrons of Aircraft**

$$Y := \begin{bmatrix} 13.3 \\ 106.5 \\ 11.5 \\ 13.1 \\ 17.5 \\ 59.7 \\ 33.1 \\ 170.8 \\ 9.8 \\ 39.4 \\ 6.8 \\ 34.7 \\ 31.2 \\ 119.7 \\ 81.8 \\ 22.3 \end{bmatrix} \qquad X := \begin{bmatrix} 1 & 3 \\ 1 & 2 \\ 1 & 4 \\ 1 & 6 \\ 1 & 2 \\ 1 & 2 \\ 1 & 5 \\ 1 & 3 \\ 1 & 1 \\ 1 & 5 \\ 1 & 5 \\ 1 & 3 \\ 1 & 6 \\ 1 & 6 \\ 1 & 4 \\ 1 & 3 \end{bmatrix}$$

Display the CROSS PRODUCT MATRIX and its INVERSE...

$$X^T \cdot X = \begin{bmatrix} 16 & 60 \\ 60 & 264 \end{bmatrix}$$

Where, n = 16 and total amount of aircraft = 264.

$$X^T \cdot Y = \begin{bmatrix} 771.2 \\ 2854.2 \end{bmatrix}$$

**3.** We next checked for singularity....

$$\left| X^T \cdot X \right| = 624$$

If determinant had been equal to zero than it would not have been invertible.

**4.** We obtain the values for Beta Estimates and the Estimate of $\sigma^2$. During this time we also determine values for SSTO, SSR, SSE, MSR, MSE, and relevant Degrees of Freedom.

**SSTO** is the total sum of squares relating to the predictor variable.
**SSR** is the treatment sum of squares relating to the predictor variable.
**SSE** is the error sum of squares relating to the predictor variable.
**MSR** is the mean square for treatments relating to the predictor variable.
**MSE** is the mean square for error relating to the predictor variable.

$n := \text{rows}(Y) \qquad p := \text{cols}(X)$

$\beta_{hat} := \left(X^T \cdot X\right)^{-1} \cdot X^T \cdot Y \qquad \beta_{hat} = \begin{bmatrix} 51.835 \\ -0.969 \end{bmatrix}$ Known as $\beta hat_0$ / Known as $\beta hat_1$

$Y_{bar} := \text{mean}(Y)$ The remediation cost mean... $Y_{bar} = 48.2$

$Y_{hat} := X \cdot \beta_{hat} \qquad e := Y - Y_{hat}$ ... Residual Values

$SSE := e^T \cdot e \qquad SSE = 3.414 \cdot 10^4$ ... Error Sum of Squares

$SSTO := \left(Y - Y_{bar}\right)^T \cdot \left(Y - Y_{bar}\right) \qquad SSTO = 3.418 \cdot 10^4$

$SSR := SSTO - SSE \qquad SSR = 36.637$

$df_{SSTO} := n - 1 \qquad df_{SSR} := p - 1 \qquad df_{SSE} := n - p$

$df_{SSTO} = 15 \qquad df_{SSR} = 1 \qquad df_{SSE} = 14$

$MSR := \frac{SSR}{df_{SSR}} \qquad MSR = 36.637$

$MSE := \frac{SSE}{df_{SSE}} \qquad MSE = 2438.707$

**5.** We now display the vectors from the Y (Remediation Costs), Yhat (Model depiction of Remediation Costs), and e (Resulting error matrix).

Y =

| | 1 |
|---|---|
| 1 | 13.3 |
| 2 | 106.5 |
| 3 | 11.5 |
| 4 | 13.1 |
| 5 | 17.5 |
| 6 | 59.7 |
| 7 | 33.1 |
| 8 | 170.8 |
| 9 | 9.8 |
| 10 | 39.4 |
| 11 | 6.8 |
| 12 | 34.7 |
| 13 | 31.2 |
| 14 | 119.7 |
| 15 | 81.8 |
| 16 | 22.3 |

$Y_{hat}$ =

| | 1 |
|---|---|
| 1 | 48.927 |
| 2 | 49.896 |
| 3 | 47.958 |
| 4 | 46.019 |
| 5 | 49.896 |
| 6 | 49.896 |
| 7 | 46.988 |
| 8 | 48.927 |
| 9 | 50.865 |
| 10 | 46.988 |
| 11 | 46.988 |
| 12 | 48.927 |
| 13 | 46.019 |
| 14 | 46.019 |
| 15 | 47.958 |
| 16 | 48.927 |

e =

| | 1 |
|---|---|
| 1 | -35.627 |
| 2 | 56.604 |
| 3 | -36.458 |
| 4 | -32.919 |
| 5 | -32.396 |
| 6 | 9.804 |
| 7 | -13.888 |
| 8 | 121.873 |
| 9 | -41.065 |
| 10 | -7.588 |
| 11 | -40.188 |
| 12 | -14.227 |
| 13 | -14.819 |
| 14 | 73.681 |
| 15 | 33.842 |
| 16 | -26.627 |

Residual Matrix <----------

**6.** The next step involves calculating the values for the Tstar (test statistic).

$$\mathrm{Var}_{betahat} := \mathrm{MSE}_1 \cdot \left(X^T \cdot X\right)^{-1} \qquad \mathrm{Var}_{betahat} = \begin{bmatrix} 1031.761 & -234.491 \\ -234.491 & 62.531 \end{bmatrix}$$

$$\mathrm{Var}_{yhat} := \mathrm{MSE}_1 \cdot \left[X \cdot \left(X^T \cdot X\right)^{-1} \cdot X^T\right]$$

MSE is the estimate of $\sigma^2$.

$$s_{\beta o} := \sqrt{\mathrm{Var}_{betahat_{1,1}}} \qquad s_{\beta o} = 32.121$$

$$s_{\beta 1} := \sqrt{\mathrm{Var}_{betahat_{2,2}}} \qquad s_{\beta 1} = 7.908$$

$$\mathrm{Tstar} := \frac{\beta\ hat_2}{s_{\beta 1}} \qquad \mathrm{Tstar} = -0.123$$

**7.** Next we determine values for Fstar and p-value as additional test.

$$F_{star} := \frac{MSR}{MSE_1} \qquad F_{star} = 0.015$$

$$Prob := 1 - pF\left(F_{star_1}, df_{SSR}, df_{SSE}\right) \qquad Prob = 0.904$$

**8.** With this information, we can display the data in an Analysis of Variance (ANOVA) table (Devore, 1995).

***Table 25. ANOVA Table for Remediation Costs Vs Aircraft***

| **Source** | **SS** | **df** | **MS** | **F & Prob Value** |
|---|---|---|---|---|
| **Regression** | $SSR = 36.637$ | $df_{SSR} = 1$ | $MSR = 36.6$ | $F_{star} = 0.015$ |
| **Error** | $SSE = 34141.9$ | $df_{SSE} = 14$ | $MSE = 2438.7$ | $Prob = 0.904$ |
| | $SSTO = 34178.5$ | $df_{SSTO} = 15$ | | |

**9.** Additional information we can calculate is a 100(1-$\alpha$)% Confidence Interval for $\beta 1$ and the Correlation Coefficient.

$\alpha := .1$ Assuming an a value of .1 which defines a Type I error of 10%.

$$LB := \beta\,hat_2 - \left| qt\left(\frac{\alpha}{2}, n - p\right) \right| \cdot s_{\beta 1} \qquad LB = -14.897$$

...Lower Bound

$$\beta\,hat_2 = -0.969$$

$$UB := \beta\,hat_2 + \left| qt\left(\frac{\alpha}{2}, n - p\right) \right| \cdot s_{\beta 1} \qquad UB = 12.959$$

...Upper Bound

This summarizes as we are 90% confident that the process will hook the true value of $\beta 1$ with the interval:

$$(\quad LB = -14.897 \quad , \quad UB = 12.959 \quad)$$

The sample correlation coefficient is calculated as follows (Devore, 1995)...

$$X_{bar} := \frac{\sum_{i=1}^{n} X_{i,2}}{n}$$

$X_{bar} = 3.75$ Mean value for the predictor values

$Y_{bar} = 48.2$ Mean value for the predicand values

$$s_{xy} := \sum_{i=1}^{n} \left(X_{i,2} - X_{bar}\right)\cdot\left(Y_i - Y_{bar}\right)$$

**R is equal to the sample correlation coefficient...**

$$R := \frac{s_{xy}}{\sqrt{\sum_{i=1}^{n} \left(X_{i,2} - X_{bar}\right)^2} \cdot \sqrt{\sum_{i=1}^{n} \left(Y_i - Y_{bar}\right)^2}}$$

R squared is the measure of correlation $R^2 = 0.001$

## APPENDIX 4-5: Mathcad Template of Costs Versus Fuel

**1.** Initially, Mathcad requires the researcher to establish a starting point for matrix operation.

$$\mathbf{ORIGIN} \equiv 1$$

**2.** The second step is inputting the variables, in matrix form, to be used....

**Y = Remediation Cost** **X = Fuel Usage of Base**

$$Y := \begin{bmatrix} 13.3 \\ 106.5 \\ 11.5 \\ 13.1 \\ 17.5 \\ 59.7 \\ 33.1 \\ 170.8 \\ 9.8 \\ 39.4 \\ 6.8 \\ 34.7 \\ 31.2 \\ 119.7 \\ 81.8 \\ 22.3 \end{bmatrix} \qquad X := \begin{bmatrix} 1 & 64370 \\ 1 & 3274 \\ 1 & 18805 \\ 1 & 27812 \\ 1 & 41587 \\ 1 & 20341 \\ 1 & 26906 \\ 1 & 20685 \\ 1 & 15572 \\ 1 & 13042 \\ 1 & 24673 \\ 1 & 67296 \\ 1 & 20248 \\ 1 & 39983 \\ 1 & 16765 \\ 1 & 9174 \end{bmatrix}$$

Display the CROSS PRODUCT MATRIX and its INVERSE...

$$X^T \cdot X = \begin{bmatrix} 16 & 4.305 \cdot 10^5 \\ 4.305 \cdot 10^5 & 1.65 \cdot 10^{10} \end{bmatrix}$$

Where, n = 16 and total amount of fuel used = 16,500,000,000.

$$X^T \cdot Y = \begin{bmatrix} 771.2 \\ 1.831 \cdot 10^7 \end{bmatrix}$$

**3.** We next checked for singularity....

$$\left| X^T \cdot X \right| = 7.865 \cdot 10^{10}$$

If determinant had been equal to zero than it would not have been invertible.

**4.** We obtain the values for Beta Estimates and the Estimate of $\sigma^2$. During this time we also determine values for SSTO, SSR, SSE, MSR, MSE, and relevant Degrees of Freedom.

**SSTO** is the total sum of squares relating to the predictor variable.
**SSR** is the treatment sum of squares relating to the predictor variable.
**SSE** is the error sum of squares relating to the predictor variable.
**MSR** is the mean square for treatments relating to the predictor variable.
**MSE** is the mean square for error relating to the predictor variable.

$$n := \mathrm{rows}(Y) \qquad p := \mathrm{cols}(X)$$

$$\beta_{hat} := \left(X^T \cdot X\right)^{-1} \cdot X^T \cdot Y \qquad \beta_{hat} = \begin{bmatrix} 61.544 \\ -4.959 \cdot 10^{-4} \end{bmatrix}$$

Known as $\beta hat_0$
Known as $\beta hat_1$

$$Y_{bar} := \mathrm{mean}(Y)$$ The remediation cost mean... $$Y_{bar} = 48.2$$

$$Y_{hat} := X \cdot \beta_{hat} \qquad e := Y - Y_{hat}$$ ... Residual Values

$$SSE := e^T \cdot e \qquad SSE = 3.297 \cdot 10^4$$ ... Error Sum of Squares

$$SSTO := \left(Y - Y_{bar}\right)^T \cdot \left(Y - Y_{bar}\right) \qquad SSTO = 3.418 \cdot 10^4$$

$$SSR := SSTO - SSE \qquad SSR = 1208.74$$

$$df_{SSTO} := n - 1 \qquad df_{SSR} := p - 1 \qquad df_{SSE} := n - p$$

$$df_{SSTO} = 15 \qquad df_{SSR} = 1 \qquad df_{SSE} = 14$$

$$MSR := \frac{SSR}{df_{SSR}} \qquad MSR = 1208.74$$

$$MSE := \frac{SSE}{df_{SSE}} \qquad MSE = 2354.986$$

**5.** We now display the vectors from the Y (Remediation Costs), Yhat (Model depiction of Remediation Costs), and e (Resulting error matrix).

$$Y = \begin{array}{c|c} & 1 \\ \hline 1 & 13.3 \\ 2 & 106.5 \\ 3 & 11.5 \\ 4 & 13.1 \\ 5 & 17.5 \\ 6 & 59.7 \\ 7 & 33.1 \\ 8 & 170.8 \\ 9 & 9.8 \\ 10 & 39.4 \\ 11 & 6.8 \\ 12 & 34.7 \\ 13 & 31.2 \\ 14 & 119.7 \\ 15 & 81.8 \\ 16 & 22.3 \end{array} \qquad Y_{hat} = \begin{array}{c|c} & 1 \\ \hline 1 & 29.623 \\ 2 & 59.92 \\ 3 & 52.218 \\ 4 & 47.752 \\ 5 & 40.921 \\ 6 & 51.457 \\ 7 & 48.201 \\ 8 & 51.286 \\ 9 & 53.822 \\ 10 & 55.076 \\ 11 & 49.308 \\ 12 & 28.172 \\ 13 & 51.503 \\ 14 & 41.716 \\ 15 & 53.23 \\ 16 & 56.994 \end{array} \qquad e = \begin{array}{c|c} & 1 \\ \hline 1 & -16.323 \\ 2 & 46.58 \\ 3 & -40.718 \\ 4 & -34.652 \\ 5 & -23.421 \\ 6 & 8.243 \\ 7 & -15.101 \\ 8 & 119.514 \\ 9 & -44.022 \\ 10 & -15.676 \\ 11 & -42.508 \\ 12 & 6.528 \\ 13 & -20.303 \\ 14 & 77.984 \\ 15 & 28.57 \\ 16 & -34.694 \end{array}$$

Residual
Matrix
<----------

**6.** The next step involves calculating the values for the Tstar (test statistic).

$$\mathrm{Var}_{\mathrm{betahat}} := \mathrm{MSE}_1 \cdot \left(X^T \cdot X\right)^{-1} \qquad \mathrm{Var}_{\mathrm{betahat}} = \begin{bmatrix} 494.084 & -0.013 \\ -0.013 & 4.791 \cdot 10^{-7} \end{bmatrix}$$

$$\mathrm{Var}_{\mathrm{yhat}} := \mathrm{MSE}_1 \cdot \left[ X \cdot \left(X^T \cdot X\right)^{-1} \cdot X^T \right]$$

MSE is the estimate of $\sigma^2$.

$$s_{\beta o} := \sqrt{\mathrm{Var}_{\mathrm{betahat}_{1,1}}} \qquad s_{\beta o} = 22.228$$

$$s_{\beta 1} := \sqrt{\mathrm{Var}_{\mathrm{betahat}_{2,2}}} \qquad s_{\beta 1} = 6.922 \cdot 10^{-4}$$

$$\mathrm{Tstar} := \frac{\beta\,\mathrm{hat}_2}{s_{\beta 1}} \qquad \mathrm{Tstar} = -0.716$$

**7.** Next we determine values for Fstar and p-value as additional test.

$$F_{star} := \frac{MSR}{MSE_1} \qquad F_{star} = 0.513$$

$$Prob := 1 - pF\left(F_{star_1}, df_{SSR}, df_{SSE}\right) \qquad Prob = 0.486$$

**8.** With this information, we can display the data in an Analysis of Variance (ANOVA) table (Devore, 1995).

***Table 26. ANOVA Table for Remediation Costs Vs Fuel Usage***

| **Source** | **SS** | **df** | **MS** | **F & Prob Value** |
|---|---|---|---|---|
| **Regression** | $SSR = 1208.74$ | $df_{SSR} = 1$ | $MSR = 1208.7$ | $F_{star} = 0.513$ |
| **Error** | $SSE = 32969.8$ | $df_{SSE} = 14$ | $MSE = 2355$ | $Prob = 0.486$ |
| | $SSTO = 34178.5$ | $df_{SSTO} = 15$ | | |

**9.** Additional information we can calculate is a 100(1-$\alpha$)% Confidence Interval for $\beta 1$ and the Correlation Coefficient.

$\alpha := .1$ Assuming an a value of .1 which defines a Type I error of 10%.

$$LB := \beta\ hat_2 - \left|qt\left(\frac{\alpha}{2}, n - p\right)\right| \cdot s_{\beta 1} \qquad LB = -0.002$$ ...Lower Bound

$$\beta\ hat_2 = -4.959 \cdot 10^{-4}$$

$$UB := \beta\ hat_2 + \left|qt\left(\frac{\alpha}{2}, n - p\right)\right| \cdot s_{\beta 1} \qquad UB = 7.232 \cdot 10^{-4}$$ ...Upper Bound

This summarizes as we are 90% confident that the process will hook the true value of $\beta 1$ with the interval:

$$(\ LB = -0.002\ ,\ UB = 0.001\ )$$

The sample correlation coefficient is calculated as follows (Devore, 1995)...

$$X_{bar} := \frac{\sum_{i=1}^{n} X_{i,2}}{n} \qquad X_{bar} = 2.691 \cdot 10^4$$

Mean value for the predictor values

$$Y_{bar} = 48.2$$

Mean value for the predicand values

$$s_{xy} := \sum_{i=1}^{n} \left(X_{i,2} - X_{bar}\right) \cdot \left(Y_i - Y_{bar}\right)$$

**R is equal to the sample correlation coefficient...**

$$R := \frac{s_{xy}}{\sqrt{\sum_{i=1}^{n} \left(X_{i,2} - X_{bar}\right)^2} \cdot \sqrt{\sum_{i=1}^{n} \left(Y_i - Y_{bar}\right)^2}}$$

R squared is the measure of correlation $R^2 = 0.035$

## APPENDIX 4-6: Mathcad Template for Polynomial Regression

**1.** Initially, Mathcad requires the researcher to establish a starting point for matrix operation.

$$\mathrm{ORIGIN} \equiv 1$$

**2.** The second step is inputting the variables, in matrix form, to be used....

**Y = Remediation Cost** **X = Aircraft on Base**

$$Y := \begin{bmatrix} 11.4 \\ 13.1 \\ 59.7 \\ 33.1 \\ 31.2 \end{bmatrix} \qquad X := \begin{bmatrix} 1 & 66 \\ 1 & 91 \\ 1 & 12 \\ 1 & 97 \\ 1 & 36 \end{bmatrix}$$

$$i := 1..5$$

$$X_{bar} := \frac{\displaystyle\sum_{j=1}^{5} X_{j,2}}{5}$$

Display the CROSS PRODUCT MATRIX and its INVERSE...

$$X_{i,2} := X_{i,2} - X_{bar}$$

Where, sample size (n) = 5.

$$X_{i,3} := \left(X_{i,2}\right)^2$$

$$X^T \cdot X = \begin{bmatrix} 5 & 7.105 \cdot 10^{-15} & 5245.2 \\ 7.105 \cdot 10^{-15} & 5245.2 & -5.005 \cdot 10^{4} \\ 5245.2 & -5.005 \cdot 10^{4} & 8.514 \cdot 10^{6} \end{bmatrix} \qquad X^T \cdot Y = \begin{bmatrix} 148.5 \\ -1974.6 \\ 2.154 \cdot 10^{5} \end{bmatrix}$$

**3.** We next checked for singularity....

$$\left| X^T \cdot X \right| = 6.646 \cdot 10^{10}$$

If determinant had been equal to zero than it would not have been invertible.

**4.** We obtain the values for Beta Estimates and the Estimate of $\sigma^2$. During this time we also determine values for SSTO, SSR, SSE, MSR, MSE, and relevant Degrees of Freedom.

**SSTO** is the total sum of squares relating to the predictor variable.
**SSR** is the treatment sum of squares relating to the predictor variable.
**SSE** is the error sum of squares relating to the predictor variable.
**MSR** is the mean square for treatments relating to the predictor variable.
**MSE** is the mean square for error relating to the predictor variable.

$n := \text{rows}(Y) \qquad p := \text{cols}(X)$

$\beta_{hat} := \left(X^T \cdot X\right)^{-1} \cdot X^T \cdot Y \qquad \beta_{hat} = \begin{bmatrix} 12.825 \\ -0.223 \\ 0.016 \end{bmatrix}$ Known as $\beta hat_0$ Known as $\beta hat_1$ Known as $\beta hat_2$

$Y_{bar} := \text{mean}(Y)$ The remediation cost mean... $Y_{bar} = 29.7$

$Y_{hat} := X \cdot \beta_{hat} \qquad e := Y - Y_{hat}$ ... Residual Values

$SSE := e^T \cdot e \qquad SSE = 125.164$ ... Error Sum of Squares

$SSTO := \left(Y - Y_{bar}\right)^T \cdot \left(Y - Y_{bar}\right) \qquad SSTO = 1524.26$

$SSR := SSTO - SSE \qquad SSR = 1399.096$

$df_{SSTO} := n - 1 \qquad df_{SSR} := p - 1 \qquad df_{SSE} := n - p$

$df_{SSTO} = 4 \qquad df_{SSR} = 2 \qquad df_{SSE} = 2$

$MSR := \frac{SSR}{df_{SSR}} \qquad MSR = 699.548$

$MSE := \frac{SSE}{df_{SSE}} \qquad MSE = 62.582$

**5.** We now display the vectors from the Y (Remediation Costs), Yhat (Model depiction of Remediation Costs), and e (Resulting error matrix).

$$Y = \begin{bmatrix} 11.4 \\ 13.1 \\ 59.7 \\ 33.1 \\ 31.2 \end{bmatrix} \qquad Y_{hat} = \begin{bmatrix} 12.081 \\ 21.065 \\ 61.299 \\ 26.213 \\ 27.842 \end{bmatrix} \qquad \mathbf{e} = \begin{bmatrix} -0.681 \\ -7.965 \\ -1.599 \\ 6.887 \\ 3.358 \end{bmatrix}$$

Residual Matrix
<----------

**6.** The next step involves calculating the values for the Tstar (test statistic).

$$\mathrm{Var}_{\mathrm{betahat}} := \mathrm{MSE}_1 \cdot \left(X^T \cdot X\right)^{-1}$$

$$\mathrm{Var}_{\mathrm{betahat}} = \begin{bmatrix} 39.693 & -0.247 & -0.026 \\ -0.247 & 0.014 & 2.356 \cdot 10^{-4} \\ -0.026 & 2.356 \cdot 10^{-4} & 2.469 \cdot 10^{-5} \end{bmatrix}$$

$$\mathrm{Var}_{\mathrm{yhat}} := \mathrm{MSE}_1 \cdot \left[ X \cdot \left(X^T \cdot X\right)^{-1} \cdot X^T \right]$$

MSE is the estimate of $\sigma^2$.

$$s_{\beta o} := \sqrt{\mathrm{Var}_{\mathrm{betahat}_{1,1}}} \qquad s_{\beta o} = 6.3$$

$$s_{\beta 1} := \sqrt{\mathrm{Var}_{\mathrm{betahat}_{2,2}}} \qquad s_{\beta 1} = 0.119$$

$$s_{\beta 2} := \sqrt{\mathrm{Var}_{\mathrm{betahat}_{3,3}}} \qquad s_{\beta 2} = 0.005$$

$$\mathrm{Tstar} := \frac{\beta\ \mathrm{hat}_3}{s_{\beta 2}} \qquad \mathrm{Tstar} = 3.237$$

**7.** Next we determine values for Fstar and p-value as additional test.

$$F_{star} := \frac{MSR}{MSE_1} \qquad F_{star} = 11.178$$

$$Prob := 1 - pF\left(F_{star_1}, df_{SSR}, df_{SSE}\right) \qquad Prob = 0.082$$

**8.** With this information, we can display the data in an Analysis of Variance (ANOVA) table (Devore, 1995).

***Table 27. ANOVA Table for Remediation Costs Vs Fuel Usage***

| Source | SS | df | MS | F & Prob Value |
|---|---|---|---|---|
| Regression | $SSR = 1399.096$ | $df_{SSR} = 2$ | $MSR = 699.5$ | $F_{star} = 11.178$ |
| Error | $SSE = 125.2$ | $df_{SSE} = 2$ | $MSE = 62.6$ | $Prob = 0.082$ |
| | $SSTO = 1524.3$ | $df_{SSTO} = 4$ | | |

**9.** Additional information we can calculate is a 100(1-$\alpha$)% Confidence Interval for $\beta 0$, $\beta 1$, $\beta 2$, and the Correlation Coefficient.

$\alpha := .1$ Assuming an a value of .1 which defines a Type I error of 10%.

**Calculations for Confidence Interval of $\beta$o.....**

$$LB_o := \beta\,hat_1 - \left|qt\left(\frac{\alpha}{2}, n - p\right)\right| \cdot s_{\beta o} \qquad LB_o = -5.571$$ ...Lower Bound

$$\beta\,hat_1 = 12.825$$

$$UB_o := \beta\,hat_1 + \left|qt\left(\frac{\alpha}{2}, n - p\right)\right| \cdot s_{\beta o} \qquad UB_o = 31.222$$ ...Upper Bound

This summarizes as we are 90% confident that the process will hook the true value of $\beta o$ with the interval:

$$(\ LB_o = -5.571\ ,\quad UB_o = 31.222)$$

### Calculations for Confidence Interval of $\beta 1$.....

$LB_1 := \beta\ hat_2 - \left| qt\left(\frac{\alpha}{2}, n - p\right) \right| \cdot s_{\beta 1}$ $LB_1 = -0.571$ ...Lower Bound

$\beta\ hat_2 = -0.223$

$UB_1 := \beta\ hat_2 + \left| qt\left(\frac{\alpha}{2}, n - p\right) \right| \cdot s_{\beta 1}$ $UB_1 = 0.125$ ...Upper Bound

This summarizes as we are 90% confident that the process will hook the true value of $\beta o$ with the interval:

$\{ \quad LB_1 = -0.571 \quad , \quad UB_1 = 0.125 \quad \}$

### Calculations for Confidence Interval of $\beta 2$.....

$LB_2 := \beta\ hat_3 - \left| qt\left(\frac{\alpha}{2}, n - p\right) \right| \cdot s_{\beta o}$ $LB_2 = -18.38$ ...Lower Bound

$\beta\ hat_3 = 0.016$

$UB_2 := \beta\ hat_3 + \left| qt\left(\frac{\alpha}{2}, n - p\right) \right| \cdot s_{\beta o}$ $UB_2 = 18.413$ ...Upper Bound

This summarizes as we are 90% confident that the process will hook the true value of $\beta o$ with the interval:

$\{ \quad LB_2 = -18.38 \quad , \quad UB_2 = 18.413 \}$

The sample correlation coefficient is calculated as follows (Devore, 1995)...

$$Correlation := 1. - \frac{SSE_1}{SSTO_1} \qquad Correlation = 0.918$$

## APPENDIX 5-1: Trip Report of US DoD Installations in Korea

MEMORANDUM FOR RECORD 12 Oct 98

Subject: Trip Report for Korea Visit to Obtain Data for Thesis

1. Purpose. The purpose of this visit was to gather data relating to risk assessment, site characterization, and cleanup cost estimation of hazardous waste sites at DoD installations in the Republic of Korea. The inclusive dates of the TDY were 16 – 25 September 1998.

2. Travelers. Dr Mark Goltz, Capt Dean Hartman, and Capt Mike Griffin

3. Discussion.

a. Yongson Post. Travelers began the data collection trip at Yongson Post on 17-18 Sept 98 by meeting with Mr John Anderson, Environmental Chief, and Mr Mark Kwon, Environmental Engineer, of the Eighth US Army (EUSA). Funds for this trip were provided by this office under the hat of US Forces Korea (USFK). Topics addressed included organizational structure of USFK/EUSA, USFK/ROK environmental policy, and objectives of the thesis research. In-depth interviews with the staff and a member from USACE introduced aspects of the Analytic Hierarchy Process (specific multiple criteria decision-making technique), and formalized requirements for site characterization technology and risk assessment. Additionally, discussions of relevant cost models and pertinent aspects of these models were discussed. Travelers briefed the ACofS Engineer (EUSA-EN), COL Moldenhauer, concerning the thesis effort, what benefits could be expected from the effort, and what was to be accomplished during site visits. COL Moldenhauer emphasized the need to ensure the thesis product would be a tool that commanders could use in order to support the need for environmental action and justify needed funding.

ACTION ITEM: Capt Hartman needs to develop decision-maker survey for USFK to evaluate AHP hierarchies and select best alternatives for site characterization and risk assessment.

b. USACE-FED Compound. Travelers visited Mr Doug Bliss, USACE-FED, at the FED compound on 18 Sep 98. Discussion focused on obtaining geologic/hydrogeologic data and information from the FED office for installations throughout the peninsula. Mr Bliss stated his office would provide a geologic site summary from each installation where borings or wells had been completed. This information is expected late October 98.

c. Camp Market. Travelers visited the DRMO-Bupyong compound located at Camp Market on 18 Sep 98. We met with Ms Lori Dwelly, Hazardous Material Specialist, to search for hazardous waste disposal summary data. The idea was to determine what materials/substances installations were using in their operations and disposing of as waste in order to make the correlation with what materials/substances may be present in the environment. The information in question is on file, but was not readily available during the site visit. We await delivery of the information. In addition, contaminated site information from a previous ECAS (72) report, which Mr William Donnelly had previously indicated that he had in his possession, was requested.

d. Osan Air Base. Travelers met with Lt Sarah Berdugo, 51 CES/CEV, on 19 Sep 98, and obtained information from Environmental Flight files and records. Information obtained included listings of possible contaminated sites (primarily POL), available site investigation data, spill reports from WIMS-ES and a spill log, environmental contract report information (including baseline risk assessment data for several sites), Integrated Natural Resources Plan information, and other relevant historical and environmental data. Travelers also met with Mr Yu, 51 AMDS/SGPB technician, to obtain well water monitoring results for various COBs and Ranges.

e. Kooni Range. Travelers met with Mr Harold Stoll, Kooni Range Manager, and Mr Shoemaker, Koonni Range Staff, 21 Sep 98. Lockheed Martin currently runs Kooni Range operations, under contract to DoD. The range was visited in order to provide data on the method of operation and to discern any potential environmental liabilities. The range contained a strafing area and a strafing/bomb drop island. The Kooni Range staff forwarded data on munition usage, in order to determine possible lead and depleted uranium contamination. This data has been extrapolated to provide "representative" usage at the range.

f. Camp Red Cloud. Travelers met with Mr Kim, Sun Ho and Mr Yi, Taek Chu, from the HQ Area I Support Activity, Office of the Staff Engineer, Environmental Office, on 22 Sep 98. Initial discussions focused on the area of responsibility for Area I Support Activities, and specific environmental concerns. No environmental reports or environmental contract documents were available, but Mr Kim suggested site visits to Camp Edwards, Camp Hovey, and Camp Casey. Camp Edwards and Hovey showed evidence of major POL contamination, and will provide an opportunity to apply thesis tools and methods as case studies, while Camp Casey was the site of a POL-contaminated soil landfarm remediation facility.

g. Camp Casey. Mr Yi, Tu Ha, Chief/COR, Environmental Management Office, Directorate of Public Works, Camp Casey, on 22 Sep 98, met travelers, along with Mr Kim and Mr Yi from Area I. We visited the Camp Hovey POL site, which consisted of a large concrete vehicle maintenance/parking ramp. The site previously contained USTs that had stored heating fuel serving several installation facilities. Product had previously been recovered from a man-made sump system, and was evidenced from seeps in the hillside adjacent to the river. Mr Yi, T.H. indicated USACE-FED cost estimates to perform site characterization were $500K. A request was made by Camp Casey and Area I staff for us to provide landfarm treatment optimization information.

ACTION ITEM: Dr. Goltz will provide information concerning landfarm treatment optimization information to Area I environmental staff. Capt Hartman will provide tank tightness testing information and possible contractors.

h. Camp Edwards. Ms Pak, the Camp Edwards environmental coordinator, on 22 Sep 98, met travelers, along with Mr Kim and Mr Yi from Area I. Data concerning chlorinated hydrocarbon contamination of the drinking water aquifer (as indicated through sampling of the drinking water wells) were requested (and later received). The site visit focused on a POL leak, presumably diesel, from one of the three 210K bulk USTs, although the source was officially unknown. The USTs were located approximately 100 meters up-gradient, and Camp Edwards public works/environmental staff had been collecting approximately 150 gallons of free product per week from several wastewater manholes. The apparent purity of the product indicated the relative speed of movement and extent of the plume. Staff indicated they had programmed for DFSC funds for tank testing and potential remedial action, but funding status was unknown. Camp Edwards staff indicated that the USACE-FED had performed a basic preliminary site investigation, consisting of soil samples, and had indicated the site was contaminated. No further information had been made available, such as the levels of contamination in the samples. The estimate for site characterization from FED was $600K. A request was made by Camp Edwards and Area I staff for us to provide tank tightness testing information in support of their requirements.

ACTION ITEM: Capt Hartman will provide tank tightness testing information and possible contractors to Area I environmental staff.

i. Camp Henry. Mr Brian Peckins, 19th TAACOM Environmental Chief, on 23 Sep 98, met travelers. Mr Peckins provided a briefing on 19th TAACOM's environmental program, including projects and funding status. Data obtained during the visit included spill reports/spill investigations, ECAS finding information that justified construction of landfarm facilities, and 19th TAACOM environmental project and programming information. No EPR remediation-coded files/documents were available, nor were any formal site investigation, risk assessment, or cost estimation data/reports. Information was not available on preliminary site investigation data generated by USACE-FED in determining site characterization cost estimates for Camps Edwards and Hovey. Mr Seung Baek, USACE-FED, Chief of Environmental Division, was contacted and the preliminary site characterization information and requirements included in developing the cost estimate were requested.

j. Taegu Air Base. TSgt Backus and TSgt Berry, 51 MMS staff, on 23 Sep 98 met travelers. Review of the pump-and-treat system was performed. The system has been in operation since 1982 following a major POL release and facility explosion, with intermittent interruptions in operation. HQ AFMC/CEV has performed a study of the site, and several monitoring wells exist at the site. Several drinking water wells at Taegu AB are contaminated with chlorinated hydrocarbons (most prominently vinyl chloride). Additionally, it was discovered that personnel from Brooks AFB had recently visited Taegu AB in order to sample the active drinking water wells (sampled wells 3, 5, and 8). As well, an USACE-FED project, Phase II-Construct Air Stripper, Taegu AB, is currently under construction.

k. Kunsan Air Base. Capt Laura Johnson, 8 CES/CEV, on 24 Sep 98, met travelers. Information obtained included Kunsan AB MAP, Woodward-Clyde site characterization and risk assessment information on five contaminated sites, an AFCEE study outlining AOCs at Kunsan, applicable portions of the Integrated Natural Resources Management Plan, WIMS-ES spill reporting module data, out-year financial plan for environmental projects and resources, and other data applicable to the theses efforts. A site visit to the bulk POL storage area was accomplished to review installation of a bioslurper system. The system was being installed by Brewer Environmental Industries, Inc., Environmental Services Division (Mr Ralph Carson and Ms Myonghee Lee) in conjunction with the USACE-POD (Mr Donald Schlack) and USACE-FED personnel. This project was funded in order to remove POL contamination (vapor phase and free product/dissolved phase) from the aquifer and vadose zone, while preventing contamination of nearby property.

l. The trip concluded upon return to Osan AB, and subsequently Seoul, on the 25th of September 1998.

# APPENDIX 5-2: List of Persons Interviewed

<table>
<tr><th colspan="4">Headquarters, United States Forces Korea (Eighth US Army)</th></tr>
<tr><th>Date</th><th>Organization</th><th>Person(s) Contacted</th><th>Position</th></tr>
<tr><td>17-18 Sep 98 Yongson Post</td><td>Eighth US Army - EN<br>Environmental Programs Office</td><td>COL Moldenhauer<br>Mr John Anderson<br>Mr Mark Y. Kwon</td><td>8th Army Engineer<br>Environmental Chief<br>Environmental Engineer</td></tr>
<tr><th colspan="4">Individual DoD Installations, Republic of Korea</th></tr>
<tr><td>18-Sep-98</td><td>US ACE Far East District</td><td>Mr Douglas A. Bliss</td><td>Chief, Foundations and Materials Branch Engineering Division</td></tr>
<tr><td>18-Sep-98 Camp Market</td><td>Defense Reutilization and Marketing Office</td><td>Ms Lori K. Dwelly</td><td>Hazardous Material Specialist</td></tr>
<tr><td rowspan="3">19-20 Sep 98 Osan Air Base</td><td>51st Civil Engineer Squadron,</td><td>Mr Nick J. Linden</td><td>Flight Chief</td></tr>
<tr><td>Environmental Flight</td><td>1st Lt Sarah E Berdugo</td><td>Chief, Hazardous Waste</td></tr>
<tr><td>51st Aerospace Medical Group</td><td>Mr Yu</td><td>Bioenvironmental Engineer</td></tr>
<tr><td rowspan="2">21-Sep-98 Kooni Range</td><td rowspan="2">Lockheed Martin Range Contractors</td><td>Mr Harold W. Stoll</td><td>Program Manager</td></tr>
<tr><td>Mr Shoemaker</td><td>Range Superintendent</td></tr>
<tr><td rowspan="2">22-Sep-98 Camp Red Cloud</td><td>HQ, Area I Support Activity</td><td>Mr Kim, Sun Ho</td><td>Environmental Engineer</td></tr>
<tr><td>Environmental Office</td><td>Mr Yi, Taek Chu</td><td>Environmental Engineer</td></tr>
<tr><td>22-Sep-98 Camp Casey</td><td>Environmental Office, Department of Public Works</td><td>Mr Yi, Tu Ha</td><td>Chief/COR Environmental Management Office</td></tr>
<tr><td>22-Sep-98 Camp Edwards</td><td>Environmental Office, Department of Public Works</td><td>Ms Pak, Hye Kyong</td><td>Chief, Environmental Office</td></tr>
<tr><td>23-Sep-98 Camp Henry</td><td>19th Theater Area Army Command (TAACOM)</td><td>Mr Brian Peckins</td><td>Environmental Chief</td></tr>
<tr><td>23-Sep-98 Taegu Air Base</td><td>51 MMS Staff</td><td>TSgt Backus<br>TSgt Berry</td><td>Environmental Specialist<br>Environmental Specialist</td></tr>
<tr><td rowspan="4">24-25 Sep 98 Kunsan Air Base</td><td rowspan="2">8th Civil Engineer Squadron</td><td>Lt Col Cruz</td><td>Commander</td></tr>
<tr><td>Capt Laura M. Johnson</td><td>Chief, Environmental Flight</td></tr>
<tr><td>USACE Pacific Ocean Division</td><td>Mr Don Schlack</td><td>Environmental Chemist</td></tr>
<tr><td>Brewer Environmental Industries, Inc<br>Brewer Environmental Industries, Inc</td><td>Mr Ralph Carson<br>Ms Myounghee Noh</td><td>Environmental Technician<br>Environmental Chemist</td></tr>
</table>

## *Vita*

Captain John M. Griffin was born on 20 June 1967 in Blackville, South Carolina. He graduated from Blackville-Hilda High School in 1985 as Valedictorian and entered undergraduate studies at The Citadel in Charleston South Carolina. He graduated with a Bachelor of Science degree in Electrical Engineering in May 1989 as a distinguished graduate, and received his commission on 13 May 1989, through the Air Force Reserve Officer Training Corps and his regular commission on 15 October 1989.

Captain Griffin's first assignment was to the 1st Strategic Aerospace Division Environmental Management Directorate, Vandenberg AFB, California, as an environmental engineer. Since his first assignment, Captain Griffin has served in a variety of positions, including Chief of Readiness and Chief of SABER at Elmendorf AFB, Alaska, and Chief of Readiness at the United States Central Command Air Forces at Shaw AFB. While serving on the US CENTAF staff, he deployed to the country of Bahrain in order to coordinate all engineering activities for the first ever Air Expeditionary Force (AEF) to include discussions with the US Embassy.

Captain Griffin is married to the former Misty Dawn Lord from Gainesville, Georgia, and they have two children: John (8) and Jenna (5).

Upon graduation, Captain Griffin will be assigned to the Headquarters United States Air Force, the Pentagon, Washington DC.

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**13. ABSTRACT** *(Maximum 200 words)*

The purpose of this research was to develop and test a method that can be used to expeditiously estimate costs of hazardous waste site remediation at US DoD installations in Korea allowing decision-makers to formulate remediation strategy. This objective was addressed through answering the following questions: (1) What cost and time constraints do the decision-makers have in developing remediation cost estimates; (2) What degree of accuracy do the decision-makers require in cost estimates; (3) What estimating models are available for determining costs of remediation activities; (4) Have models been used to estimate remediation activities' costs at Korean installations; and (5) Of the models elicited in question (3), which met the needs of decision-makers as defined in questions (1) and (2)? This research resulted in selection of the Remedial Action Cost Engineering and Requirements system as a model for use in obtaining expeditious site specific costs. A regression model was developed for use in obtaining a rough estimate of an entire installation's remediation costs. These models can be applied to our Korean installations to rapidly provide decision-makers with cost estimates that can be used for formulating a remediation strategy that meets mission requirements while responding to evolving domestic and international conditions.

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