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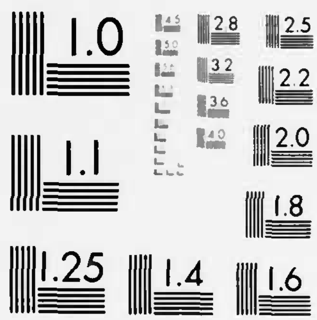

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EXPLORING THE FEASIBILITY OF
DEVELOPING AN AUTOMATED WORK
ESTIMATION SYSTEM FOR THE AIR FORCE
COMMUNICATIONS COMMAND ENGINEERING
AND INSTALLATION FUNCTION

Brian J. Kelly, Captain, USAF
Carl L. Ward, Captain, USAF

LSSR 68-83

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Air Force Communications Command (AFCC) accomplishes more than 2,500 installations, modifications, and removals of ground communications-electronics equipment and systems each year. The responsibility for this mission is assigned to the Engineering Installation Center (EIC). Since its inception in 1981, the EIC has witnessed numerous instances where target completion dates were not met and unprogrammed resources were consumed. Although many factors contribute to these problems, the root issue can be traced to the original man-hour projections annotated during the request for technical assistance process. Specifically, man-hour estimates are made solely on the subjective judgement and experience of scheme engineers. This research explores the feasibility of developing an automated work estimation system which, as a component of the EI Management System (EIMS), could be applied to arrive at man-hour estimates. This paper evaluates the existing EIMS data base and applies multiple regression analysis to a set of explanatory variables. The research concludes that the existing data base does not lend itself to an automated estimating system due to the paucity of germane physical and performance characteristic data to set up an estimating relationship.

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EXPLORING THE FEASIBILITY OF DEVELOPING AN AUTOMATED WORK ESTIMATION SYSTEM FOR THE AIR FORCE COMMUNICATIONS COMMAND ENGINEERING INSTALLATION FUNCTION

A Thesis

Presented to the Faculty of the School of Systems and Logistics

of the Air Force Institute of Technology

Air University

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

By

Brian J. Kelly, BS
Captain, USAF

Carl L. Ward, BS
Captain, USAF

September 1983

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This thesis, written by

Captain Brian J. Kelly

and

Captain Carl L. Ward

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

MASTER OF SCIENCE IN LOGISTICS MANAGEMENT

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COMMITTEE CHAIRMAN

Ronald H. Rasch

READER

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OVERVIEW

Introduction

Military Command, Control, and Communication (C3) systems are receiving the same degree of attention as weapon systems in the competition for limited defense dollars. In his 1983 budget address to Congress, President Reagan (28:13) summarized a recent study of our C3 capability in one simple statement, "Current communications and warning systems were found to be vulnerable to severe disruption from an attack of a very modest scale." The administration acknowledges that in order to provide for the effective use of our forces in crisis situations, there is a need for reliable real time communications to transmit warning and intelligence data to the National Command Authorities and for the subsequent dissemination of orders to operational forces. To meet this need, the administration has made a commitment to identify existing deficiencies in our C3 capability, and has pledged the resources to eliminate them. The FY 83 defense budget, which contains significant increases for C3 modernization and upgrade programs, has grown from $14.0 billion in FY 82 to $18.0 billion in FY 83 (29). With the commitment of fiscal resources comes the challenge to ensure the prudent and efficient application of these resources.

Part of this responsibility rests with the Air Force Communications Command (AFCC). From its headquarters at Scott Air Force Base, Illinois, AFCC manages worldwide communications, air traffic services, and common user data automation services for the Air Force and various federal agencies. Additionally, AFCC is responsible for the engineering, installation, modification, and removal of communications-electronics (C-E) equipment and systems at bases throughout the world.

The magnitude of the Engineering and Installation (EI) responsibility can best be appreciated when one considers that AFCC was tasked with the accomplishment of more than 5,600 schemes (projects) in calendar year 1982 (33), amounting to a total cost of $95.3 million (18). This figure, however, fails to capture the actual amount of resources expended. Most of the program costs are funded by the procuring commands such as the Air Force Logistics Command (AFLC), Air Force Systems Command (AFSC), and Electronic Security Command (ESC). Regardless, it has become imperative that management action be taken to improve our ability to control costs and accurately forecast resource requirements.

The responsibility to oversee the efficient management of the EI function is delegated to the Engineering and

Installation Center (EIC) located at Oklahoma City AFS, Oklahoma. Established in 1981, the EIC is responsible for programming new requirements; engineering, installing, and retrofitting the equipment and systems; and performing on-site depot level maintenance. These tasks involve a complex series of actions distributed among many organizations and management levels within those organizations.

The Engineering Installation Management system (EIMS)--a vast computerized EI data base--provides EI managers with their primary tool for meeting this challenge. Since its implementation in 1967, the system has undergone numerous modifications to improve its usefulness. For many years, the system, previously known as the Ground Electronics Engineering Installation Agency (GEEIA) management information system, proved to be useful only for the management of short-term work schedules (22:74). The system was unable to provide managers with accurate data for long-range forecasts, and its output products were often cumbersome and difficult for functional managers to interpret. Consequently, EIMS was regarded by the EI community as a large historical data base with little analytical potential. Few individuals within the EI community knew how to access and process this information to improve their ability to forecast future workload (22:82). Both cost and schedule estimates were developed independently and later entered into the system. The estimates provided were often inconsistent and unreliable (2).

Compounding the problem is the fact that the cost and schedule estimates developed by EI managers are used by the requiring commands (customers) to make a variety of decisions. These estimates may be required for comparative studies, trade-off studies, funding decisions, program changes, cost-effectiveness analysis, independent reviews, and program approval determinations (23). Without some knowledge and experience of communications engineering and installation, customers find it extremely difficult to verify and adjust the estimates provided. A manager within the Military Airlift Command (MAC), for example, is not in a position to verify whether the projected direct labor hours required to install the scheme in question are indeed accurate. In most cases, he will accept the estimate as provided.

Unfortunately, the estimator, normally the scheme engineer, has a limited set of tools to develop accurate estimates. Traditionally, estimates are obtained by asking someone familiar with the type of scheme being implemented. Clearly, one engineer's estimate is not representative of a scientifically developed estimate. This tradition is:

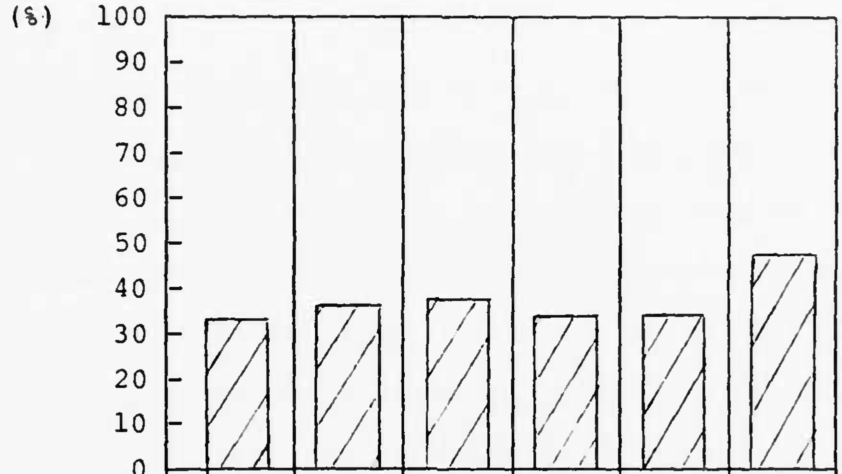
> . . . too often 'top-of-the-head', based on a sample of one, not documented, and non-reproducible, resulting in an estimate that cannot be evaluated by the user [34:1].

This technique also suffers from a number of other shortcomings. First, engineers are generally not concerned with how long it takes the installers to complete the scheme. They are only accountable for whether the system satisfies the needs of the customer. Secondly, it is often common practice to "pad" the estimate to ensure that ample resources are programmed. Finally, each scheme is sufficiently unique that, regardless of the experience level of the engineer, his estimates are prone to be inconsistent and unreliable.

The EI community has acknowledged these shortfalls and has initiated a variety of modifications to the EI Management System in an effort to alleviate them. In 1976, an AFCS study titled "Introspective Look" recommended a complete overhaul of EIMS. This recommendation was the catalyst for a number of modifications; one of which was the development of an EI work measurement system. The system was simply a catalogue of standard times to accomplish units of work. The initial standards were based on the collective judgement of a committee of "experts". The committee segregated each major category of EI work into the major operations involved. A standard time for each operation was then subjectively determined. These standards were to be updated as schemes were completed.

The system, however, failed to improve the estimates. In a letter to the EI community from AFCS (2:1), it was stated that "the existing EI work measurement system is inadequate in that the work standards generated through the system are unsubstantiated and unreliable." In the aggregate, however, the estimates appeared to be relatively accurate. One study indicated that the average of all the estimates came within "two percent" of the actual man-hour expenditures (22:75). Presumably, any estimation errors may have been cancelling one another out. Taken individually, the variability between the actual and estimated man-hours was often so large that it shortly became apparent that the system was not useful (2).

Although there has been a lot of discussion concerning the development of an improved work estimating system, nothing has yet materialized. Engineers have returned to the method of subjectively formulating estimates (22). As can be expected, many of the problems inherent with this technique are present today. For example, as depicted in Figure 1-1, in the first quarter of FY 1983, 48 percent of the required operational dates (ROD's) were delinquent (16:2). Much of this problem can be attributed to the inaccurate man-hour estimates provided at the outset. These same estimates are used to develop budgets, schedule workload, forecast resource requirements, and establish milestones against which progress and performance are measured. Despite the vast number of modifications to the EI management system, none of them attacked the most fundamental problem. That is, until the inputs to the system are improved, the outputs will continue to be useless. More



QTY/FY	4/81	1/82	2/82	3/82	4/82	1/83
% Delinquent	33.3	37.5	38.0	34.6	35.8	48.1
# Delinquent	528	630	767	690	596	748
Approved Rods	1584	1678	2019	1994	1942	1554

Figure 1-1. Required Operational Date (ROD) Delinquencies First Quarter FY 1983

specifically, a system must be developed that will draw on the available historical data base to systematically formulate man-hour estimates. The purpose of this research is to explore the feasibility of developing an automatic work estimation system which, as a component of the EI management system, can be applied by EI engineers to arrive at man-hour estimates that are accurate and reliable, yet flexible enough to adjust to the uniqueness of a particular scheme.

Problem Statement

There is a need to provide analytic support to EI managers for estimating the man-hours required to accomplish an AFCC EI scheme. Presently, there is inaccuracy between the original man-hour estimates and the actual number of man-hours expended. This results in an inability of management to adequately budget, schedule, forecast, evaluate, and control resources.

Background

The purpose of this section is to familiarize the reader with the mission and organization of Air Force Communications Command and the Engineering and Installation Center. An explanation of the C-E programming process is included to provide an insight into the complexity of the process and highlight associated problem areas pertinent to this research effort. A brief overview of the Engineering Installation Management system is presented to associate the reader with the architecture of the system as it exists today.

Air Force Communications Command

The mission of AFCC has remained the same since 1938: to provide the communications-electronics, meteorological, and air traffic control services for the Air Force and for other agencies as directed by the Chief of Staff of the Air Force (32:141). AFCC's mission responsibilities can be divided into six functions. These are base communications, which range from telephone and message centers to on-base radio networks; interbase communications via radio, cable and satellite links which encompass 50 percent of the Defense Communications System which serves all military activities; air traffic services, which involve assistance to both military and civilian aircraft in the air space designated for Air Force control; data automation, including the acquisition and evaluation of computer systems, and maintenance and enhancement of the software for many common-user programs; maintenance and evaluation of existing and new communications systems and equipment, air traffic, data automation, weather, intrusion detection, and radar systems; and engineering and installation of communications, air traffic services, weather and other electronic equipment including replacement, retrofit and on-site depot level maintenance actions (3).

These activities are carried out through seven subordinate command organizations called communications divisions, an Engineering and Installation Center, and nine direct reporting units (Figure 1-2). Five of the seven communications divisions manage the communications and air traffic service needs of five of the Air Force's flying commands. These include the Strategic Communications Division (SCD), Tactical Communications Division (TCD), Airlift Communica-

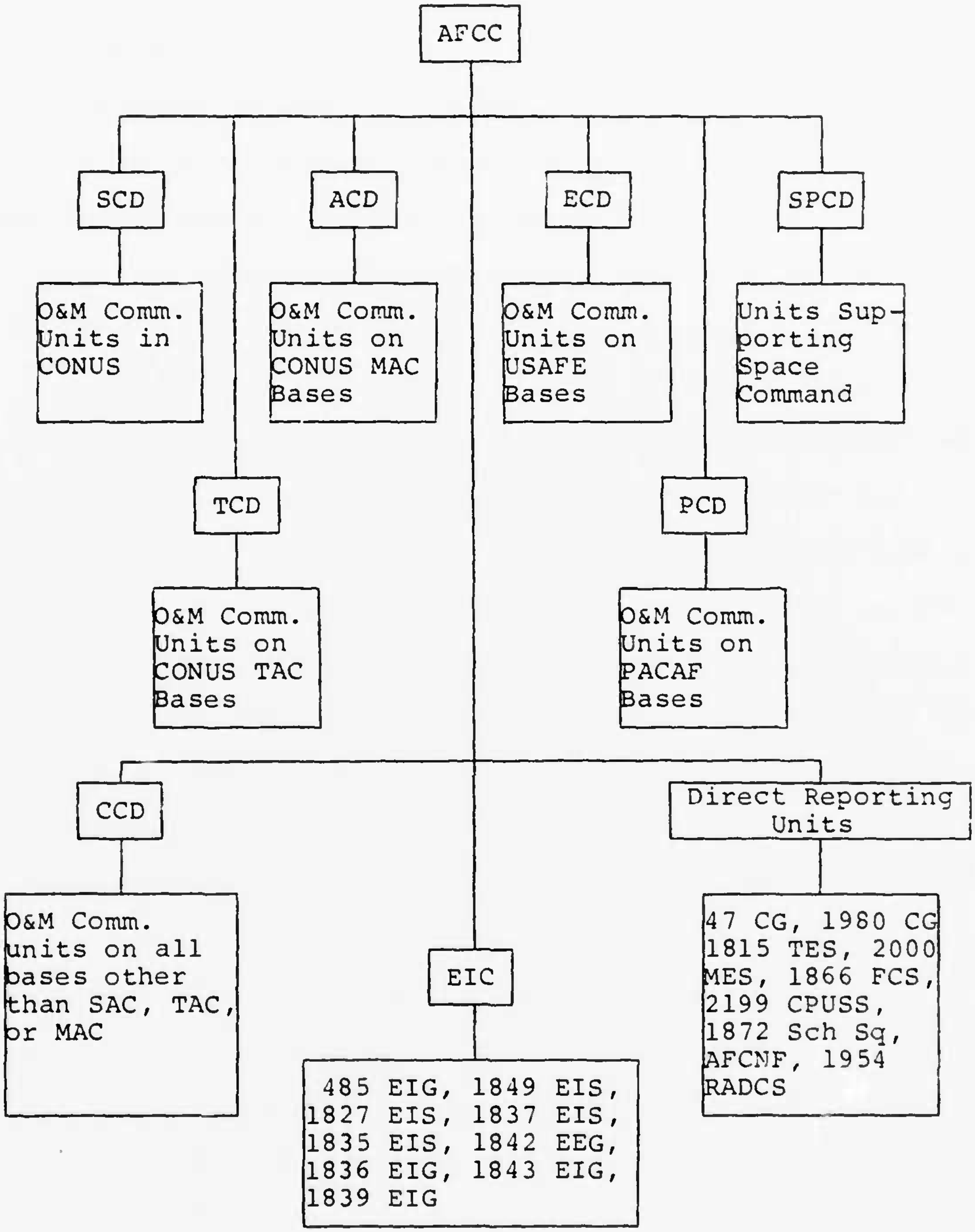


Figure 1-2. Air Force Communications Command Organizational Chart

tions Division (ACD), European Communications Division (ECD), and the Pacific Communications Division (PCD). The Continental Communications Division (CCD) serves the remaining major commands and separate operating agencies with the exception of the Space Command which is serviced by the Space Communications Division (SPCD) (1).

Engineering and Installation Center

As one of AFCC's intermediate headquarters, the Engineering and Installation Center (EIC) is the focal point for Air Force engineering and installation activities. Their responsibility encompasses the full range of planning, programming, engineering, material acquisition, installation, and mobile depot maintenance. These services are also provided to other military services, federal agencies, and foreign nations on a case-by-case basis. The center is responsible for nine active duty units as shown in Figure 1-2. The center also advises and trains personnel at 19 Air National Guard electronic installation squadrons. In 1982, the center's 350 electronic installation teams and 600 plus engineers spent nearly 3,000,000 man-hours completing more than 5,600 schemes at 400 locations around the world (33).

C-E Programming Process

To place the complexity of the EI management responsibility in perspective, a review of the basic process through which a scheme is developed and implemented is in order. The C-E programming process provides the framework through which an operational need is transformed into a C-E scheme and subsequently an operational capability. A C-E program can follow one of two paths: downward directed or upward directed. A downward directed program is one that is initiated at a management level above the ultimate user. An upward directed program is generated by the ultimate user. In many respects, both programs are handled identically. The major difference is that the downward directed program has already been approved. The upward directed program must be processed through a series of validation boards before receiving program approval. Thus, in the latter instance, the accuracy of information provided during the approval process impacts the validity of decisions reached by the validation boards.

Presently, the need for a specific communications requirement is first identified through the development of a program communications requirement (PCR). Much like a Statement of Need (SON) required for major systems acquisition, the PCR identifies deficiencies in the existing communications-electronics capability of a base and the impact on the base's ability to carry out its mission. It is the PCR that transforms the requiring command's need into a C-E program and facilitates the subsequent programming, budgeting, funding, and implementation activities. The validity of decisions made throughout the process depends on the accuracy of the initial cost, schedule, performance, and supportability estimates presented in the PCR.

The process of defining the need for a new or improved communications capability is a continuous one that occurs before the actual development of the PCR as illustrated in Figure 1-3. Once the need is defined, the first action is to assess whether the requirement can be satisfied with existing resources. The responsibility for this decision rests with the base Command and Control, and Communications Requirements Board (C3RB). The C3RB is an activity established at major commands, bases, and intermediate levels if necessary, for the purpose of validating communications-electronics requirements. They are also the focal point for establishing and maintaining coordination among command supporting activities (35:A-4). The board considers items such as mission impact, alternative solutions, schedule, and cost. The emphasis at this stage in the process, however, is often placed on the justification and clarification of the need. The other considerations are given less attention.

The current system provides an avenue through which the requiring command can request assistance from the communications community with the preparation of the PCR, as illustrated in Figure 1-4. The process is initiated when the requiring command submits a request for technical

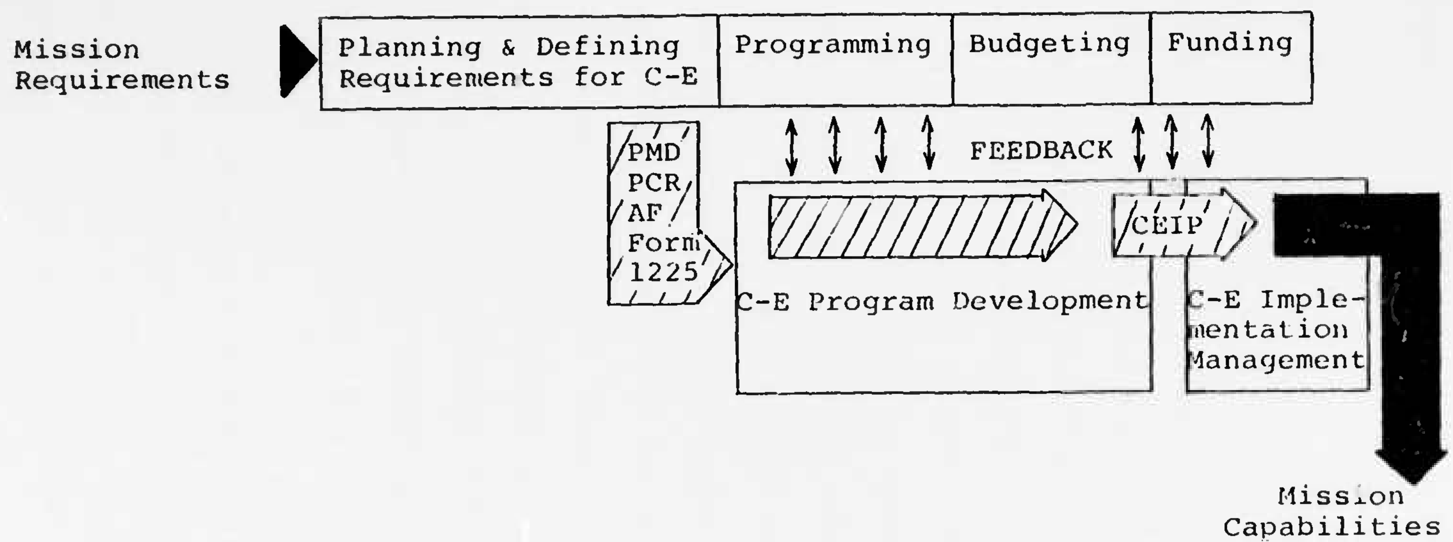


Figure 1-3. C-E Requirement Process

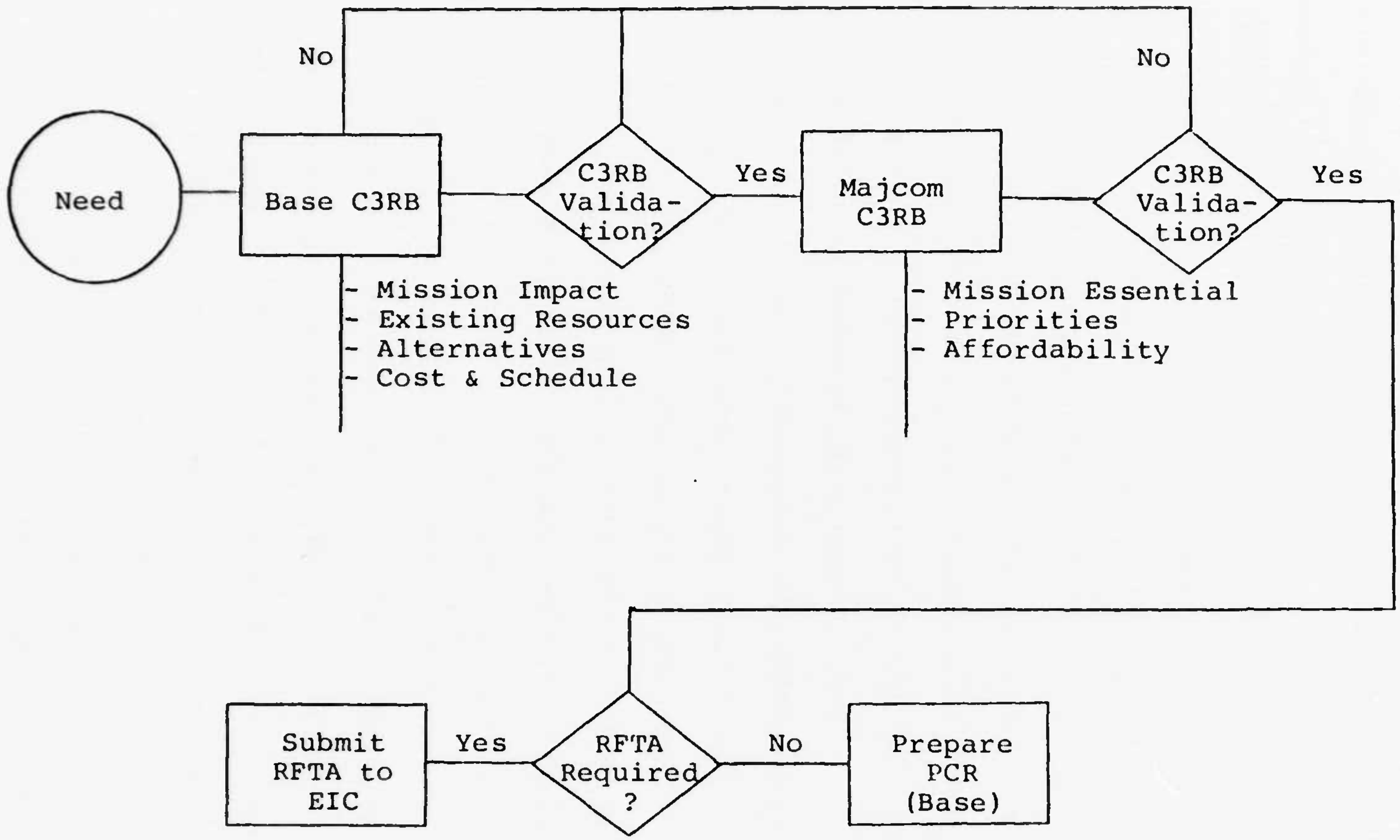


Figure 1-4. Request for Technical Assistance Process

assistance (RFTA). The RFTA is processed through the requiring command's channels to the Engineering and Installation Center. The request is forwarded to the appropriate branch and assigned to an engineer. The RFTA is the instrument that brings the experience and expertise of the communications community into the process. It is a critical document because it serves as the foundation from which many subsequent documents originate. For example, the RFTA is returned to the requiring command after completion, and the requiring command will incorporate the information provided into the PCR. The PCR is processed through a series of validation boards and, if approved, becomes an input to the command's program objective memorandum (POM). The POM then becomes one of the primary inputs into the Planning, Programming, and Budgeting System (PPBS). Clearly, if the information provided in the RFTA is inaccurate or incomplete, the validity of the managerial decisions made at subsequent stages will be suspect.

AFR 100-18, the governing directive for C-E program management, requires a detailed cost breakout be included in the PCR. Implicit in this directive is the requirement to provide such a cost breakout in the RFTA. The breakout must address the total cost of the program in terms of nonrecurring costs and projected first-year operation costs (35:A2-3). Nonrecurring costs include acquisition costs of major items of equipment, engineering and installation costs, minor hardware and equipment, travel and per diem, and minor construction costs. Annual recurring costs encompass O&M supplies, leasing and other contractual costs, and other miscellaneous materials. The cost figures are included in the PCR for review and approval by the major commands C3R board. Upon program approval, the PCR is sent back to the EIC where a program manager is assigned to oversee the development of the scheme. The first step in the development of the program is the writing of the communications engineering and implementation plan (CEIP). The CEIP is a comprehensive document showing the resources required for a particular facility or system. Basically, it is a recapitulation of previous planning and programming decisions. It includes an analysis of the type of action required (removal, installation, relocation, etc.), the equipment required, a tentative system design, estimate of the costs, and a detailed schedule of all the actions required (35:A-4). Upon approval of the CEIP, the program formally enters into program development as governed by AFR 100-18. The scheme engineer then begins with the preparation of the Site Concurrence Letter (SCL) which describes the proposed site for the equipment and other related information such as available supporting structures and host command responsibilities (22:68). Once the requiring command agrees to the proposals in the SCL, the engineer proceeds with the development of the scheme package. The scheme package is a formal planning document that provides specific guidance as to the supply, installation, testing, and other requirements of the scheme. The scheme package becomes the central document for governing the activities of the EI team. The EI team has the opportunity to review the package and comment on its contents. They also have the chance to adjust the estimated man-hours provided by the engineer. In many instances, the team will perform a pre-installation survey after which they can again make adjustments to the man-hour estimates. If everything is in order, the team is redeployed to perform the work.

The progress of the scheme is monitored through the workload control function of the tasked EI group/squadron. Daily status reports are called in from the field each day. The team provides a brief summary of the work accomplished, potential problem areas, percentage of the job completed, and man-hours expended. The vehicle by which the expended man-hours are gathered is the AFCC Form 377. The form is completed daily by the work-center responsible for the deployed team. Expended man-hours are assigned a specific "action taken" code. Action taken codes explain how the man-hours for direct labor personnel were expended. The codes fall into eight general areas (4:A1):

100 series - Engineering productive

200 series - Maintenance/Installation productive

300 series - Lag time

400 series - Productive indirect

500 series - Supervisory time

600 series - Training

700 series - Duty absences

800 series - Non-duty absences

Each of the series are further segregated into more specific action taken codes. For example, "309 time" is time lost due to weather conditions which prevent C-E installation or maintenance, flight checks, etc.

It is evident that the C-E programming process and subsequent control of EI workload involves many activities distributed among many organizations and management levels. For the sake of simplicity, however, a number of activities were not incorporated in this overview. The point is that the process is dependent upon estimates, both cost and schedule, provided in the early stages. Although the estimates are refined at subsequent stages in the process, it is often too late to correct for the problems created by poor quality initial estimates. At this point, resources have already been budgeted and scheduled for use.

Engineering and Installation Management System

The EI management system was first implemented in 1967. At that time, the Ground Electronics Engineering Installation Agency (GEEIA) was responsible for the system which they called the GEEIA management information system.

It was not until 1970 when GEEIA was absorbed by the Air Force Communications Service (AFCS) that it was renamed EIMS. EIMS is comprised of two major subsystems as depicted in Figure 1-5.

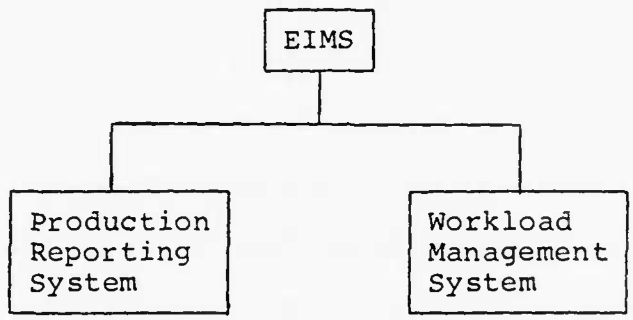


Figure 1-5. Engineering and Installation Management System

These subsystems are the Workload Management System and the Production Reporting System. The workload management system is maintained by HQ AFCC and includes information such as costing data, man-hour estimates, material delivery estimates, and team composition. The production reporting system identifies total EI direct labor man-hour resources assigned by work-center and the number of man-hours expended by these work-centers on specified EI workload. It is essentially the feedback loop to the workload management system. Once a week, the data from the production reporting system is interfaced with the workload management system to update the established milestones.

Justification

The justification for this research is based on two aspects: an AFCC request to develop an EI work measurement system which would provide reliable estimates; and a recommendation for a follow-on study to an AFIT sponsored research project.

A 1976 AFCS study titled "Introspective Look" suggested that the EI management information system be overhauled so that it would provide more accurate and reliable information. The study concluded that man-hour projections are not consistent with actual expenditures (20). The study further recommended the development of man-hour standards for use in making projections. The result was the development of an EI work measurement system. Unfortunately, the system was short-lived. A letter to the EI community from AFCS stated:

> For some time, it has been evident that a new system is needed for estimating hours required to accomplish AFCS EI work. The existing EI work measurement system . . . is inadequate, in that the work standards generated through the system are unsubstantiated and unreliable. This inadequacy is compounded by the fact that the system is also inflexible [2:1].

In 1979, an AFCS project proposal titled "AFCS TAB 35123 -- EIMS Software" (6:2) proposed a vast expansion and update of the EI management system. Specifically, four requirements were outlined:

a) Workload assignment system: to evaluate implementation requirements versus resource availability, remove the geographical boundaries for the division of work, provide consideration for seasonal work, and allow task leveling among EI units.

b) Automated standards updating and estimation system: to compute and keep current standard engineering and installations man-hours for use in project estimations.

c) Milestone adjustment system: to automatically order programs, offer alternative courses of action, and maintain cognizance of all interested parties when changes occur.

d) Unapproved/forecast workload projection system: to allow identification, estimation of costs, and estimation of man-hours required for all potential EI workload for up to a seven-year period.

Acting on the study's recommendation, AFCS suggested the development of a table of estimates which, for the purposes of work estimation, would provide a range and average of the man-hours required to complete a similar job. The engineer would project future jobs based on the table of estimates. The effort never proceeded beyond the planning stages, however, because of the reorganization of AFCC in June of 1981. In 1982, AFCC tasked the newly created Engineering and Installation Center with the continuation of the project. Presently, the EIC has been unable to devote much attention to this project due to a large number of higher priority projects. This research addresses a portion of the overall requirement which, when combined with the efforts of the EIC, will lay the groundwork for the development of an automated standards updating and estimation system as recommended by the 1979 AFCS study.

In 1980, HQ AFCC sponsored an AFIT research project by Hammel (19). Hammel developed and used two mathematical models for the assignment and scheduling of EI workload. Throughout the study, Hammel (19:90) used several simplifying assumptions, for which he explained that "It is necessary to expand this effort to incorporate some real world aspects in the model which had to be assumed away." Brylski and Nelson, a year later, attempted to incorporate realism into Hammel's model. One assumption that remained, however, was that the man-hours within the EIMS data base were accurate. Brylski and Nelson (10:17) concluded that the Hammel model would not be valid until the EIMS data base was "cleaned up". This research provides the groundwork from which this recommendation can be achieved.

Scope

The scope of this research is confined to the development of a model for estimating the installation man-hours required for one specific category of communications-electronics facilities (facility code 0xxx). The methodology discussed in Chapter 3, however, is applicable to all facilities. Facility code 0xxx, base wire plant, includes all schemes on base wire and telephone systems, government-owned and commercial, off-base and on-base, that are part of the overall base switchboard and switching facilities, station equipment, and supporting structures. Excluded are missile countdown and launch control C-E facilities which are included within a separate facility code. Additionally, mobile depot maintenance (MDM) activities will be excluded due to the fact that these actions are controlled by the AFCC logistics staff and not the EI community. Also, this study is restricted to schemes completed within the continental United States (CONUS) in the last two years. The reason for this is that only two years of historical data are available, and the apparent need to obtain additional data through telephone contacts.

Research Questions

The following research questions are proposed:

1. Does the EIMS data base contain sufficient information to construct a model to estimate the man-hours required to install an EI scheme?

2. What degree of estimation accuracy is being achieved today without the support of the EIMS data base?

3. What variables directly influence the time required to accomplish a C-E scheme within facility code 0xxx?

4. What is the relationship between the dependent variable, total man-hours required, and the variables identified?

5. Is there an interrelationship between the selected independent variables?

Research Objectives

1. Identify and analyze the variables which impact the total man-hours required to install an AFCC EI scheme within facility code 0xxx.

2. Develop a multivariate regression model for estimating total man-hours based on the variables identified.

3. Determine a level of accuracy that is feasible for the model.

4. Test the model's accuracy and reliability.

CHAPTER 2

LITERATURE REVIEW

Work Measurement

Introduction

Work measurement is an indispensable part of the planning and control of an organization and its resulting productivity. The development and implementation of work standards based on the principles of work measurement offers valuable potential improvements in the productivity of civilian, government, or military organizations. The cornerstone of any productivity program built on work measurement techniques is the determination of how long it takes the average employee to produce one unit of work. In other words, what is the standard?

History

Time and motion studies are two work measurement techniques commonly applied in the development of work standards. Barnes (7:4) defines time and motion study as the:

> Systematic study of (1) developing the preferred system and method - usually the one with the lowest cost; (2) standardizing this system and method; (3) determining the time required by a qualified and properly trained person working at a normal pace to do a specific task or operation; (4) assisting in training the worker in the preferred method.

In 1760, a Frenchman named Perronet utilized time study techniques to develop a work standard for the production of common pins (26:10). However, except for work done by Charles Babbage in the 1800s, the real development of time study methods and principles began in 1881.

Frederick W. Taylor, generally referred to as the father of time study within the United States, began his time study work in 1881 while employed as chief engineer for the Midvale Steel Company in Philadelphia. In June 1885, he presented his research to the American Society of Mechanical Engineers (ASME). Due to the prevailing attitude held by these engineers towards piecework manufacturing theories and techniques, his work was not readily accepted. In June 1903, Taylor presented a second study to the ASME which contained the results of his previous study and also his famous scientific management philosophy for organizations. This philosophy, which included the principles of time study techniques as an integral part of the entire mechanism for scientific management, was well received by many factory managers and engineers. Although the theory gained acceptance, implementation of the principles advanced rather slowly and failed in many applications. The slow implementation and subsequent failure of the scientific management concept can be attributed to several factors such as the limited existence of literature outlining the concept, unavailability of implementation training, worker/union resistance, and the growth of so-called scientific management experts eager to reap large consultation fees (26:10).

Responding to demands by workers and union leaders, the US military establishment banned the use of time studies and specifically stopwatch studies in its departments until 1947, when the House of Representatives removed the restrictions (26:12).

Taylor's time study procedure consisted of breaking each task into identifiable elements which were separately timed. Once all the elements were timed, they were summed to arrive at a standard time for the task studied (26:10).

Concurrent with Taylor's work, Frank and Lillian Gilbreth were involved in the study of body motions relating to task accomplishment. In contrast to time studies which emphasize methods of obtaining the shortest time to complete a task, motion studies seek to develop improved methods for task accomplishment by eliminating unnecessary motions and simplifying necessary ones to establish the most favorable motion sequence in terms of efficiency.

Today, time and motion studies are recognized as necessary tools to effectively and efficiently manage business or industrial operations. A large number of colleges and universities are teaching the principles, techniques, and philosophies of time and motion studies within their industrial engineering curricula. Labor unions are training their representatives on the results and uses of such studies, and both small and large businesses/industries are capitalizing on the benefits derived from these techniques.

The US Air Force requires any contractor awarded a contract which exceeds $1 million to adhere to the provisions of MIL-STD 1567 which requires a work measurement plan and procedures, a plan to establish and maintain engineered standards of known accuracy and traceability, a plan for methods of improvement in conjunction with standards, and a plan for the use of standards as an input to budgeting, estimating, planning, and performance evaluation (26:19). There is also an increasing trend to extend the application of time and motion studies to the area of indirect labor, as well as computerization of several predetermined time standard systems.

In August 1973, the Deputy Secretary of Defense announced the establishment of a permanent productivity program within the DOD (13:Encl. 3). The implementing DOD Directive 5010.31 requires all DOD components to implement a department wide productivity program. The primary objective of such a program is to achieve optimum productivity growth (13:1). Productivity increases will assist in offsetting increased personnel costs and reduce the unit cost of goods and services provided by the DOD. DOD Instruction 5010.34 distinguishes between two types of productivity--resource and labor productivity. Total resource productivity represents the efficiency with which organizations utilize the various types of fund resources (14:1). Labor productivity represents the efficiency with which labor resources are utilized. Within the realm of labor productivity, DODI 5010.34 mandates the refinement of labor performance standards as an approach to increasing labor productivity. Despite this instruction, there is no supplemental guidance to assist in the development of work standards. The need for the development of work standards is apparent; the manner in which to achieve these standards is not.

Charles Day (12:61), in a recent article, conveyed that the science of work management has been hampered by the inordinate attention being given to macro productivity ratios. Industry, much like the DOD, is so concerned with the productivity question that it has completely forgotten about the foundation on which productivity rests--work standards. Simply stated, productivity is the ratio of output to input. The output is the time it should take a trained employee working under normal conditions to complete a unit of work. The input is the actual time spent to produce that unit of work. The common element to both output and input is time. Thus, the cornerstone of any productivity program is a determination of how long it takes an average employee to produce a unit of work.

DODI 5010.34 (14:Encl. 3) classifies labor standards as either engineered or non-engineered. An engineered standard is one that is developed by the application of standard time data, predetermined time systems, time study, rated work sampling, or a combination of techniques. It further stipulates that at least 80 percent of the total time included in the standard be based on data which have, at a minimum, an accuracy of plus or minus 25 percent at a 90 percent confidence level. A non-engineered standard is normally based on statistical or historical data, technical estimates, or man-hour allowances. The degree of statistical reliability does not have to be determined. Although less time consuming and often less costly, non-engineered standards lack the accuracy and reliability of engineered standards. The type of standard selected should be commensurate with the type and magnitude of workload being evaluated, the time and resources available to develop the standard, and the statistical reliability required.

The US Navy implemented a work standards program to take the place of the former system of self-reported information. Prior to the new system, workers estimated the time required to perform a particular unit of work based on how long it took them to do the job previously. The Navy was uncomfortable with this technique because of the high turnover and wide variation in experience levels of the crews involved. Another method to gauge true performance and productivity was needed. The method, developed by the Planning Research Corporation, as discussed by Bihr, consists of an integrated system that combines engineered time values (ETV) with special allowances. The ETV system is derived from a scientific measurement system common to industry called universal maintenance standards. This technique employs benchmarks which are simply practical standards based on a range of time within which a given job should be done by a qualified worker (8:59).

The Navy's ETV system modifies the UMS data to reflect the working conditions of a particular location. Based on the norm of a middle-grade technician with at least one year of experience, the work standards are adjusted to reflect the skill levels of the personnel involved. Additionally, learning curve theory is incorporated into the UMS to account for additional job experience and extra training.

The ETV system has proven to be the best method for applying industrial standards to the Navy work environment. The Navy claims that performance increases within the six shops in which the ETV technique was applied have ranged from 18 percent to 147 percent (8:61). ETV has taken the trial and error approach out of the development of maintenance standards and has given managers a more accurate account of the amount of work which can and is being accomplished. Although the ETV system cannot increase a technician's skills, it can ensure better utilization of the existing resources. Additionally, ETV has assisted managers in pinpointing training deficiencies and identifying poor performers. Disclosure of unfavorable trends enables managers to take appropriate steps to correct such trends. Trend data also provides managers with an assessment of past actions and their corrective impact on the problem.

Cost Estimation Methods

This section reviews several estimating techniques and methodologies used by the DOD. Although the majority of the models studied are aimed at projecting dollar amounts for aircraft systems or armament cost, the underlying principles of these cost models are applicable to the development of an automated work measurement system.

A cost estimate is a judgement or opinion regarding the cost of an object, commodity, or service which is arrived at formally or informally through a variety of methods. Most estimates are based on the assumption that past performance or experience is a reliable guide or predictor of future costs. The techniques or methods utilized in developing cost estimates range from intuition to detailed application of material and labor standards.

Air Force Systems Command Manual (AFSCM) 173-1 lists seven basic estimation methods: industrial engineering standards; rates, factors, and catalog prices; estimating relationships; specific analogies; expert opinion; cost model applications; and trend analysis (21:4-1). Each of these methods can be applied to the development of valid cost estimates. Four of the most relevant techniques are: industrial engineering techniques, specific analogies, expert opinions, and estimating relationships.

Industrial engineering standards (IES) define and measure the work content of discrete elements which comprise a production task (21:4-2). An IES is developed by carefully analyzing work statements, drawings, and specifications, outlining the tasks required to complete the project, and then timing each task to arrive at the standard man-hour estimate.

Industrial engineering standards require a large number of personnel specifically trained in data gathering techniques and methodology application.

> One of the largest aerospace firms judges that the use of this approach in estimating the cost of an airframe requires about 4,500 estimates; for this reason the firm avoids making industrial engineering estimates whenever possible [30:5].

Additionally, they are often less accurate than statistically derived estimates. As stated earlier, the engineer identifies the various tasks required to complete a project by analyzing initial work statements, drawings, and specifications and assigns a standard to each task. In many instances, the whole turns out to be greater than the sum of its parts. Also, many tasks are situationally unique and are not accomplished the same way each time (30:5-6). However, given adequate time and significant amounts of data, this method is generally accepted to be the best estimation technique.

Specific analogies (21:4-1) depend on the known cost of an item used in prior systems as the basis for the cost estimate of a similar item in a new system. Adjustments are made to account for differences in relative complexities of the design, performance, and operational characteristics. Since many new systems are essentially combinations of existing systems or subsystems, the use of analogies represents one practical method of obtaining estimates.

Expert opinion type estimates are obtained directly from organizations or persons possessing specific knowledge or expertise in a particular area to be estimated. This method is normally used in situations where estimating or other relationships cannot be used due to time and/or appropriateness. Specialists are often consulted to verify estimates which have been obtained by analogy or other estimation methods.

The Delphi technique, developed by the Rand Corporation in the late 1940s, utilizes the estimates of several specialists to arrive at a final estimate.

> Essentially, the Delphi technique is a series of intensive interrogations of each expert (by a series of questionnaires) concerning some primary question

> interspersed with controlled feedback. The procedures are designed to avoid direct confrontation of the experts with one another [21:61].

The answers to each series of questionnaires are shared with each of the other specialists in an iterative process until a general consensus is reached.

The Delphi technique eliminates many of the disadvantages and pressures of round table discussions, thereby allowing each expert to apply independent thought to the problem under consideration.

Cost Estimating Relationships (CER)

The cost of equipment often varies in relation to its weight, speed, frequency, power, or other distinguishing characteristics. Data on these various factors can be collected, statistically analyzed, and transformed into CERs to predict equipment cost. These CERs may be cost-to-cost, cost-to-noncost, or noncost-to-noncost relationships depending on the variables used and the intended use of the relationship (21:4-1).

Cost-to-cost relationships are used when the cost of one item depends on the cost of another, such as the cost of aircraft spares in relation to the cost of the airframe. Cost-to-noncost relationships are developed for situations in which the cost of equipment varies with system characteristics such as weight, power, frequency, and range. A variant of this method, a noncost-to-noncost relationship, is often used to estimate the number of administrative personnel required to support a system based on the number of personnel needed in the operation of the system. Installation man-hours often depend on the amount of cable to be installed, the number of phone lines required, or the quantity of equipments installed. Man-hour estimation CERs are basically noncost-to-noncost relationships based on previous or historical man-hour data.

The US Army utilizes CERs in several functional areas (27:D-1). The Health Services Command employs a CER to objectively quantify direct nursing care requirements and the manpower required to staff these requirements. The system: (1) assesses direct nursing care activities by care area, (2) identifies the appropriate skill level mix needed, (3) is readily adaptable to automated systems, (4) easy to update, and (5) provides a 24-hour retrospective assessment for the establishment of both patient care and staff requirements.

The Detailed Operating and Support Cost Estimate (DOSE) computer model (9:i) utilizes simple cost equations to calculate the material and manpower requirements associated with both scheduled and unscheduled maintenance actions during the operations and support (O & S) phase of a weapon system's life. This model, developed by the US Army Aviation Research and Development Command, contains a simulation capability which allows the user to vary operating parameters such as cost growth, reliability growth, and maintenance induced failures to assess the effects of the changes of cost required for O & S. Outputs can be obtained in several different formats such as cost per year per maintenance level, cost per Line Replaceable Unit (LRU), listings of the 50 highest Shop Replaceable Unit (SRU) cost drivers, or a maintenance allocation chart which summarizes labor hour requirements for each item and lists each required maintenance action.

Man-Hour Estimation

The economical and effective utilization of resources (money, manpower, and materials) depends upon the proper planning, programming, budgeting, and scheduling of these available resources.

The American Telephone and Telegraph (AT&T) and the US Air Force Communications Command were two of many organizations which recognized this fact in the early 1970s and developed management systems to assist them in their efforts. AT&T developed the Broad-gauge Manual which was primarily a cost guide for the installation of telephone cable (24). AFCC developed an Engineering-Installation Work Measurement System to compute standard installation time for particular jobs which, when combined with material and travel cost, would represent the total cost of an installation.

Used primarily by AT&T engineers, the Broad-gauge Manual provides cost factors for the manpower and materials involved in a telephone cable installation. Once the type of installation and the amount of cable required are determined, the engineer can consult the Broad-gauge Manual to obtain the applicable cost factors for materials and labor. Although the manual provides work unit amounts which can be readily converted to man-hours, the engineering personnel really have no need for actual man-hours. The construction crews are very interested in the amount of hours required to complete each job. Unfortunately, the estimated hours obtained from the Broad-gauge are often inaccurate by as much as twice the actual man-hours required, which is the main reason construction crews must estimate their hours using some other method. For the most part, they formulate estimates based on the standard time increment concept and prior experience. Although the Broad-gauge is inefficient for specific jobs; in the aggregate, estimates are within approximately three percent of the actual man-hours consumed per year. Even so, AT&T has become more concerned with the dollar figures in all areas of a particular job and has decided to implement a mechanized system called the Job Management Operation System (JMOS) which will allocate resources, schedule workload, and cost out the various portions of a job. The man-hours are to be computed using standard time increments which have been developed as a result of a $1 million dollar effort by AT&T. The JMOS is being tested in Illinois; and if successful, it will be offered to the independent Bell Telephone companies by AT&T.

The EI Work Measurement System, developed by AFCS in the early 1970s, was designed to furnish EI managers with a standard installation time for various tasks which could be used for budgeting, scheduling, and planning. The initial standards were developed (5:1-1) by knowledgeable experts such as program managers, project engineers, and technicians. As jobs were completed, the actual task times were to be reported and entered into the system. Once adequate sample sizes were gathered, the computer was to update the applicable standard automatically.

The system had great potential but never materialized due to nonstandard reporting from the field, inadequate sample sizes, and the lack of overall management support from all levels (11). The standards never changed; and managers fell back to estimations based on experience, judgement, analogies or any method they chose. This type of estimation continues today and is the target of this research effort.

CHAPTER 3

METHODOLOGY

Chapters 1 and 2 provided a statement of the problem, the relevant background, and a brief discussion of four techniques available for developing estimates. This chapter outlines the methodology employed in this research effort. The chapter is divided into two sections. Section one describes the research approach, the data base, the selection of variables, and the sampling plan. Section two addresses the specific statistical techniques applied in developing and selecting our final model.

Research Approach

The development of our functional model is carried out within the framework of the general linear regression model. The model is of the form:

$$Y = B_0 + B_1X_1 + B_2X_2 + \ldots + B_nX_n + E$$

where,

Y = the variable we wish to predict

$[X_1, \ldots, X_n]$ = the set of predictor variables on which Y depends

$[B_0, \ldots, B_n]$ = the corresponding set of regression coefficients to be estimated by the method of least squares.

E = the random error component

Although regression analysis is a widely accepted tool for modeling the response of one variable as a function of one or more independent variables, there are a few aspects of the general model that merit further discussion. First, our ability to make valid inferences depends on the satisfaction of a certain set of assumptions. Specifically, regression analysis assumes that the random error components (E) are uncorrelated random variables with a mean of zero and a variance of σ^2. In order to perform hypothesis testing and to construct confidence intervals for the various regression coefficients, the assumption of normality is also required.

A second point to be emphasized is the set of predictor variables does not necessarily contain all the possible variables that influence the dependent variable. There may be other pertinent variables that have not been addressed. The influence of these variables will show up in the random error component only. The presence of the error term suggests the existence of a measurement error which, depending on the magnitude of the term, will impact our ability to make predictions based on the functional model specified.

Finally, our ability to predict based on our functional model is limited to the range of values in which the sample data fall. Beyond this range, a straight line may not provide a good model on which to base predictions.

Data Base

The data for the candidate set of variables was collected from two sources. The principle source was the workload management system. The workload management system is a two year historical data base maintained by AFCC. The data base contains over 200 data fields for nearly 15,000 file records (schemes). These include the actual man-hours expended, estimated man-hours, workload identification number, and commodity code to name just a few. Only schemes that have been completed or deleted are included in the data base. Once each week, the data base is updated. The second source of information was telephonic contact with communications squadrons responsible for maintaining the installed schemes. A preview of the data maintained in EIMS indicated that this was necessary because of the difficulty ascertaining the nature of each scheme. Although the data base contains a narrative description of each scheme, in almost all cases, the narrative was too general to accurately determine the scope of the project.

Selection of Variables

The criteria for selecting the set of variables used was based on three requirements: the potential significance of the variable in predicting changes in the response variable, the availability and accessibility of the data, and the objectivity of the data. Initially, we conjectured that several variables have an influence on actual installation man-hours. Our set included variables such as the size and length of the cable, the number of splices required, the location of the cable (i.e., buried, underground, aerial), the skills required (i.e., inside plant, outside plant construction, outside plant cable, etc.), the season of the year, the region of the country, the type of soil (i.e., sand, rock, etc.), type of trenching equipment used, the requirement to hand dig around obstacles such as existing cables, and the need to cut across roads, parking lots, etc. Through discussion with managers within the engineering and installation community, a number of these variables were eliminated because of a lack of data. The final set of variables consisted of:

Dependent Variable

Total installation man-hours expended (MITOT) - MITOT includes all direct labor hours considered normal duties incidental to the installation of a C-E scheme.

Independent Variables

Cable length (CLEN) - CLEN is a ratio variable that specifies the physical length of a communications cable expressed in feet.

Cable pair (CPAR) - CPAR is a ratio variable that specifies the quantity of wire conductors in a cable. For example, a 300 pair cable contains 600 conductors.

Cable location (CLOC) - CLOC is a nominal variable that identifies the physical location of the cable (i.e., aerial, buried, or underground).

Commodity code (CMDY) - CMDY is a nominal variable that identifies the type of skill required. Commodity codes are listed in Table 3-1.

Region (REGN) - REGN is a nominal variable that specifies the particular region of the country the scheme was installed. The seven regions are illustrated in Figure 3-1.

Season (SEAS) - SEAS is a nominal variable that specifies the season of the year the installation began (i.e., spring, summer, fall, winter).

Sampling Plan

Population

In this study, we define the population as all communications-electronics schemes completed in the CONUS within the last two years involving base wire and telephone

TABLE 3-1

ENGINEERING AND INSTALLATION COMMODITY CODES

Commodity Code	Description
A	Telephone Inside Plant
B	Telephone Outside Plant
C	Other Government Communications
D	Commercial Leased Inside Plant Facilities
E	Commercial Leased Outside Plant Facilities
F	Other Commercial Leased Facilities
G	Radiation Interference
H	Radiation Hazard
J	Microwave and Tropospheric Scatter
K	Cryptographics
L	Telemetry
M	Meteorological
N	Navaids Radio
P	Public Address
Q	Commercial Public Address/Closed Circuit TV
R	Radio
S	Antenna Outside Plant
T	Instrumentation
V	Closed Circuit TV
W	Navaids Radar
X	Radar
Y	Electronic Data Processing Equipment
Z	None of the above apply

systems, switchboard, and switching facilities. These facilities are identified with a facility code of 0xxx. The facility code is a four digit code that identifies C-E facilities. It is divided into two components. The first digit, the "A" code, identifies the general category to which a facility belongs. There are 11 possible categories (35:A1-4):

0000 - Base wire plant

1000 - Aerospace warning/weapon control facilities

2000 - Navaids, meteorological, and flight facilities

3000 - USAF common long-haul communications systems

4000 - Other intercommand systems

5000 - Weather communications

6000 - Base command communications systems

7000 - Training facilities

8000 - Aerospace C-E facilities

9000 - Special projects

0000 - Air National Guard facilities

The last three digits, the "B" code, specifically identifies an operational requirement. At present, there are 153 specific B codes, as shown in Appendix A. For example, the facility code 0011 identifies a government-owned telephone facility.

Sample

The sample used in this research effort was drawn from a population of 1,084 possible schemes. A two stage sampling plan was used. The first step was the stratification of population elements into seven mutually exclusive categories. The specification of strata was based on the previous areas of responsibility of the seven active duty EI units as illustrated in Figure 3-1. Division of the CONUS into mutually exclusive regions may facilitate the analysis of the possible influence of weather, soil conditions, and terrain on the dependent variable. It should be noted that the classification of strata violates the requirement that the elements within each strata be homogeneous--that is, having less variation than the elements in the population insofar as the characteristic of interest is concerned (31:199). No classification scheme was available to guarantee homogeneity of the strata elements. For example, soil conditions and terrain could vary not only from region to region, but also base to base. Further, there could be differing soil and terrain conditions on a particular base. Thus, the selection of strata was for convenience.

The second step in the sampling plan was a random sample from each strata. The number of schemes included in each sample was dictated by two requirements: the need to obtain information from various communications squadrons

Figure 3-1. Stratification of CONUS into Seven Previous Areas of Responsibility of Active Duty E-I Units

and the desired level of confidence of the results. Initially, it was determined that 20 schemes would be selected from each strata for a total sample of 140 schemes.

Analysis Approach

The objective of the analysis was to develop a functional model to predict the total installation man-hours required for a scheme within facility code 0xxx. The analysis involved the application of analysis of variance (ANOVA) and multiple regression.

ANOVA is a statistical procedure for comparing two population means. In its simplest form (that is, in the case involving the comparison of only two population means), ANOVA is equivalent to the two-sample T-test (25:24). ANOVA was used to test the hypothesis that there is no difference between the original man-hour estimates developed by engineers and the actual man-hours expended. The null hypothesis (Ho) and the alternate hypothesis (Ha) are:

$$Ho:\quad Ue - Ua = 0$$

$$Ha:\quad Ue - Ua \neq 0$$

where,

Ue = original man-hour estimate, and

Ua = actual man-hours expended

Table 3-2 illustrates four possible consequences involved in the selection of the null or alternate hypothesis stated above. Rejection of a true null hypothesis results in a type I error. The probability of rejecting a true null hypothesis is known as the level of significance (α). Acceptance of a false null hypothesis produces a type II error (β). The β risk can be reduced by allowing a greater α risk or increasing the sample size. It is important to note that a null hypothesis is never said to be "accepted". A researcher can only reject or fail to reject the null hypothesis based on the information available. A larger sample size or even a different sample from the same population may result in an entirely different conclusion (15).

TABLE 3-2

DECISIONS AND CONSEQUENCES FOR A TEST OF AN HYPOTHESIS

		True State of Nature	
		Ho True	Ha True
DECISION	Ho True	Correct Decision	Type II Error (β)
	Ha True	Type I Error (α)	Correct Decision

Multiple regression analysis was used to model the response of the dependent variable as a function of the independent variables. The independent variables consisted of both quantitative and qualitative (indicator) variables. The variables used are listed in Table 3-3.

TABLE 3-3

HYPOTHESIZED REGRESSION VARIABLES

Quantitative Variables

X1 = Cable length (CLEN)
X2 = Cable Pair (CPAR)

Indicator Variables

X3 = Commodity code	(CMDY)	1-if	telephone IP	0-if not
X4 = Commodity code	(CMDY)	1-if	telephone OP	0-if not
X5 = Commodity code	(CMDY)	1-if	other Gov. Comm.	0-if not
X6 = Commodity code	(CMDY)	1-if	comm. IP fac.	0-if not
X7 = Commodity code	(CMDY)	1-if	comm. OP fac.	0-if not
X8 = Commodity code	(CMDY)	1-if	other Comm. fac.	0-if not
X9 = Commodity code	(CMDY)	1-if	radiation int.	0-if not
X10 = Commodity code	(CMDY)	1-if	radiation haz.	0-if not
X11 = Commodity code	(CMDY)	1-if	micro or tropo	0-if not
X12 = Commodity code	(CMDY)	1-if	crypto	0-if not
X13 = Commodity code	(CMDY)	1-if	telemetry	0-if not
X14 = Commodity code	(CMDY)	1-if	meteorological	0-if not
X15 = Commodity code	(CMDY)	1-if	navaids	0-if not
X16 = Commodity code	(CMDY)	1-if	public address	0-if not
X17 = Commodity code	(CMDY)	1-if	comm. pa or cctv	0-if not
X18 = Commodity code	(CMDY)	1-if	radio	0-if not
X19 = Commodity code	(CMDY)	1-if	antenna	0-if not
X20 = Commodity code	(CMDY)	1-if	instrumentation	0-if not
X21 = Commodity code	(CMDY)	1-if	cctv	0-if not
X22 = Commodity code	(CMDY)	1-if	navaids radar	0-if not
X23 = Commodity code	(CMDY)	1-if	radar	0-if not
X24 = Commodity code	(CMDY)	1-if	edp	0-if not
X25 = Region	(REGN)	1-if	region 1	0-if not
X26 = Region	(REGN)	1-if	region 2	0-if not
X27 = Region	(REGN)	1-if	region 3	0-if not
X28 = Region	(REGN)	1-if	region 4	0-if not
X29 = Region	(REGN)	1-if	region 5	0-if not
X30 = Region	(REGN)	1-if	region 6	0-if not
X31 = Season	(SEAS)	1-if	spring	0-if not
X32 = Season	(SEAS)	1-if	summer	0-if not
X33 = Season	(SEAS)	1-if	fall	0-if not
X34 = Cable location	(CLOC)	1-if	aerial	0-if not
X35 = Cable location	(CLOC)	1-if	buried	0-if not

A stepwise selection of independent variables was conducted to identify the variables determined to be significant for predicting changes in the dependent variable. In general, the process leading to the selection of significant variables involved three steps. First, all possible functional models were evaluated via the following statistics: R^2, adjusted R^2, t-ratios, F-test, correlation coefficients, and the standard error of the estimate. Next, the models remaining were examined to determine the presence of departures from the model assumptions. Finally, alternative functional models derived from interactions or transformations were entered and evaluated.

CHAPTER 4

ANALYSIS AND FINDINDINGS

EIMS Data Base

The EI community has been collecting program data for many years--sometimes in detail, sometimes in aggregate form. This information has been used as the basis for controlling and auditing in-process workload, and preparing various output products such as lists of upcoming workload and charts depicting resource utilization. Considering the overwhelming numbers of schemes in the system at any one time, this collection effort has been extremely beneficial. The Engineering and Installation Management System has proven to be a useful tool to assist first level supervisors with the management of their short-term work, and has provided upper level managers with at least some conception of how well the EI community is doing and where it is having difficulties. Its major weakness lies in its inability to assist managers in making long-range forecasts. Although a lot of interest was expressed over the years to improve the system's forecasting capability, it became apparent during the course of this research that the architecture of the EIMS data base does not allow for the specific needs of those tasked with the responsibility of estimating future workload.

In general, the estimating methodology employed during this research requires three types of historical data (30:12). The first is resource data. Resource data are normally made available in aggregate form and are generally classified into functional categories such as labor, material, overhead, etc. The EIMS data base uses a number of categories to aggregate program costs such as minor construction costs and major equipment costs. Further, it aggregates both the man-hour estimates and the actual man-hour expenditures. It is this man-hour data that is required to develop an estimating relationship.

A second type of data required is physical and performance characteristic data. This data allows an estimator to relate future requirements with past requirements based on one or more specific identifying characteristics. For example, cost estimators within the aircraft industry collect and maintain data such as wing length, aspect ratio, thrust to weight ratio, maximum speed, etc., in order to provide a basis of comparison to a future aircraft design.

The last type of data required is program data. Program data normally takes the form of key dates and significant milestones. This data is useful for providing background information and highlighting problems such as delays and exceptions. Appendix B provides a description of the EIMS data base categorized by the three types of data requirements just discussed. Of the 202 distinct data fields maintained, 161 fields are used for program data. Approximately 38 fields are reserved for resource data and only 3 fields for physical and performance characteristic data.

Although a preview of the data base prior to the start of the research suggested that a limited amount of physical and performance data was available, we believed the data that was available, supplemented by the data obtained from the telephone contacts, would be sufficient to obtain the proposed sample of 140 schemes. As the research progressed, however, several problems were encountered which forced the alteration of the proposed sampling plan.

In general, the problems encountered were of two types: incomplete entries and lack of physical and performance characteristic data. Initially, the data base contained nearly 15,000 file records (one file record equates to one C-E scheme). The records were then screened to extract only completed schemes within facility code 0xxx, of which 1,084 were obtained. These records were further screened to remove all schemes accomplished outside the CONUS. The result was a population of 639 possible schemes from which to draw the sample. Unfortunately, 53 percent of the remaining schemes had incomplete entries which prohibited their use. For instance, 223 schemes lacked the required resource data. That is, they had no entries for both the man-hour estimates and actual man-hour expenditures. Eighty-six schemes were missing only the actual man-hour expenditures. Thirty-two schemes were missing the pertinent program data such as team start dates and location of the installation. As a result, the population fell to 298 schemes.

Further analysis of the remaining schemes surfaced additional problems. As previously discussed, the scope of the research was limited to an analysis of C-E cable installations. One variable hypothesized to have an effect on the time required to install communications cable was the location of the cable--that is, where the cable is to be installed (either aerial, direct buried, or within a conduit system). In approximately 20 instances, the scheme involved a combination of these locations. The resource data, on the other hand, only provided man-hour expenditures for the total scheme. There was no way to determine the man-hours expended on the separate portions of the scheme. As a result, the schemes were eliminated from consideration.

A more serious problem encountered during the research was the lack of physical and performance characteristic data. At the outset of the study, the researchers did not know which characteristic data would provide the best explanation of the variations in expended man-hours. Discussions with EI managers led to the identification of a possible set of explanatory variables such as cable length, cable size, and the number of splices. However, it was discovered during the data collection effort that none of this type data is centrally maintained. The only way to obtain this data was through telephone contacts to the communications squadrons on the bases where the schemes were installed. In 35 instances, the communications squadrons no longer maintained the records for a particular scheme.

A more significant finding was that the EIMS data base did not contain this information. The data base includes three fields from which to obtain some idea of the type of equipment installed. One is the facility code. The purpose of the facility code is to identify both a general category and a specific operational requirement for each scheme. Unfortunately, the facility code classifications are very general and can encompass many types of equipment under one facility code. For instance, the cable installations evaluated during this study were all assigned a facility code of 0011. Also within the same facility code were a number of related, but different, types of communications equipment such as traffic recorders, data bridges, switching equipment, repeaters, and battery systems. As a result, the facility code classification was of no use in identifying specific physical and performance data.

Two additional data fields were available to obtain the needed data; however, both did not prove to be useful. Together, the two fields (workload title and narrative description) occupy 60 positions. However, some of the information provided was, at best, sketchy. For instance, the following entries are representative of some of the narrative descriptions provided:

Scheme Number	Narrative
1861A1D0	Bldg 1232
1976A9D0	Bldg 531
0858A1D0	Between buildings
0327A9B0	Cable to wing command post
0660A0B0	Cable to new medical supply building

In summary, the EIMS data base, as it exists today, does not lend itself to a parametric estimating technique. In some instances, there are gaps in the data such as incomplete resource and program data. In other instances, there is no record of the physical and performance characteristics of individual schemes and their relationship to the aggregated resource data. Moreover, this information is not available from any other centralized source.

Current Estimating Technique

As was discussed in Chapter 1, EI engineers today do not use EIMS to assist with the development of man-hour estimates. Rather, the estimates are subjectively determined. One study conducted by the EI community in 1981 indicated that the average of all estimates came within two percent of the actual man-hour expenditures (22:75). As a comparison, an analysis on the 298 schemes for which the estimated and actual man-hour data was available was performed to determine what degree of estimation accuracy is being achieved today without the support of the EIMS data base.

A paired difference t-test was used on the independent samples to compare the means of the populations associated with the estimated man-hours and the actual man-hours expended. This test investigates the issue of bias. The null and alternate hypotheses tested were as follows:

$$Ho: \quad Ue - Ua = 0$$
$$Ha: \quad Ue - Ua \neq 0$$

The null hypothesis presumes that no difference exists between the mean of the man-hour estimates and the mean of the actual man-hour expenditures, i.e., the man-hour estimates are unbiased. The alternate hypothesis assumes that a significant difference ($\alpha = .05$) existed between the two means, i.e., the man-hour estimates are biased. The results of the test are displayed in Table 4-1.

TABLE 4-1

PAIRED DIFFERENCE T-TEST RESULTS
(298 Cases)

Variable	No. of Cases	Mean	S.Dev.	S.E.
Est. Man-Hours	298	2717.4396	6426.024	372.250
Act. Man-Hours	298	2412.6544	5432.852	314.717
Difference	298	304.7852	2292.470	132.799

T Value	Degrees of Freedom	2-Tail. Prob.
2.30	297	.022

At a level of significance of .05, the rejection region is $t>1.96$ or $t<-1.96$. Based on the results of the above test, we would reject the null hypothesis and suggest that a significant difference (α = .022) did in fact exist between the two means. These results would indicate that, unlike the previous study, the EI community is biased in its man-hour estimates.

The variability within the data, however, warrants closer evaluation. Upon review of the 298 observations, several data points appeared to be questionable and were thought to be possible outliers which may have influenced the t-test. (Outliers were considered to be those points which were greater than three standard deviations from the mean of the differences.)

Possible outliers were identified by computing the difference between the estimated and actual man-hours for each of the 298 observations, measuring the variance of these differences, and then calculating three standard deviations from the mean difference. Figure 4-1 is a histogram of the 298 differences recoded to plus and minus three standard deviations.

The figure indicates that five schemes could be outliers. Each of the five schemes was investigated to determine if there were any assignable cause (such as typographical errors or inaccurate/improper data) which would justify removing them from the sample. In all five cases,

```
ESTIMATED MINUS ACTUAL HOURS

 CODE
        I
   -3.  * (      1)
        I
        I
   -2.  *** (      6)
        I
        I
   -1.  ******************************** (   127)
        I
        I
    1.  ************************************* (   149)
        I
        I
    2.  *** (      7)
        I
        I
    3.  ** (      3)
        I
        I
 7697.  * (      1)
        I
        I
 7940.  * (      1)
        I
        I
16448.  * (      1)
        I
        I
17649.  * (      1)
        I
        I
22416.  * (      1)
        I
        I
        I.........I.........I.........I.........I.........I
        0        40        80       120       160       200
        FREQUENCY
```

Figure 4-1. Histogram of Observations
(298 Cases)

it was found that the data provided was inaccurate, and the additional information required was unavailable. The t-test was performed once again on the remaining 293 observations. Table 4-2 depicts the results:

TABLE 4-2

PAIRED DIFFERENCE T-TEST RESULTS
(293 Cases)

Variable	No. of Cases	Mean	S.Dev.	S.E.
Est. Man-Hours	293	2215.4061	3463.807	202.358
Act. Man-Hours	293	2151.6655	3602.391	210.454
Difference	293	63.7406	1141.621	66.694

T Value	Degrees of Freedom	2-Tail. Prob.
.96	292	.340

As a result, we do not reject the null hypothesis and suggest that there may be no significant difference between the two means at a level of significance of .05. This result supports the original EI community finding that there is little difference between the actual and estimated man-hour expenditures.

As was previously discussed, this t statistic indicates that, in the aggregate, the estimates are unbiased, i.e., the estimates of man-hour expenditures are just as likely to be greater than the actual expenditures as they are less than the actual expenditures. Presumably, the estimation errors balance each other out. However, the standard deviation of the difference in means indicates that the variability within individual schemes is large. Even though the average difference between the estimated and actual man-hours was 63.74, five schemes had a difference of greater than 4,000 hours, six were greater than 3,000 hours, ten greater than 2,000 hours, and forty-two greater than 1,000 hours. This equates to approximately 20 percent of the schemes being either over or underestimated by at least 1,000 man-hours.

Note that the man-hours maintained in the data base are only direct labor hours. All time lost due to other causes such as vehicle breakdowns, non-availability of material, weather, etc., are assigned different action taken codes and are not included within the resource data maintained. Thus, we are at a loss to explain the large variability between estimated and actual direct man-hour expenditures except to say that the estimators are not consistently accurate, albeit they are unbiased.

Parametric Model Development

Despite the inadequacies of the EIMS data base, the purpose of this research was to explore the feasibility of developing a work estimation system based on the parametric estimation technique. As such, the researchers obtained supplemental data through telephone contacts with the individual communications squadrons at each base where the sampled schemes were accomplished. Some problems were encountered during the data collection effort.

First, there was a reluctance on the part of a number of communications squadrons to release the requested information. As a result, 22 schemes were dropped from the sample. In some instances, the squadrons were willing to provide the data, but the records were unavailable. Thus, an additional 32 schemes were excluded, bringing the number of usable schemes to 239. The number was subsequently reduced to 150 due to the fact that 89 schemes involved various types of equipment other than communications cable.

The process of arriving at a usable sample of schemes could potentially bias the results obtained. Originally, an equal number of randomly selected schemes was to be obtained for each of the seven CONUS regions identified in Figure 3-1. As the research progressed, it became apparent that disproportionate samples from the regions had to be obtained to ensure as large a sample as possible. Table 4-3 identifies the number of schemes used from each region and the percentage of usable schemes per region.

TABLE 4-3

STRATIFIED SAMPLE RESULTS

Region	No. Usable Schemes	% of Original
1	11	39
2	7	38
3	15	64
4	28	44
5	26	71
6	26	49
7	37	49

Another problem noted during the data collection effort was the lack of consistency of documentation from which the data provided by the communications squadrons was extracted. Although we attempted to ensure all data was obtained from the same document, in many instances, the required document was unavailable. In some cases, the data was taken from the site concurrence letter; in others, from the statement of work, and in others, the consolidated list of materials. This lack of consistency could further bias the results. However, since the main intent of the research was to explore the feasibility of a work estimating system and illustrate its development, the prediction accuracy of the model presented in this research was not of paramount importance. With this in mind, we eliminated all erroneous data for which a valid cause could be determined. For example, from the set of 150 schemes, two schemes were identified as outliers. Further investigation determined that the data for these two schemes was incomplete. As a result, the two schemes were dropped from the sample. The final number of schemes employed in the study was 148. Appendix C provides the pertinent data for the schemes used.

Originally, we intended to use the length of the cable and the size of the cable as two independent variables. However, we found that any one particular scheme could consist of various lengths and sizes of cable. Consequently, we created a single variable to obtain a consistent measure for which to relate expended man-hours. The variable, conductor miles, was calculated by determining the number of conductors in a particular piece of cable, multiplying by the length of the cable, and dividing by 5,280. Conversion to conductor miles versus conductor feet reduced the amount of internal storage utilized during the computing operations.

The proposed set of explanatory variables consisted of one quantitative variable--conductor miles--and three qualitative variables--cable location, season, and region. A scatterplot of the actual man-hours expended against the number of conductor miles was generated to determine if there was an obvious linear relationship between the two variables. If the plot indicates that a straight line is not a good measure of the relationship between the variables, we would have to consider transforming the data to make it linear. The plot shown in Figure 4-2 failed to highlight any identifiable linear pattern. The horizontal and the vertical axes of the plot represent the mean values of man-hours and conductor miles, respectively. Although there was a clustering of points near the mean, there were a number of other points for which a straight line did not appear to be a good summary measure. At this point, we suspected there was a curvilinear relationship between the variables. We chose to run a simple linear regression with only man-hours and conductor miles in order to analyze the residuals to gain insight into the true relationship between

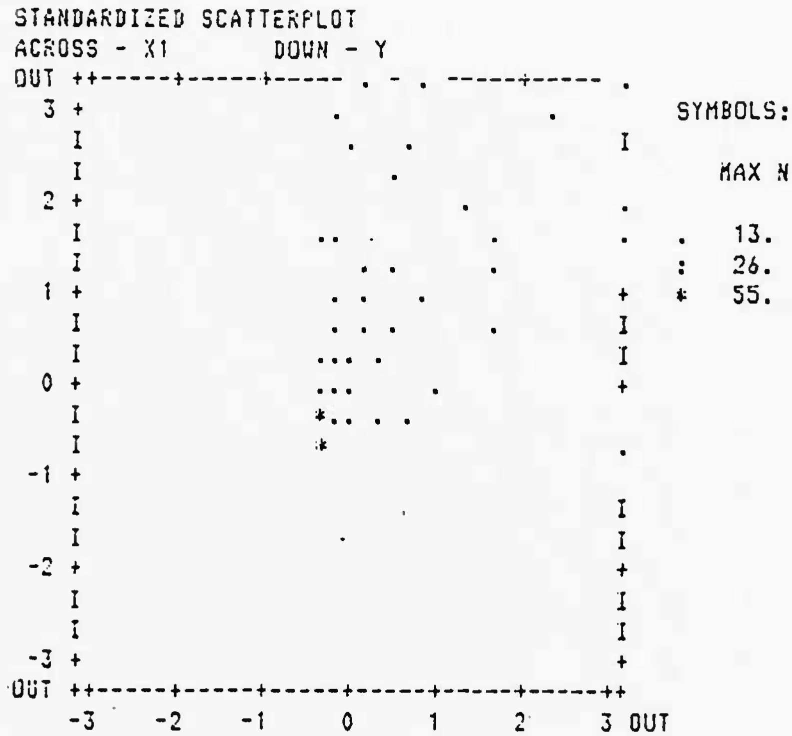


Figure 4-2. Scatterplot of Man-Hours Against Conductor Miles

the variables. The model was of the form:

$$Y = Bo + B_1X_1$$

where:

Y = Man-hours expended

X_1 = Conductor miles

The statistical results of this model (noted as model 1) and all subsequent models are recorded in Table 4-4.

The results of model 1 suggest that the coefficient, B_1, may not be significantly different from zero. An

TABLE 4-4

STATISTICAL RESULTS

Model	R^2	Adj R^2	Adj R^2 - R^2	SE	F	Var	T (STG)
1	.23417	.22893	.00524	2132.36	44.643	X_1	6.68 (.0000)
2	.47463	.47103	.00360	1766.16	131.897	$\log X_1$	11.49 (.0000)
3	.57609	.57318	.00291	.820490	198.410	$\log X_1$	14.09 (.0000)
4	.58370	.57503	.00867	.818710	67.301	$\log X_1$	13.41 (.0000)
						X_2	-1.42 (.1569)
						X_3	.7080 (.4801)
5	.58567	.57408	.01159	.819620	50.435	$\log X_1$	13.37
						X_2	-1.41 (.1603)
						X_3	.7790 (.4372)
						X_4	.8250 (.4105)
6	.58571	.57598	.00973	.81780	50.920	$\log X_1$	13.49 (.0000)
						X_2	-1.38 (.1703)
						X_3	.9740 (.3318)
						X_4	-1.00 (.3183)

TABLE 4-4 (Continued)

Model	R^2	Adj R^2	Adj R^2 - R^2	SE	F	Var	T (STG)
7	.58888	.58321	.00567	.81080	103.850	$\log X_1$	13.91 (.0000)
						X_6	-2.12 (.0354)
8	.58993	.58139	.00854	.81257	69.050	$\log X_1$	13.82 (.0000)
						X_6	.9610 (.3381)
						X_4	-2.06 (.0408)
9	.59189	.58339	.00850	.81062	69.610	$\log X_1$	13.95 (.0000)
						X_6	-1.03 (.3044)
						X_4	-2.17 (.0320)
10	.59375	.58814	.00561	.80560	105.960	$\log X_1$	13.98 (.0000)
						X_5	-2.51 (.0132)

analysis of the residuals of model 1 suggests a curvilinear relationship between the two variables is present. The distribution of residuals may not appear to be normal for reasons such as misspecification of the model or nonconstant variance. When evidence of a violation of assumptions is present, the next step is to formulate an alternative model by transforming the current model. As shown in Figure 4-3, the assumption of normality appeared to have been violated. The histogram contains a frequency count of the observed number of residuals (N) in each interval and the number expected in a normal distribution with the same mean and variance as the residuals (EXP N). The intervals labeled "out" contain residuals more than 3.16 standard deviations from the mean. The histogram suggested a log-normal relationship.

As a consequence, we propose model 2 of the form:

$$Y = Bo + B_1 \log X_1$$

where:

Y = Man-hours expended

$\log X_1$ = Natural logarithm of conductor miles

The results showed a marked improvement in the coefficient of determination (R^2) over model 1 indicating an improvement in the predictive capability of the model. However, a scatterplot of man-hours against the logarithm of conductor miles suggested the relationship was still not linear.

```
HISTOGRAM
STANDARDIZED RESIDUAL
 N EXP N      ( * = 1 CASES,     . : = NORMAL CURVE)
 3  0.11   OUT ***
 2  0.23  3.00 **
 1  0.58  2.66
 2  1.32  2.33  *
 2  2.70  2.00 **
 1  4.95  1.66 *
 3  8.12  1.33 ***
 3 11.94  1.00 ***
 8 15.72  0.66 ********
11 18.54  0.33 ***********
23 19.59  0.00 ******************** ***
49 18.54 -0.33 ****************** ******************************
37 15.72 -0.66 *************** *********************
 1 11.94 -1.00 *
 0  8.12 -1.33
 0  4.95 -1.66
 1  2.70 -2.00 *
 0  1.32 -2.33
 0  0.58 -2.66
 0  0.23 -3.00
 1  0.11   OUT *
```

Figure 4-3. Histogram of Standardized Residuals
For Man-Hours Against Conductor Miles

Our third model is a cubic logarithmic model (c.f. Shannon, pg. 81) of the form:

$$\log Y = Bo + B_1 \log X_1$$

where:

$\log Y$ = Natural logarithm of man-hours expended

$\log X_1$ = Natural logarithm of conductor miles

Again, the predictive power of the model increases significantly.

At this point, we included the remaining three variables in the model. The model was of the form:

$$\log Y = Bo + B_1 \log X_1 + B_2X_2 + B_3X_3 + B_4X_4$$

where:

$\log Y$ = Natural logarithm of man-hours expended

$\log X_1$ = Natural logarithm of conductor miles

X_2 = Cable location

X_3 = Season

X_4 = Region

This particular model was regressed three separate times to determine if the number of regions was significant. Model 4 treated the entire CONUS as one region. Model 5 divided the CONUS into two regions--north and south, and model 6 used the seven distinct regions. Although the addition of more explanatory variables caused the R^2 to increase, the adjusted R which corrects for the normal tendency of the R^2 to increase as variables are added, decreased. This suggests that the variables are not adding any predictive capability to the model. In all three models, conductor miles was the only variable that was statistically significant at the 95 percent level of confidence. Location (i.e., underground, buried, or aerial) was significant at an 83 percent level of confidence. The region variable did not prove to be statistically significant; however, the results did indicate that, as the number of regions increased, the variable became more significant.

At this point, we conjectured that there was a possible interaction between the variables' location, season, and region. That is, a change in one variable is dependent on the value of another. Models 7, 8, 9, and 10 included various interactions coupled with the cubic logarithmic transformation. Of particular interest, however, was model 10. Model 10 was of the form:

$$\log Y = Bo + B_1 \log X_1 + B_5 X_5$$

where:

$\log Y$ = Natural logarithm of man-hours expended

$\log X_1$ = Natural logarithm of conductor miles

X_5 = An interaction term consisting of location x season x region (Note: Region included seven regions.)

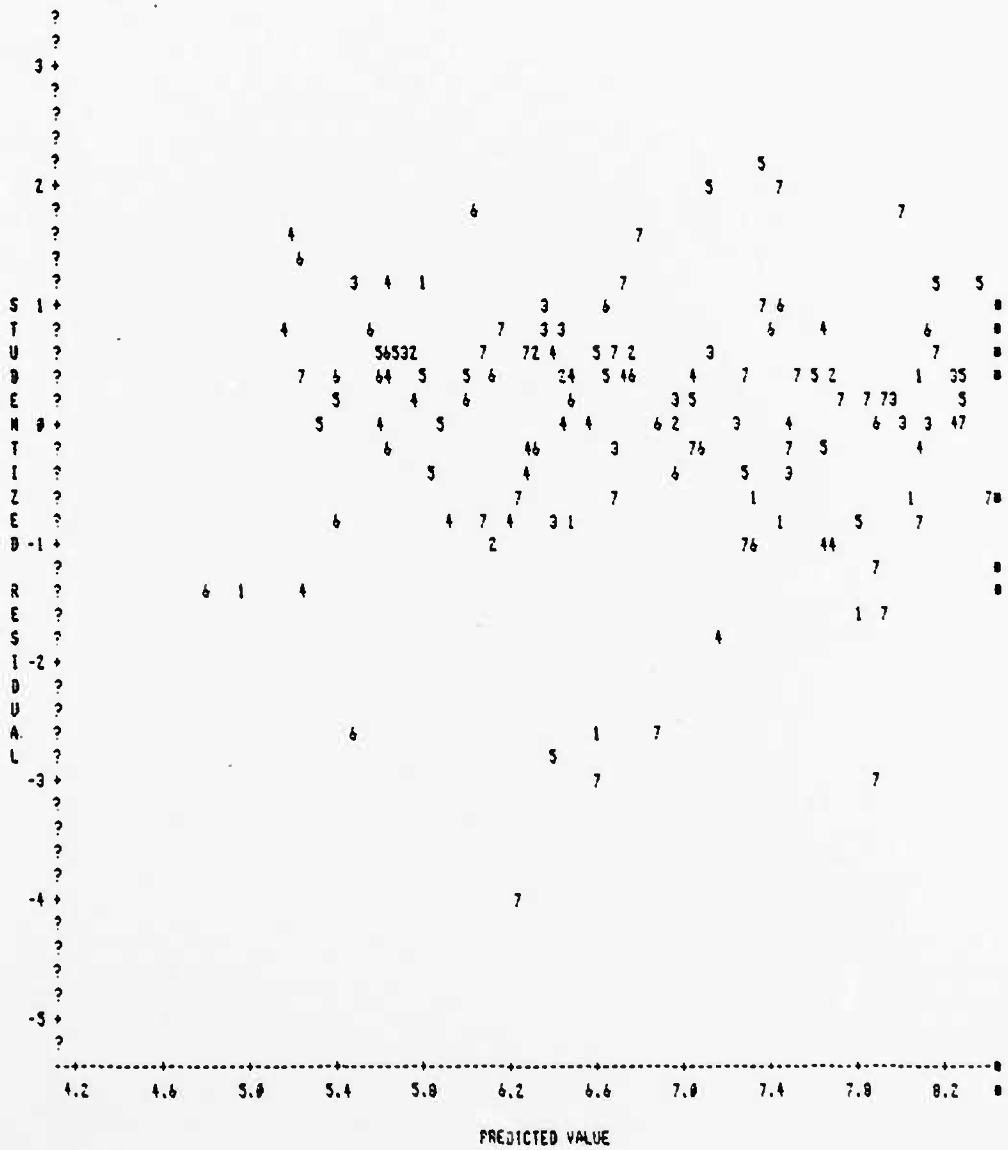
Inclusion of the interaction term increased the predictive power of the model and lowered the standard error of the estimate. The interaction variable also was significant at a 99.9 percent level of confidence.

Selection of Final Model

At this stage, we narrowed the model selection to model 3 and model 10. We prefer model 3 for several reasons. First, although the statistical results of model 10 appeared to be an improvement over model 3, the difference between the R^2 and the adjusted R^2 widened relative to the difference between the two for model 3. The adjusted R^2 compensates for the propensity of the R^2 to increase as you increase the number of variables in the model. If the difference between the R^2 and the adjusted R^2 increases, this indicates that the introduction of an additional variable is not adding any predictive power to the model. Second, the inclusion of an interaction term in a model, by its nature, introduces multicollinearity. When highly correlated independent variables are present in a regression model, the results may be confusing. Third, using the Proc plot procedure contained within the Statistical Analysis System (SAS), the predicted values for each qualitative variable were plotted against the regression residuals of model 10 in order to determine if these variables were in fact contributors to the regression equation. If the plotted variable is a contributor, its values should approximate a linear pattern on the plot (i.e., the "0" values should be grouped in a linear fashion, as well as the other values of the variable being plotted.) This was not the case as depicted in Figures 4-4 through 4-6. Thus, we chose not to include the three-way interaction of these variables based on the fact that, taken individually, they were not useful.

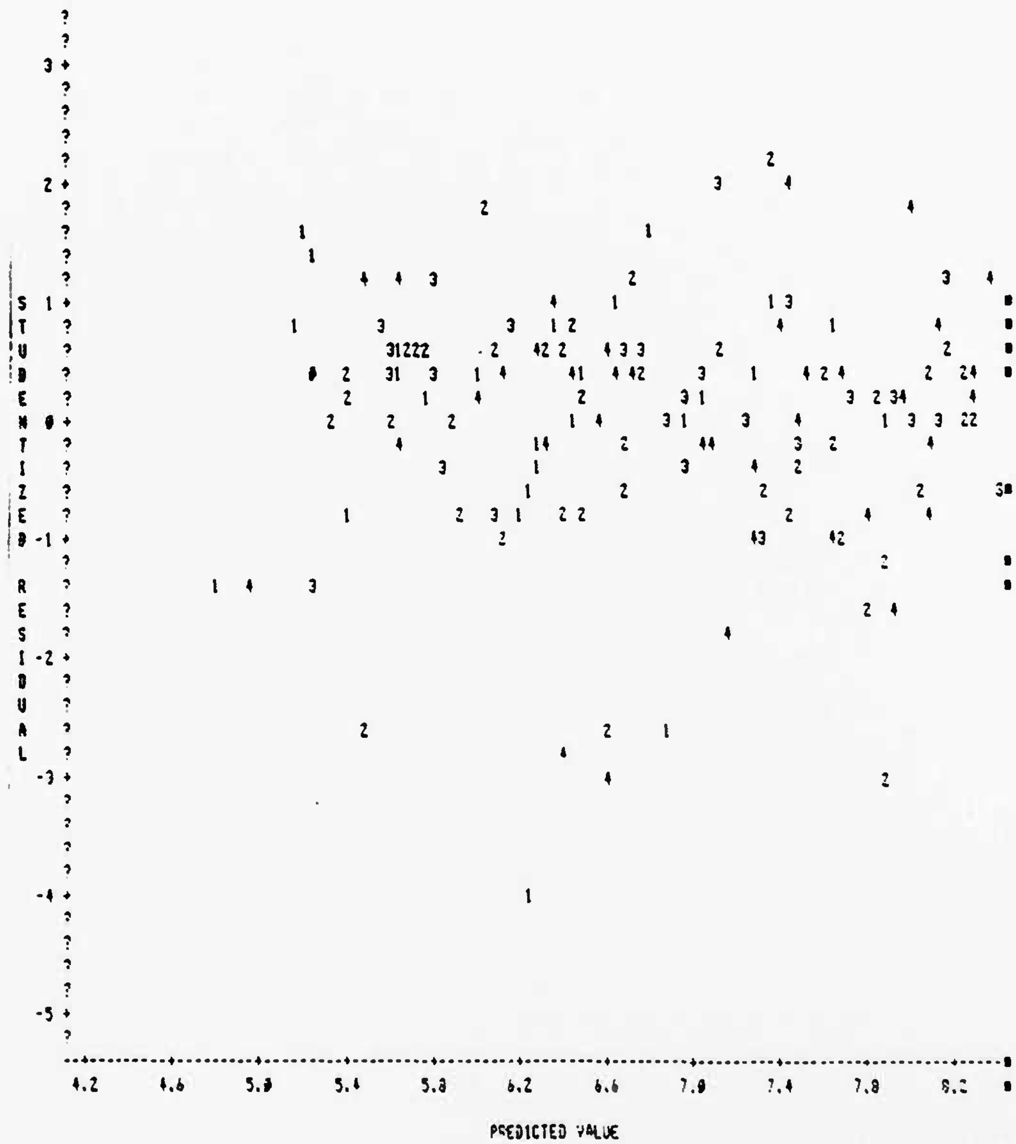
Final acceptance of model 3 depends upon whether the assumptions of the regression model were reasonably met. As discussed in Chapter 3, in order to perform hypothesis testing and to construct confidence intervals for the various regression coefficients, the following assumptions must be satisfied:

1. The final model is linear in its coefficients.



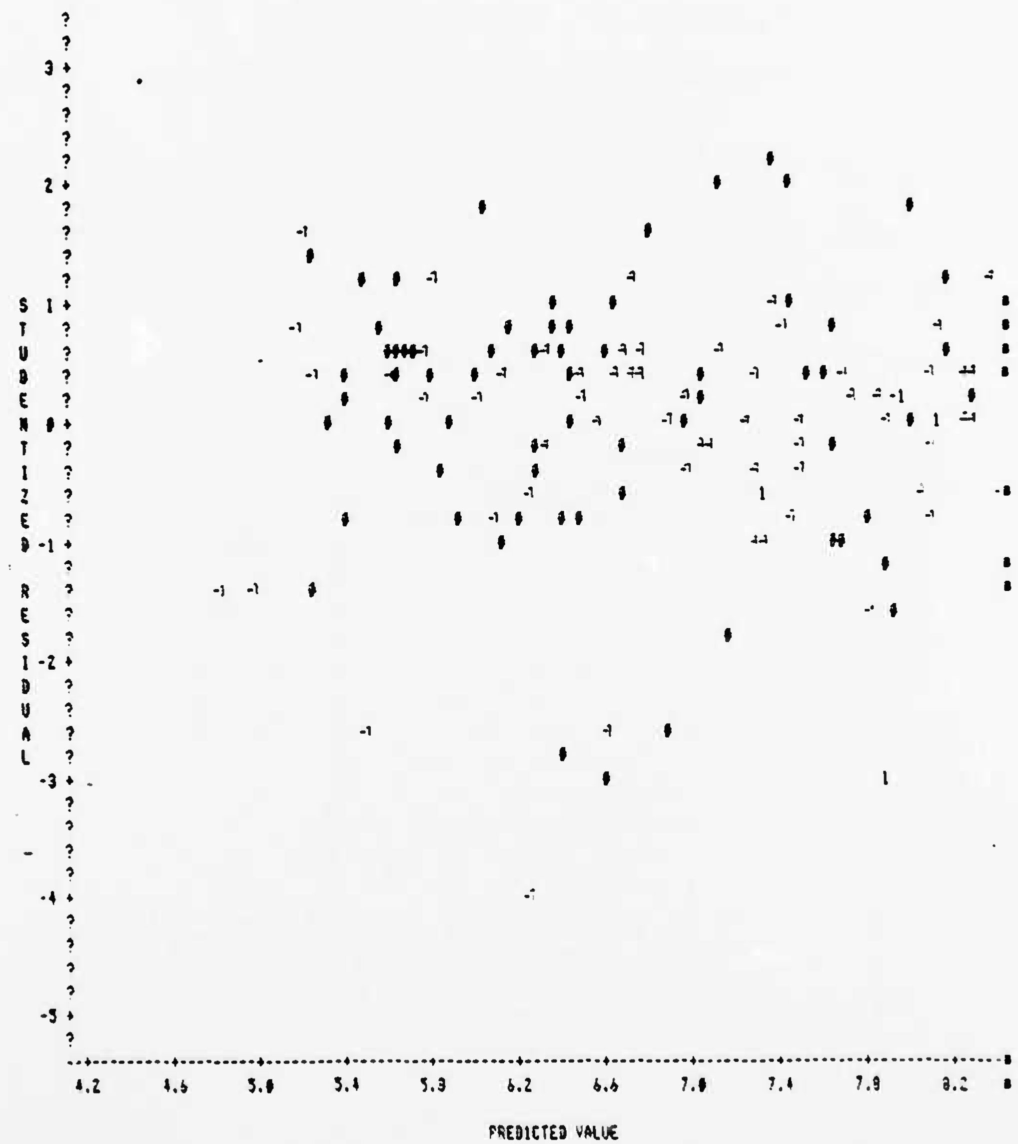
Key: Seven regions as illustrated in Figure 3-1

Figure 4-4. Studentized Residuals Against Predicted Value - Region



Key: Season - (1) Spring, (2) Summer, (3) Fall, (4) Winter

Figure 4-5. Studentized Residuals Against Predicted Value - Season



Key: Location - (-1) underground, (0) buried, (1) aerial

Figure 4-6. Studentized Residuals Against Predicted Value - Location

2. The residuals have a constant variance and mean of zero.

3. The residuals are uncorrelated.

4. The residuals are normally distributed.

The final model selected did meet all assumptions reasonably well. The plot of the residuals against the predicted values, as depicted in Figure 4-7, was used to verify the assumptions of linearity and constancy of variance.

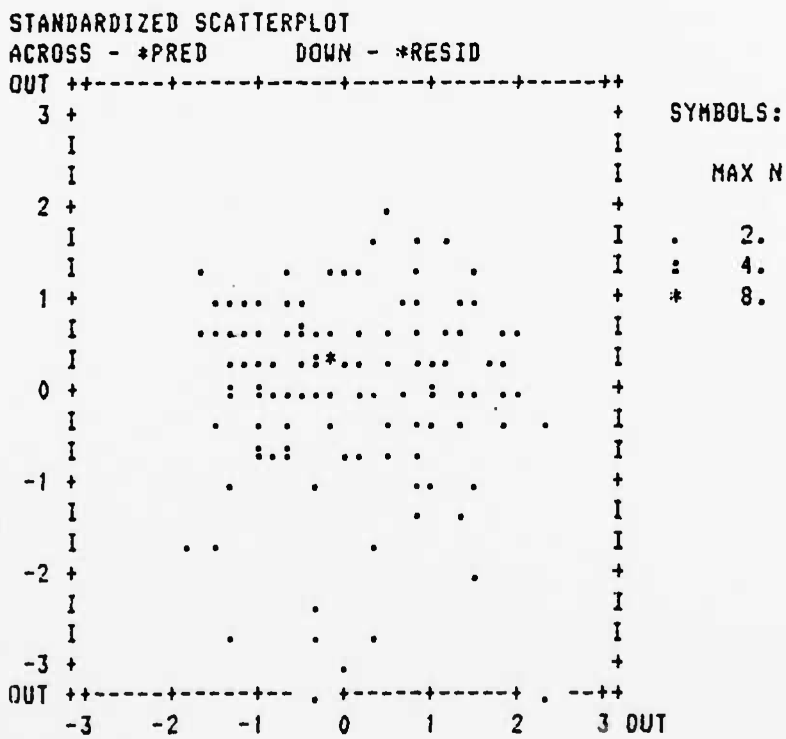


Figure 4-7. Standardized Residuals Against Predicted Value - Final Model

In both cases, if an observable pattern is present, the assumptions should be questioned.

The assumption of correlation of residuals was verified through a casewise plot of studentized residuals. Again, if a discernible pattern is evident, the assumption should be questioned. No pattern was evident. Additionally, the Durbin-Watson was calculated. The statistic, however, proved to be indecisive. That is, we could not accept or reject the hypothesis that positive serial correlation existed.

Lastly, normality was verified through a histogram of studentized residuals and the normal probability plot. The distribution of residuals in the histogram, Figure 4-8, appeared to be normal with the exception of a clustering of values in the center and a small tail toward large negative values.

```
HISTOGRAM
STANDARDIZED RESIDUAL
 N EXP N     ( * = 1 CASES,     . : = NORMAL CURVE)
 0  0.11   OUT
 0  0.23  3.00
 0  0.58  2.66
 0  1.32  2.33
 1  2.70  2.00 *
 3  4.95  1.66 ***
 7  8.12  1.33 *******
12 11.94  1.00 ************
22 15.72  0.66 **************** ******
28 18.54  0.33 ******************* *********
28 19.59  0.00 ******************* *********
14 18.54 -0.33 **************
13 15.72 -0.66 *************
 6 11.94 -1.00 ******
 2  8.12 -1.33 **
 4  4.95 -1.66 ****
 1  2.70 -2.00 *
 1  1.32 -2.33
 3  0.58 -2.66  **
 1  0.23 -3.00 *
 2  0.11   OUT **
```

Figure 4-8. Histogram of Residuals

The normal probability plot, Figure 4-9, follows a straight line suggesting normality.

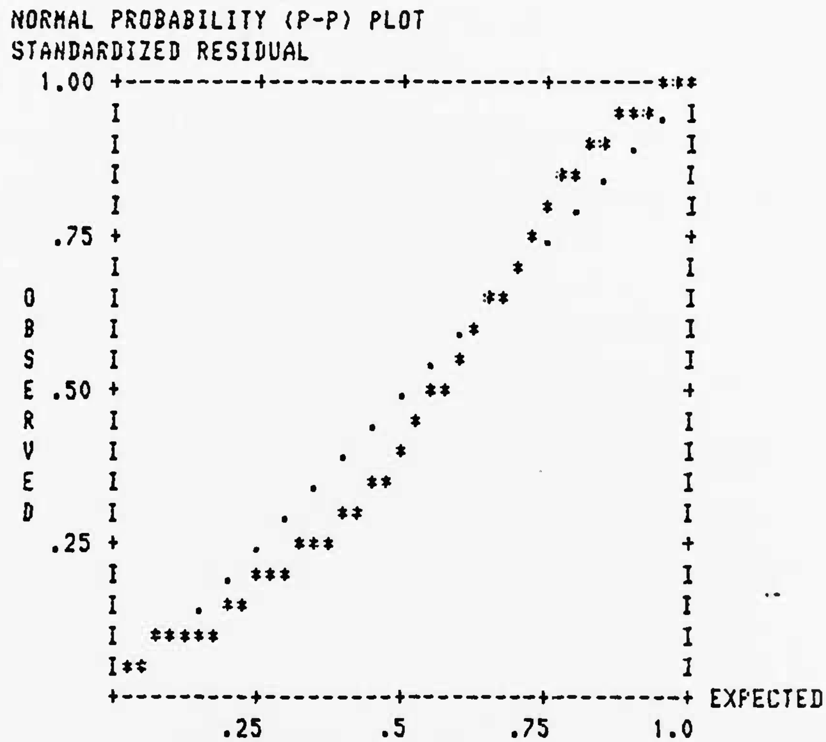


Figure 4-9. Normal Probability Plot

Thus, model 3 was selected for the following reasons:

1. The regression coefficient for the independent variable conductor miles was statistically significant.

2. The coefficient of determination and the standard error of the estimate were improved over other models.

3. The model assumptions were reasonably well met.

Application of Model for Estimation and Prediction

Before illustrating an application of the model, we point out that a major source of difficulty in using any estimating relationship is uncertainty. Basically, there are two types of uncertainty that are of concern to estimators (17:158):

1. Uncertainty about the "state of the world" in the future
2. Statistical uncertainty

Uncertainty about the "state of the world" exists because of the many changes occurring in many areas such as materials technology, system and operational concepts and efficiencies, improvements in work methods, etc. Because of these changes, it is likely that the future that we are trying to estimate may differ significantly from the sample of the past we used to generate the estimating relationship. For example, in 1982, the EI community tested a new splicing technique introduced by the Western Electric Company. This system, called the WECO 710, has decreased the required splicing time for communications cable by almost 25 percent. Presumably, use of the historical data to predict future cable installations will result in an overestimate of the actual man-hours required to install a future scheme because of the improved splicing technique. Unfortunately, there is no easy way to circumvent this difficulty. Analysts must consider the changes in the state of technology and how it influences their ability to develop estimates based on the historical data.

Statistical uncertainty, on the other hand, can be dealt with by developing confidence bounds for the value you wish to predict. The analyst may then adjust his estimate within the confidence limits set.

Basically, there are two types of confidence intervals that an estimator can generate. The first is a confidence interval for the mean value of Y (Dependent Variable) given a specific value of X (Independent Variable). This can be calculated as follows (25:431):

$$\hat{Y} + t_{\alpha/2} \text{ (Estimated standard deviation of } \hat{Y}\text{)}$$

The second type of confidence interval, also called a prediction interval, involves predicting a particular value of Y for a given X. It can be calculated as follows:

$$\hat{Y} + t_{\alpha/2} \text{ [Estimated standard deviation of } (Y-\hat{Y})\text{]}$$

These two formulas can be used to generate confidence bounds for the regression model arrived at above. Figure 4-10 is an illustration of the log of man-hours versus the explanatory variable, log conductor miles.

Notice that the bounds for the confidence limits are narrower. This is because, in the case of estimating a mean value of Y, we are attempting to estimate the mean result of a large number of experiments at a given value of X. In the

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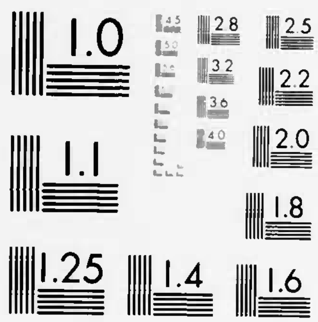
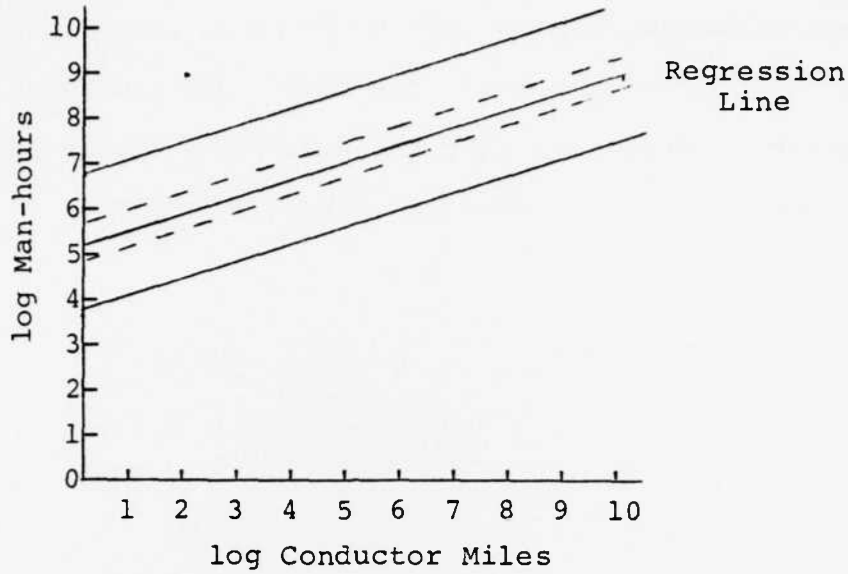


MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A



KEY:

---- 95% Confidence Interval Bound
—— 95% Prediction Interval Bound

Figure 4-10. 95% Confidence Interval and 95% Prediction Interval for the Selected Model

second case, we are trying to predict the outcome of a single experiment at the given value of X. Thus, the prediction interval for an individual value of Y will always be wider than the confidence interval for a mean value of Y. It is also important to note that although our confidence and prediction intervals appear to be linear over the range of values presented, they do in fact widen as the values for the log of conductor miles depart from the mean value of the sample. That is, the intervals are narrower at the mean value of Y than they are at the extreme values. The difference, however, is relatively small. This implies that although we have less confidence in our predictions as we depart from the mean, the model identified in this research is robust in that the intervals remain relatively constant over the range of values presented.

CHAPTER 5

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Summary

The parametric estimating technique employed in this research effort was based on the premise that experience is a reliable guide to the future. It would seem reasonable to expect the time to install a particular C-E facility two years ago would be representative of the time required to install the same type of facility at some future date. If this being the case, one could deduce that the process of developing estimates would consist of searching through historical data until similar schemes are identified. The man-hours expended could then be extracted and used to develop a man-hour estimate for a future project.

Clearly, this is an oversimplification of the process of generating estimates and can be criticized on several counts. One obvious criticism is that the reliability of the estimates is only as good as the input data used to generate the estimate. This statement may seem tautological; nevertheless, it is one that merits emphasis. EI managers have, on many occasions, identified discrepancies in the EIMS data base ranging from simple inaccuracies to incomplete entries. This research confirms that these problems still exist today. Although there are many explanations as to why these discrepancies exist, we have not seen any empirical evidence to support these explanations. This problem is not the responsibility of any one office or function; rather, it is shared by many individuals from team chiefs in the field to program managers within the EI community. Careful attention must be focused on ensuring the data entered in the system is accurate and complete. Only then will the EIMS data base be of any value for long-range planning, scheduling, or budgeting.

A second criticism concerns the vast amount of data maintained in the EIMS data base. The process of searching for schemes that are similar to some future scheme is likely to be a monumental task.

First, the historical data base must contain some type of identifying physical or performance data that is consistent over time to allow for comparison with future schemes. As we discovered, no amount of statistical manipulations can compensate for the lack of usable data. The informational needs of estimators ought to be considered when identifying and categorizing specific data elements required to generate proper estimates.

The second reason why searching the data base for a comparable scheme may be difficult is attributable to the ever-changing environment in which AFCC operates. Many systems are unique and have no predecessor on which to base a man-hour estimate. In these cases, parametric estimation techniques may not be valid. A more applicable estimating technique may be that of estimating by analogy or obtaining estimates from experts as was discussed in Chapter 2.

Up to this point, we have identified several problems inherent within the present EIMS data base which diminishes its usefulness for the development of parametric estimates. One could recommend a data collection system be established to meet the needs of EI managers at all levels. Unfortunately, such an all-purpose information system may not be economically feasible. Management must consider the incremental costs of the system expansion and determine if the increased benefits justify the expansion. It may be possible to incorporate the informational needs of the estimators without such an expansion. The structure of the present data base may allow alterations which would enable storage of the needed physical and performance characteristics data.

The question of what physical and performance data to include is an issue. The data requirements will vary significantly depending on the type of C-E facility being installed. This research focused on communications cable installations within facility code 0011. As illustrated in Appendix A, there are numerous facility codes associated with different operational requirements, all of which are likely to have different physical and performance characteristics. The identification of the pertinent characteristics data for each requirement would be a major undertaking.

Although limited in scope, this research explored the feasibility of using selected physical characteristics data and program data to establish a parametric estimating relationship for predicting the number of man-hours required to install communications cable. The methodology and model discussed were not intended for use in the field and were designed only to demonstrate the feasibility of the parametric estimating technique as applied to the engineering and installation function. Despite the limited scope, the methodology employed is applicable and adaptable to more general classes of communications-electronics facilities.

Conclusions

Research Question 1

Does the EIMS data base contain sufficient information to construct a model to estimate the man-hours required to install an EI scheme?

At the present time, the EIMS data base does not contain the needed physical and performance characteristics data from which man-hour estimates can be generated. Although vast amounts of program and resource data are available, the data is not sufficient to identify specific system characteristics of past schemes needed to set up a functional relationship with future schemes. The facility code classification system currently in use also does not provide the required system characteristics needed to develop parametric estimates. Additionally, the title of the workload and the narrative description of each scheme contained in the historical base were, in part, sketchy. As a result, an automated workload estimation system using the EIMS data base is not feasible at this time.

Research Question 2

What degree of estimation accuracy is being achieved today without the support of the EIMS data base?

Based on a sample of 293 schemes, we determined the average of all facility code 0xxx man-hour estimates came within three percent of the actual man-hour expenditures. This finding agreed with those of a previous study conducted by AFCC in 1981. However, over 20 percent of the estimates were either over or understated by greater than 1,000 man-hours relative to the average difference of only 63.74 hours. Thus, the ability of managers to adequately budget for, schedule, evaluate, and control individual schemes is impaired.

Research Question 3

What variables directly influence the time required to accomplish a C-E scheme within facility code 0xxx?

Presently, the facility code classification scheme used by AFCC does not allow for the identification of a specific set of explanatory variables for any one particular code. This is due to the fact that many different types of equipment are grouped under individual facility codes. For example, facility code 0011 not only includes cable installation, but also various types of inside plant schemes. Therefore, prediction based on facility codes is not feasible.

Several variables were proposed as having an influence on the number of man-hours required for cable installations. Initially, this set consisted of cable length, cable size, location of cable, commodity code, season, and region of the country. Intuitively, these variables are appealing. However, only two variables were statistically significant. The commodity code variable did not even enter the regressions because each scheme in the sample of 148 had the same commodity code. The variables season, location, and region, taken individually, were not significant predictors at a level of significance of $\alpha = .05$. Location did prove to be significant but only at a level of significance of $\alpha = .17$. The region variable was not significant; however, as the number of regions increased, the significance increased. This suggests that evaluation of cable installation time on a state or base sampling scheme may prove useful. Unfortunately, it is likely that a significant amount of data would have to be collected before this could be accomplished.

Based on this research, one variable proved to be a very significant predictor. Conductor miles was clearly a useful predictor of required man-hours. Calculation of conductor miles was necessary due to the various lengths and sizes of cable in any one scheme.

Research Question 4

What is the relationship between the dependent variable, total man-hours required, and the variables identified?

The research identified that a curvilinear relationship exists between man-hours and the variable conductor miles. The final regression equation was:

$$\log Y = 5.19503 + .43387 * \log X_1$$

where:

$\log Y$ = Natural logarithm of man-hours required

$\log X_1$ = Natural logarithm of conductor miles

Research Question 5

Are there interrelationships between the selected independent variables?

Although several models were identified which contained various combinations of the selected independent variables, the model we selected contained only one independent variable--conductor miles of cable installed.

Therefore, there were no interrelationships.

Recommendations

The purpose of this research was to explore the feasibility of developing an automatic work estimation system which, as a component of the EI management system, could be applied by EI managers to arrive at man-hour estimates that are accurate and reliable, yet flexible enough to adjust to the uniqueness of a particular scheme. The research concluded that, at the present time, such a system is not feasible. We believe that such a system has great potential and could be employed in the near future but on a limited basis. The major obstacle to its development and implementation is the paucity of physical and performance data on which to base estimates. Some system of collecting and maintaining this data is essential if a work estimation system based on historical data is ever to be developed. We acknowledge that this recommendation encompasses a great deal of work if it is to be applied command-wide. We believe, however, that follow-on research to this effort could be conducted focusing on only those communications installations for which a majority of the man-hours are expended; for example, cable installations.

Before the data collection ca begin, future researchers must determine the type of data they would require. That is to say, physical and performance data common to the system under study that are hypothesized to influence the number of man-hours to install the equipment would have to be collected. Because of the inadequacies of the present EIMS data base, data for the hypothesized variables would have to be collected as in-progress schemes are completed. As the sample size expands, the models developed could be improved.

The data collection effort would have to involve the various engineering branches responsible for the schemes of interest in order that the appropriate data is maintained and reported. Expansion of the EIMS data base or a restructuring of its contents may be required in order to accommodate increased data requirements. As previously discussed, an expansion of the data base would require an economic analysis to determine if the benefits outweigh the expense. Perhaps the new data requirements could be incorporated into the existing data base. We recommend that a critical evaluation of the data requirements be conducted to ensure the data maintained is indeed required.

We further recommend that additional research be accomplished to extend this study to predict the required man-hours for engineering workload. Budgeting, programming, and scheduling of EI workload requires man-hour estimates for both engineering and installation resources. Improvements in either one will be a step in the right direction; however, until both are improved, the ability of the EI community to control costs and forecast resource requirements will be impaired.

APPENDICES

APPENDIX A

"B" FACILITY CODE GROUPINGS

"B" FACILITY CODE GROUPINGS

"B" Code	Description
Telephone Inside Plant (A)	
011	Government Owned Telephone
013	Govt. Crash Reporting
014	Govt. Security System
015	Govt. Auxiliary & Satellite
016	Govt. Aerospace Telephone
017	Govt. Electronic Telephone
018	Govt. Weather Wire
021	Commercial Telephone
025	Coml. Auxiliary & Satellite
027	Coml. Electronic Telephone
380	Autovon Switch
381	Autovon 4-wire Terminal
Telephone Outside Plant (B)	
011	Government Owned Telephone
015	Govt. Auxiliary & Satellite
021	Commercial Telephone
Data Communications (C)	
026	Alert Net/Command Post
071	Govt. Recording Terminal
081	Coml. Recording Terminal
184	Air Weapons Control COC
300	LL TT Half Duplex
308	TT Conference Facility
310	LL TT Duplex
320	Torn Tape Relay Center
353	LL Fax, Weather, S/R
354	LL Fax, Weather, R/O
360	TT Tape Preparation
365	Automated Comm. Terminal, large
368	Emergency Msg. Auto. Transmitter
369	Command Post Record Facility
370	Automatic TT Switch Center
372	RATT Weather Terminal
374	Automatic Data Switch Center
379	Auto Error Detect/Correct
475	LL Telephone Carrier
476	LL Telegraph Carrier
477	Wire Fox
801	Data Transfer Facility
805	Data Display Facility
809	Electronic Local Data Comm. Center
810	Simplex Remote Comm. Center

"B" Code	Description
Tech Control (C)	
650	Patch & Test Facility
652	Channel & Tech Control
656	Comm. Center Auxiliary Equipment
Microwave (J)	
450	VF Microwave Trunk
451	VF Microwave Terminal
452	VF Microwave Relay
453	VF Micro. Relay w/Dropout
455	Fixed Video Microwave
460	VF VHF Link
461	VF VHF Terminal
653	Intersite Microwave
664	Tropo Terminal
665	Tropo Relay
666	Tropo Relay w/Dropout
Space Communications (J)	
280	Weather Satellite Data Receiver
385	Space/Ground Link
386	Satellite Control & Display
640	Communications Satellite Link
Crypto (K)	
000	Unknown
502	TT Crypto, Duplex, Sync.
503	TT Crypto, H/D, Non-sync.
504	Off Line Crypto
505	Multi-Purpose Crypto
507	Fax Crypto
508	HiSpeed Digital Crypto
509	Speech (Ciphony)
511	TT Crypto H/D Sync.
512	Autodin Crypto Switch Center
513	Status Authentication Sys. Crypto
514	Command Security System
520	G/A Speech (Ciphony)
521	G/A Digital Crypto
590	COMSEC Spares
Meteorological (M)	
270	Area Storm Detection Radar
271	Local Storm Detection Radar
272	Atmospherics Locating Facility
274	Surface Wind Measurement
275	Surface Temp. & Humidity
277	Cloud-Base Height Measurement
278	Horizontal Visability Measurement
279	Dual Runway Instrument Meas. Fac.

"B" Code	Description
Control Tower (N)	
201	Control Tower
203	Control Tower w/Approach Control
Nav Aids (N)	
226	ILS
238	VORTAC
239	UHF Beacon
242	VOR
243	TACAN
244	RADAR Beacon
247	LF/MF Beacon
HF/LF Radio (R-S)	
409	LF Receive Only
410	RATT Weather Intercept
411	CW Weather Intercept
419	Voice, HF, G/A Medium Power
428	Voice, HF, Low Power
429	Voice, HF, Medium Power
601	SSB, TT, HF, Medium Power
602	SSB, TT, HF, High Power
603	SSB, Voice, HF, Medium Power
604	SSB, Voice, HF, High Power
626	RA, Voice, HF, High Power
654	Transmitter Station Aux. Equip.
655	Receiver Station Aux. Equip.
658	Radio Monitor Facility
670	G/A/G Digital Comm. Terminal
680	SSB, Voice, G/A, Low Power
681	SSB, Voice, G/A, High Power
685	SSB, Voice, Low Power
691	Mobile SSB, Medium Power
699	MARS
Armed Forces Radio/TV (R-S)	
697	AFRT-TV
698	AFRT Radio
UHF/VHF Radio (R-S)	
104	Air Defense Control Center
105	Air Defense A/G Communications
107	BOMARC G/A Transmitter
112	Missile Guidance
164	Frequency Control, Analysis, Monitoring
175	SAGE G/A Communications
183	Air Weapons Control & Reporting
202	Runway Supervisory Unit
204	ATC A/G Communications
207	Special Aircraft Control

"B" Code	Description
209	Flight Following Center
210	Enroute ATC Center
211	Tactical Control
212	Transport Control
213	Pilot/Forecaster
214	Pilot/Dispatcher
408	Supervisor of Flying
445	Voice VHF G/A, Low Power
447	Voice UHF G/A, Low Power
448	Voice UHF G/A, High Power
449	Voice UHF G/A, Medium Power

Instrumentation (I)

078	Integrated Program/Base Defense (BISS)
165	Ground Telemetry

Closed Circuit TV (V)

062	Government Owned CCTV
091	Situation Display

Nav Aids Radar (W)

220	Permanent RAPCON
221	Mobile RAPCON

Radar (X)

100	Early Warning Station
101	E.W. Ground Cont. Intercept
102	Ground Controlled Intercept
106	Special Radar
109	Missile Tracking
110	Ballistic Missile Detection
115	Ballistic Missile Impact Predict.
172	Radar Course Direction
177	SAGE Long Range Radar

EDPE (Y)

170	Combat Data Processing
376	Government Data Terminal
377	Commercial Data Terminal
384	Cmd. Cont. Data Processing
806	Data Processing System

APPENDIX B

STRUCTURE OF EIMS DATA BASE

Starting Position	Field Length	Data Field	Data* Type	Description
1	8	WIN	PD	Workload Identification Number
1	4	SEQ	PD	Sequence Number (WIN)
5	1	TYPEWL	PD	Type Workload (WIN)
6	1	FY	PD	Fiscal Year, Last Digit (WIN)
7	1	ACTY	PD	Activity Code (WIN)
8	1	AMD	PD	Amendment Number/Letter (WIN)
9	8	PRGNR	PD	Program Record Number
9	4	PSEQ	PD	Sequence Number (PRGNR)
13	1	PTYPEWL	PD	Type Workload (PRGNR)
14	1	PFY	PD	Fiscal Year, Last Digit (PRGNR)
15	1	PACTY	PD	Activity Code (PRGNR)
16	1	PAMD	PD	Amendment Number/Letter (PRGNR)
17	9	PROID	PD	Program Identification
17	1	CAT	PD	Category of Requirement
18	6	CEMPAC	PD	C-E-M Program Aggregation Code
24	1	REQCMD	PD	Requiring Command Code
25	1	PROAMD	PD	Program ID Amendment Number
26	6	CCN	PD	Command Control Number
32	1	PC	PD	Phase Implementation Code
33	2	HOST	PD	Host-MAJCOM/Subcommand
33	1	MAJ	PD	Host Major Command Code
34	1	SUB	PD	Host Subcommand Code
35	4	LOC	PD	Location (Base/Site) Code
39	4	FAC	CD	Facility Code
43	1	CMDY	PD	Commodity Code
44	4	RODPOD	PD	Required/Programmed Operational Date
44	1	RODIND	PD	ROD Indicator (Y=ROD, N=POD)
45	3	RODQFY	PD	Required/Programmed Operational Date
48	3	JCD	PD	Job Completion Date
51	4	PRI	PD	Priority (99) and Interest (AA)
55	1	ML	PD	Management Level (1=HQ, 2=EIC and 3=EIC, 485EIG, 1842EEG or 1843EIG)
56	3	JOBRMK	PD	Job Status and Remarks
59	2	APM	PD	Lead Activity Program Manager Code

Starting Position	Field Length	Data Field	Data* Type	Description
61	2	IPM	PD	Implementing Acty. Program Manager Code
63	2	HPM	PD	HQ AFCC Program Manager Code
65	2	AGG	PD	Aggregation Code
67	6	ERD	PD	Engineering Required Date
73	6	DMR	PD	Date Material Required
79	6	MIRD	PD	Maintenance/Installation Required Date
85	6	DES	PD	Date Entered System
91	6	DLA	PD	Date of Last Action
97	1	GROUP	PD	Group(1=SCHEME, 3=ENG JO, 5=WO)
98	12	PMNME	PD	Lead Acty/Implementing Program Manager's Name
110	7	PMTEL	PD	Lead/Implementing Program Mgr. Telephone #
117	1	PAO	PD	MAJCOM Program Staff/ Action Officer
118	16	BASENM	PD	Base (Location) Name
134	2	STATE	PD	State/Country Code
136	7	DL01	RD	Direct Labor Field #1 (AA=Eng. Branch, X= Installation, Skill 99999=Man-Hours)
143	7	DL02	RD	Direct Labor Field #2
150	7	DL03	RD	Direct Labor Field #3
157	7	DL04	RD	Direct Labor Field #4
164	7	DL05	RD	Direct Labor Field #5
171	7	DL06	RD	Direct Labor Field #6
178	7	DL07	RD	Direct Labor Field #7
185	7	DL08	RD	Direct Labor Field #8
192	7	DL09	RD	Direct Labor Field #9
199	7	DL10	RD	Direct Labor Field #10
206	7	DL11	RD	Direct Labor Field #11
213	7	DL12	RD	Direct Labor Field #12
220	7	DL13	RD	Direct Labor Field #13
227	7	DL14	RD	Direct Labor Field #14
234	7	DL15	RD	Direct Labor Field #15
241	7	DL16	RD	Direct Labor Field #16
248	1	POM	PD	Program Objective Memorandum (Y or N)
249	10	CEID	PD	Communications-Electronics Implementation Directive
259	4	CDCN	PD	Command Document Control Number

Starting Position	Field Length	Data Field	Data* Type	Description
263	4	ENGTDY	RD	Engineering TDY Costs
267	4	MITDY	RD	M/I TDY Costs
271	6	EMCC	RD	Estimated Minor Construction Costs
271	2	EMCCFY	RD	Fiscal Year Estimated Minor Construction Costs
273	4	EMCCDOL	RD	Estimated Minor Construction Costs Dollars
277	1	AFCC	RD	AFCC Funded for Minor Construction (Y or N)
278	6	AMCC	RD	Actual Minor Construction Costs
278	2	AMCCFY	RD	Fiscal Year Actual Minor Construction Costs
280	4	AMCCDOL	RD	Actual Minor Construction Costs Dollars
284	6	EMAJ	RD	Estimated Major Equipment Costs
290	6	AMAJ	RD	Actual Major Equipment Costs
296	5	MPA	RD	Military Personnel Appropriation Man-Days
304	7	ESD	PD	Engineering Start Date (D/S)
304	6	ESDDATE	PD	ESD Date
310	1	ESDSTAT	PD	ESD Status
311	7	SSS	PD	Site Survey Start (D/S)
311	6	SSSDATE	PD	SSS Date
317	1	SSSSTAT	PD	SSS Status
318	7	SCL	PD	Site Concurrence Letter (D/S)
318	6	SCLDATE	PD	SCL Date
324	1	SCLSTAT	PD	SCL Status
325	7	SCR	PD	SCL Returned (D/S)
325	6	SCRDATE	PD	SCR Date
331	1	SCRSTAT	PD	SCR Status
332	7	LMS	PD	LOM Submitted (D/S)
332	6	LMSDATE	PD	LMS Date
338	1	LMSSTAT	PD	LMS Status
339	7	EFD	PD	Eng. Finalization Date (D/S)
339	6	EFDDATE	PD	EFD Date
345	1	EFDSTAT	PD	EFD Status
346	7	ECD	PD	Eng. Completion Date (D/S)
346	6	ECDDATE	PD	ECD Date

Starting Position	Field Length	Data Field	Data* Type	Description
352	1	ECDSTAT	PD	ECD Status
353	7	ENGBR	PD	Eng. Branch
360	7	ENGSPT	PD	Eng. Support Unit
367	2	ENGMTH	PD	Eng. Method
369	3	ENGRMK	PD	Eng. Phase and Status Remarks
372	7	MJ	PD	Material Milestone #1 (Not Used)
379	7	LMR	PD	LOM Received (D/S)
379	6	LMRDATE	PD	LMR Date
385	1	LMRSTAT	PD	LMR Status
386	7	M3	PD	Material Milestone #3 (Not Used)
393	7	M4	PD	Material Milestone #4 (Not Used)
400	7	MSD	PD	Material Shipped Date (D/S)
400	6	MSDDATE	PD	MSD Date
406	1	MSDSTAT	PD	MSD Status
407	7	M6	PD	Material Milestone #6 (Not Used)
414	7	MAD	PD	Material Availability Date (D/S)
414	6	MADDATE	PD	MAD Date
420	1	MADSTAT	PD	MAD Status
421	2	MM	PD	Material Monitor
423	2	MATMTH	PD	Material Method
425	3	MATRMK	PD	Material Phase Status and Remarks
428	7	EIR	PD	EI Review of Scheme (D/S)
428	6	EIRDATE	PD	EIR Date
434	1	EIRSTAT	PD	EIR Status
435	7	WR	PD	Workload Release (D/S)
435	6	WRDATE	PD	WR Date
441	1	WRSTAT	PD	WR Status
442	7	ASC	PD	Allied Support Complete (D/S)
442	6	ASCDATE	PD	ASC Date
448	1	ASCSTAT	PD	ASC Status
449	7	TSR	PD	Telecommunications Service Request (D/S)
449	6	TSRDATE	PD	TSR Date
455	1	TSRSTAT	PD	TSR Status
456	7	PSS	PD	Preinstallation Survey Start (D/S)
456	6	PSSDATE	PD	PSS Date
462	1	PSSSTAT	PD	PSS Status
463	7	PSC	PD	Preinstallation Survey Complete (D/S)

Starting Position	Field Length	Data Field	Data* Type	Description
463	6	PSCDATE	PD	PSC Date
469	1	PSCSTAT	PD	PSC Status
470	7	TSD	PD	Team Start Date (D/S)
470	6	TSDDATE	PD	TSD Date
476	1	TSDSTAT	PD	TSD Status
477	7	TCD	PD	Team Completion Date (D/S)
477	6	TCDDATE	PD	TCD Date
483	1	TCDSTAT	PD	TCD Status
484	2	MIMTH	PD	M/I Method
486	3	MIRMK	PD	M/I Phase Status and Remarks
489	7	MIRESP	PD	M/I Unit Responsible
496	7	MISPT	PD	M/I Support Unit
503	7	PIP	PD	Plant-in-Place (D/S)
503	6	PIPDATE	PD	PIP Date
509	1	PIPSTAT	PD	PIP Status
510	2	PIPBR	PD	PIP Branch
512	3	PIPRMK	PD	PIP Status and Remarks
515	7	TOA	PD	Transfer of Accountability (D/S)
515	6	TOADATE	PD	TOA Date
521	1	TOASTAT	PD	TOA Status
522	7	CDD	PD	Completion Document Distribution (D/S)
522	6	CDDDATE	PD	CDD Date
528	1	CDDSTAT	PD	CDD Status
529	5	SOW	PD	Statement of Work Number
534	2	RELSCH	PD	Related Schemes Code
536	2	RELENG	PD	Related Eng. Code
538	4	ECRA	PD	Eng. Change Request/ Authorization
542	12	ENGNME	PD	Engineer's Name
554	7	ENGTEL	PD	Engineer's Telephone Number
561	12	TCNME	PD	Team Chief's Name
573	3	TCGRD	PD	Team Chief's Grade
576	5	TCAFSC	PD	Team Chief's AF Specialty Code (AFSC)
581	3	COMP	PD	Percent Job Completion (M/I)
584	13	TEAM	RD	Team Composition (9=NR, A=Skill)
597	10	MCP	PD	Military Construction Project Number
607	3	LCQTY	PD	LSCMP Quantity
610	13	LCNOM	PD	LSCMP Nomenclature
623	6	LCCOST	RD	LSCMP Material Cost

Starting Position	Field Length	Data Field	Data* Type	Description
629	3	SRD	PD	Standard Reporting Designator
632	19	TITLE	CD	Title of Workload
651	41	NARR	CD	Narrative Description
692	6	ENGEST	RD	Eng. Hours Estimated
698	6	ENGCUR	RD	Eng. Hours Expended This Month
704	6	ENGTOT	RD	Eng. Hours Expended Total
710	6	ENGREM	RD	Eng. Hours Remaining
716	6	MIEST	RD	M/I Hours Estimated
722	6	MICUR	RD	M/I Hours Expended This Month
728	6	MITOT	RD	M/I Hours Expended Total
734	6	MIREM	RD	M/I Hours Remaining
740	4	ORGROD	PD	Original ROD/POD (A= IND, Y=ROD, N=POD)
744	2	HIAMOS	PD	Months This Job Has Been HIA
746	2	EXCMOS	PD	Months Accepted With Exceptions
748	6	ORGMIEST	PD	Original MIEST When PC Status Went "A"
754	7	ORGTCD	PD	TCD When TSD Status Went "A"
761	6	ORGENGEST	PD	Original ENGEST When PC Status Went "A"
767	7	ORGECD	PD	ECD When ESD Status Went "A"
774	6	ORGERD	PD	Original End (See Note)
780	6	ORGDMR	PD	Original DMR (See Note)
786	6	ORGMIRD	PD	Original MIRD (See Note)
792	1	CMPDELCD	PD	Completion/Deletion Code (C=COMP, D=DELE)
793	4	CMPDELYRMO	PD	Completion/Deletion Date
797	4	ORGASC	PD	Original ASC
801	6	PROGAPRVDT	PD	Program Approval Date
811	1	RCDTYPE	PD	Record Type (2=SCHEME, J.O. or W.O.)
817	8	ANIMADOL	PD	Actual Minor Material Costs
825	6	FPODDATE	PD	Forecast Program Operational Date (Date When PC Coded F)

*RD = Resource Data; PD = Program Data; CD = Characteristic Data

APPENDIX C

SELECTED DATA

SELECTED DATA

WIN	Commodity Code	Estimated Manhrs	Actual Manhrs	Conductor Miles	Location	Region	TSD
0378A0D0	B	3,200	3,564	2,294.09	Undergnd	1	810310
0043A0B0	B	1,237	359	9.47	Buried	1	810514
1287A7B0	B	3,000	763	253.79	Undergnd	1	810419
0175A3B0	B	224	102	18.94	Undergnd	1	800315
0189A5B0	B	520	54	1.42	Undergnd	1	801018
0014A1B0	B	2,512	1,064	37.89	Aerial	1	810305
0030A0B0	B	5,600	2,056	436.06	Undergnd	1	810526
0614A0B0	B	12,288	7,288	893.15	Undergnd	1	810211
1087A7B0	B	963	919	115.81	Undergnd	1	810426
0130A7B0	B	3,691	4,609	497.00	Undergnd	1	800430
0246A9B0	B	900	949	11.36	Undergnd	2	810314
0580A4B0	B	1,682	1,279	36.93	Undergnd	2	800715
0751A9B0	B	1,395	495	3.41	Undergnd	2	801203
0103A5B0	B	435	204	5.68	Buried	2	810501
0258A9B0	B	968	2,767	380.09	Undergnd	2	800908
0514A9B0	B	672	1,117	30.30	Buried	2	800225
0750A9B0	B	1,302	874	14.68	Buried	2	801119
0924A0B0	B	544	1,296	48.48	Undergnd	3	820216
0252A0B0	B	1,352	1,976	68.18	Undergnd	3	810323
0327A9B0	B	832	1,293	15.15	Buried	3	811008
0724A1B0	B	4,176	3,070	454.55	Buried	3	811026
0364A8B0	B	2,048	5,258	909.09	Buried	3	810513
0848A9B0	B	963	1,008	10.04	Buried	3	810226
0910A9B0	B	1,648	2,800	454.55	Buried	3	810621
0847A9B0	B	169	556	2.18	Buried	3	810921
1419A7B0	B	689	1,460	90.91	Undergnd	3	800813
0237A8B0	B	500	1,117	14.20	Buried	3	800408
0209A8B0	B	384	786	5.30	Undergnd	3	810126
0281A0B0	B	544	520	2.95	Buried	3	810512

WIN	Commodity Code	Estimated Manhrs	Actual Manhrs	Conductor Miles	Location	Region	TSD
0487A8B0	B	645	1,342	140.15	Undergnd	3	800501
0166A8B0	B	768	3,315	561.55	Aerial	3	800601
1318A7B0	B	531	312	12.31	Buried	3	800519
1317A7B0	B	561	656	22.73	Buried	3	800527
1880A8D0	B	752	584	15.15	Buried	4	820204
2288A1D0	B	300	278	2.84	Buried	4	820518
1863A1D0	B	948	672	37.90	Buried	4	811013
2174A6D0	B	668	294	94.70	Buried	4	791105
1985A9D0	B	240	272	9.47	Buried	4	801204
2156A9D0	B	220	416	2.84	Buried	4	801203
1869A8D0	B	384	288	2.56	Buried	4	810116
2285A7D0	B	245	344	1.23	Undergnd	4	810117
2287A7D0	B	560	584	1.36	Undergnd	4	810107
2339A0D0	B	11,200	11,705	4,386.36	Undergnd	4	801103
2158A5D0	B	1,268	58	1.42	Buried	4	810701
1769A8D0	B	5,200	2,828	465.91	Undergnd	4	811027
2232A8D0	B	560	702	17.19	Undergnd	4	810901
1789A0D0	B	1,700	1,792	125.00	Undergnd	4	800903
2227A8D0	B	1,500	1,162	23.20	Undergnd	4	791003
2085A9D0	B	8,934	9,414	2,884.09	Undergnd	4	810323
0660A0B0	B	600	200	5.68	Buried	4	810420
0242A8B0	B	1,896	3,608	887.31	Undergnd	4	800428
0245A8B0	B	530	993	15.53	Buried	4	800422
0433A9B0	B	141	1,298	140.15	Undergnd	4	800728
0201A4B0	B	358	344	4.26	Undregnd	4	810221
0404A9B0	B	1,416	3,632	200.76	Buried	4	820108
0871A0B0	B	773	910	19.89	Undergnd	4	820202
2197A8D0	B	1,800	904	288.75	Buried	4	801020
2201A8D0	B	659	1,602	64.38	Buried	4	800607
2192A8D0	B	706	464	11.00	Buried	4	810217
2196A8D0	B	293	404	10.48	Buried	4	810201
2198A8D0	B	6,400	1,017	238.64	Buried	4	810326

WIN	Commodity Code	Estimated Manhrs	Actual Manhrs	Conductor Miles	Location	Region	TSD
1771A0B0	B	5,530	6,863	8,852.50	Buried	5	810623
2315A8D0	B	800	1,096	34.09	Buried	5	800918
2318A8D0	B	298	72	22.72	Buried	5	801007
2317A5D0	B	3,500	1,990	1,423.59	Undergnd	5	800724
2274A9D0	B	650	488	4.17	Buried	5	810406
2319A8D0	B	1,400	1,312	484.85	Buried	5	800925
1739A9D0	B	2,640	2,634	249.38	Buried	5	820310
2215A0D0	B	1,872	239	6.63	Buried	5	820811
1794A0D0	B	3,600	5,160	559.09	Undergnd	5	801105
2199A7D0	B	640	258	2.37	Buried	5	810317
2183A7D0	B	1,856	1,240	67.16	Buried	5	810129
2349A7D0	B	12,000	11,329	665.45	Undergnd	5	801023
2172A7D0	B	1,480	1,800	275.76	Buried	5	810401
2235A0D0	B	2,380	419	5.68	Buried	5	820702
1761A7D0	B	398	358	6.63	Buried	5	820310
1916A7D0	B	6,480	9,544	156.87	Buried	5	810511
2362A7D0	B	5,000	6,902	1,927.56	Undergnd	5	800506
1932A8D0	B	750	400	3.79	Buried	5	800715
1753A8D0	B	5,642	5,739	97.51	Buried	5	800822
2012A4D0	B	4,100	4,781	2,229.07	Buried	5	800911
2203A3D0	B	680	362	5.68	Buried	5	810204
2204A3D0	B	500	592	7.58	Buried	5	810129
2214A0D0	B	550	338	22.73	Buried	5	810310
1930A8D0	B	191	192	1.89	Buried	5	820329
1792A2D0	B	1,780	1,008	56.82	Undergnd	5	821004
2264A1D0	B	2,280	1,032	14.30	Undergnd	5	821108
1865A1D0	B	4,560	6,186	255.49	Undergnd	6	811009
2222A2D0	B	900	960	27.65	Undergnd	6	811118
1845A8D0	B	1,320	745	75.76	Undergnd	6	800811
1837A8D0	B	404	511	5.68	Undergnd	6	801018
1767A5D0	B	500	361	1.89	Undergnd	6	800811
2343A7D0	B	300	300	2.84	Buried	6	810511

WIN	Commodity Code	Estimated Manhrs	Actual Manhrs	Conductor Miles	Location	Region	TSD
2385A0D0	B	1,200	976	28.94	Undergnd	6	820729
222949D0	B	310	732	34.09	Undergnd	6	810711
1976A9D0	B	3,300	4,032	248.01	Buried	6	810814
2225A9D0	B	390	40	.95	Undergnd	6	810120
1741A8D0	B	241	521	4.26	Buried	6	820815
1895A0D0	B	820	800	19.70	Undergnd	6	820325
1896A0D0	B	1,200	432	4.26	Buried	6	820201
1898A0D0	B	480	581	1.89	Buried	6	820220
2492A0D0	B	275	112	2.73	Buried	6	820107
1749A3D0	B	500	238	5.68	Buried	6	801003
2275A9D0	B	700	641	3.64	Undergnd	6	801007
2248A0D0	B	290	32	2.46	Undergnd	6	810323
1906A0D0	B	860	1,703	36.63	Buried	6	820108
2038A0D0	B	2,000	2,636	786.27	Undergnd	6	820205
2060A0D0	B	380	460	2.84	Undergnd	6	811102
2386A7D0	B	3,160	2,842	53.41	Undergnd	6	801006
1848A1D0	B	200	288	11.36	Aerial	6	810108
1788A7D0	B	1,400	1,208	37.64	Undergnd	6	810309
2381A7D0	B	1,500	1,592	10.83	Buried	6	810522
2039A0D0	B	680	772	27.18	Buried	6	820528
0821A1D0	B	6,976	1,911	234.62	Undergnd	7	820119
1900A8D0	B	3,500	3,131	284.73	Undergnd	7	820125
1807A0D0	B	7,740	5,914	3,810.61	Undergnd	7	800528
1897A8D0	B	500	247	5.68	Undergnd	7	800613
2092A7D0	B	1,600	1,632	170.81	Undergnd	7	800925
2100A7D0	B	2,000	703	32.67	Undergnd	7	800901
2094A7D0	B	2,200	1,784	465.91	Undergnd	7	801014
2083A7D0	B	960	24	24.62	Undergnd	7	801210
1998A8D0	B	698	2,277	35.28	Undergnd	7	800415
1996A8D0	B	1,000	1,245	17.27	Undergnd	7	800722
2521A0D0	B	1,416	2,768	404.24	Undergnd	7	810302
1924A9D0	B	2,377	2,481	151.52	Undergnd	7	820701
2319A7D0	B	6,500	4,115	1,292.61	Undergnd	7	820318
2254A8D0	B	8,880	8,668	1,067.65	Undergnd	7	820823

WIN	Commodity Code	Estimated Manhrs	Actual Manhrs	Conductor Miles	Location	Region	TSD
2321A7D0	B	3,400	3,181	241.29	Undergnd	7	820802
2421A0D0	B	240	146	79.55	Buried	7	820210
1960A9D0	B	80	80	52.89	Buried	7	810930
2188A7D0	B	606	776	1,084.47	Buried	7	800915
1849A1D0	B	1,600	1,104	842.05	Buried	7	810317
2248A1D0	B	800	380	68.18	Undergnd	7	820322
2456A1D0	B	800	511	53.03	Buried	7	820308
0945A7B0	B	11,592	11,590	1,323.86	Buried	7	780911
0961A7B0	B	2,156	2,625	772.73	Undergnd	7	800602
0980A7B0	B	3,519	2,916	63.07	Buried	7	800206
1764A9D0	B	325	1,423	94.70	Undergnd	7	820831
1866A1D0	B	1,420	1,052	18.94	Undergnd	7	820908
1763A9D0	B	100	337	11.36	Undergnd	7	811017
1861A1D0	B	1,420	889	26.52	Undergnd	7	811120
1843A9D0	B	2,252	2,635	380.00	Undergnd	7	801018
0955A7B0	B	312	312	23.86	Buried	7	800111
1751A9D0	B	308	252	4.93	Buried	7	800701
1765A9D0	B	90	705	15.15	Undergnd	7	800503
2010A0D0	B	550	832	18.90	Undergnd	7	810708
2034A7D0	B	8,400	8,169	322.50	Undergnd	7	800908
1996A0D0	B	6,209	6,047	2,181.82	Undergnd	7	820405

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