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A STUDY OF ESTIMATING PROJECT DESIGN MANHOURS

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LSSR 12-78B

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The purpose of this thesis was to analyze design variables which affect the time required to design a project and to develop a model for estimating required design time based on these variables. A survey was distributed to all Civil Engineering design sections located in the CONUS. Specific data were requested on previously designed projects and on pertinent factors considered when estimating project design manhours. The results of the survey indicated that the three most important factors were: complexity of the project, estimated cost of the project, and experience of the engineer. Multiple linear regression analysis was used to statistically analyze what effect the independent design variables (cost of project, complexity, number of disciplines, experience of the engineer, type of work, type of funds, modularity, previous similar projects, and drafting work by the engineer) would have on the dependent variable (design manhours). A relationship was found to exist between project design manhours and the independent variables. However, this relationship was too weak to produce an accurate enough model to estimate project design manhours. Although a weak relationship was demonstrated for the composite analysis of all bases, a relatively strong relationship existed for individual bases.

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A STUDY OF ESTIMATING PROJECT DESIGN MANHOURS

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 Facilities Management

By

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COMMITTEE CHAIRMAN

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CHAPTER I

INTRODUCTION

Air Force Civil Engineering is responsible for the design, construction, modification, operation, maintenance, and disposal of all Air Force real property (i.e., land, structures, pavements, utilities, and associated systems). This is a tremendous task involving an annual expenditure of millions of manhours and billions of dollars. As a significant part of this total effort, approximately 785 military and civilian engineers, assigned to the design section of civil engineering units at 87 continental United States Air Force installations, annually design $250 to $300 million in maintenance, repair, and construction projects.[1] Moreover, for each dollar's worth of projects designed, an estimated two dollars in project requirements are identified and backlogged, awaiting available design manhours. It seems apparent that design time is an important civil engineering resource that must be allocated as efficiently and effectively as possible. In a period of increasingly austere manning and budgets, design time is a scarce resource that demands positive

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[1]Estimate provided by Lieutenant Colonel Wesley D. Nottinghan, HQ USAF/LEEPV, 4 August 1978.

management and control. A first step in controlling design time is developing accurate estimates of the time required to design projects. This thesis proposes to study the current design time estimating methods and to develop an accurate and reliable method for estimating the number of manhours required to design a project.

What can be gained by having a method of making more accurate estimates of the engineering manhours required to design a project? First, an accurate estimate of project design time provides the basic building block for an accurate design schedule, which helps insure the timely completion of high priority projects or year-end projects. Second, more accurate project design time estimates are essential in forecasting in-house capability and architect-engineer (A-E) requirements. Third, valid manhour estimates can serve as a plan from which to monitor the progress of a project design. Fourth, valid manhour estimates can provide a basis for evaluating the performance of an individual engineer and the design section as a whole. Fifth, the same method could serve as a way to help develop the government estimate of manhours required by an A-E to design a project. Sixth, having a method of making accurate estimates of design manhours would be particularly useful for the young and inexperienced officer who finds himself in charge of a design section.

Each of these six concerns will be addressed later in the section on "Current Air Force Interest and Justification." First, however, the background which leads to description of methods currently used for estimating design manhours will be discussed.

Background

Within an Air Force base civil engineering squadron, the design section has responsibility for the design of facilities projects. In addition, the section is responsible for other technical duties including construction management, review and assistance in developing programming documents, project technical reviews, engineer-manager duties, consultant services, and technical studies. It is an Air Force target to expend approximately 40 percent of total available engineering manhours against project design (10:137-138). In the survey distributed by the authors to design sections at eighty-seven CONUS bases, twenty-five of forty-two bases responding were scheduling at least 40 percent of the engineer's total time for project design (see Figure 1). In order to get the most productivity out of that 40 percent, we need to provide methods and techniques for improving "the management of design manhour resources [5]."

For the purpose of this thesis, project design is defined to include: (1) review of programming

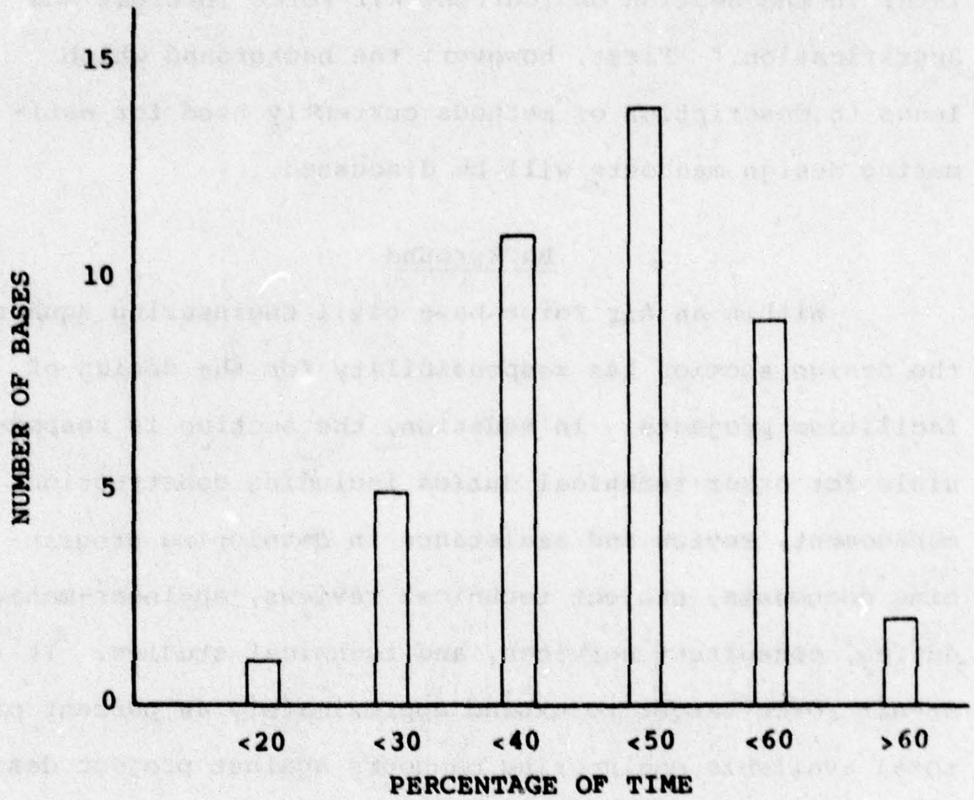

Fig. 1. Frequency Distribution of Engineer's Total Time Scheduled For Direct Project Design

documents, (2) review of record drawings, (3) necessary site visits to verify actual conditions, (4) meetings with using agencies to insure that their functional requirements are met, (5) necessary research to insure that Air Force regulations are complied with, (6) development of the project drawings and specifications, (7) required final coordination and approval procedures, and (8) compliance with any MAJCOM/AF project review comments.

The project design may be for new construction, but most often it involves the maintenance, repair, or alteration of existing structures and systems. The projects are normally designed for accomplishment by civilian contractors. Unlike most A-E's or the U.S. Army Corps of Engineers who work on relatively few, but large scope or dollar value projects, base design sections generally work on the design of many small scope or dollar value projects. Information collected in this study on 553 projects designed at thirty-four bases showed an average estimated construction cost of $95,900 with a range between $1,400 and $1,447,000. Almost 10 percent (52 out of 553) of these projects were estimated to be less than $10,000. The frequency distribution of the 553 projects by estimated cost is shown in Figure 2. Based on a sample of forty-two design sections, a typical base design section has an average of 9.28 engineers. Thirty-six

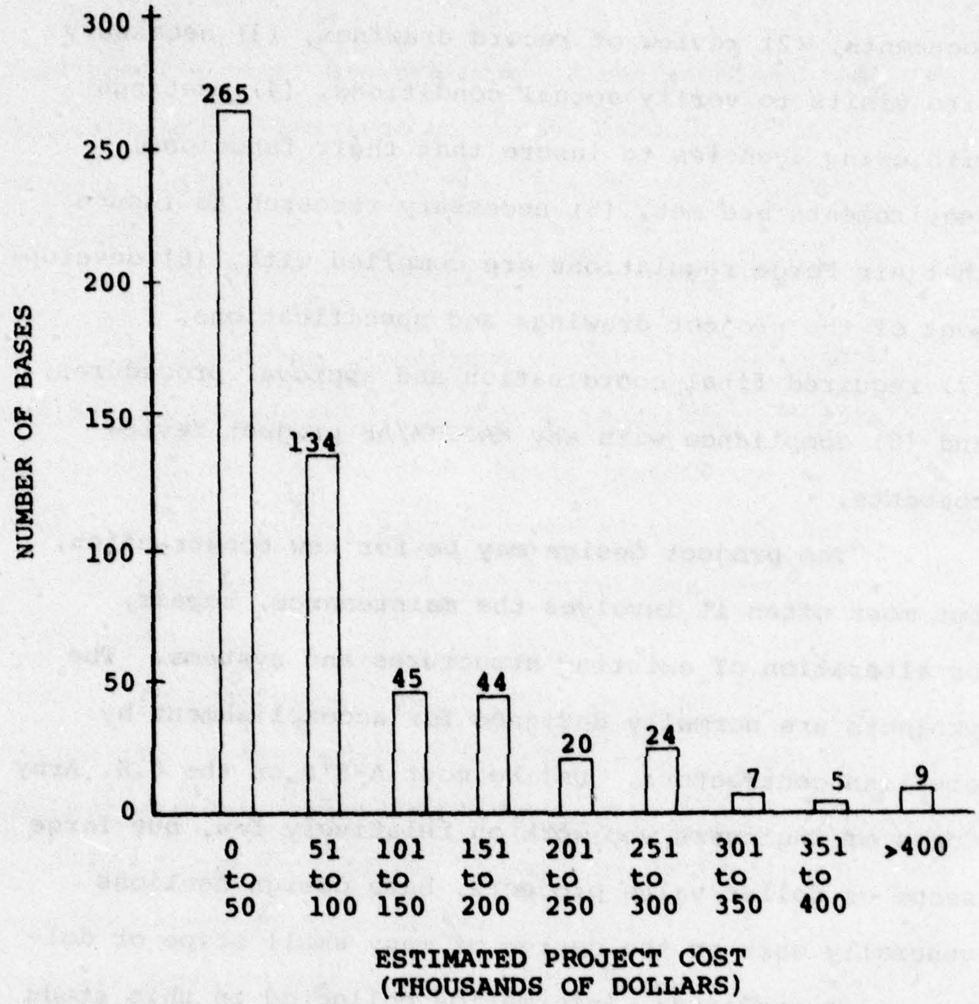

Fig. 2. Frequency Distribution of Estimated Project Costs

of the forty-two design sections had engineering staffs composed of both military and civilian engineers, while the remaining six staffs were all civilians.

The Chief of Design is responsible for the effective and efficient utilization of the design section resource. "Estimating design time is the key to scheduling and measurement of efficiency [7:3]."

The Chief of Design must not only prepare "individual project design schedules which encompass all phases of in-house design . . . .," but must also:

> . . . establish clear-cut work plans for effective management of in-house engineering resources. This should include an annual design plan which projects design objectives and milestones [19:Para.5-11].

To design all the projects authorized for a monthly design period, the design section will be working on many projects, and each of the engineers will often be required to work on several projects simultaneously. The difficult task of managing this design effort is a primary job of the Chief of Design. According to AFR 89-1: "Design management is the use of technical and management skills to achieve a satisfactory design within fund and time limitations [19:Para.2-3]."

Since no direct guidance is provided on methods for estimating project design manhours, numerous methods are currently being used by the Chiefs of Design to schedule their engineers' workloads. The purpose of the next section is to present some of the methods being used to estimate the required number of manhours to design a project.

Methods Currently Used for Estimating Design Manhours

Most of the techniques used by the Air Force for estimating the number of manhours required to design a project are similar to those being used in commercial practice. A discussion of several of the current methods used in both the Air Force and commercial practice is presented below.

In the "phase and compensation" method, a given design fee is assumed, and the fee is broken down into a payment schedule according to each project phase. For example, 20 percent of the fee may be designated for the concept phase; 30 percent for preliminary design; 40 percent for working drawings; and 10 percent for bidding or negotiations. The amount of money in each phase is then divided by the hourly rate normally charged, and a resulting number of manhours for each phase is determined. The accuracy of this method relies on the experience and ability of the estimator to determine the required amount of design effort which is used to determine the design fee. An inexperienced estimator can overestimate or underestimate the fee by a considerable amount (2:3).

The "fee" method is very similar to the "phase and compensation" method and is a technique used by a number of bases, where the design section is compared to an A-E office. In effect, the amount of money available to accomplish the design, the fee, is used to determine how many manhours are available. This number of manhours is normally moderated by the judgement and experience of the Chief of Design. Following is an example of this technique as used by one base. Information required includes estimated project cost, engineering shop rate,[2] and a scaling factor. The scaling factor takes into account type of work and modularity (degree of repetition) to determine complexity (perceived difficulty) as follows:

Minor Construction and Alteration	1.00
Repair	.75
Maintenance--Nonmodular	.50
Maintenance--Modular	.30
Maintenance--Annual Recurring	.20

An A-E may be paid a maximum of 6 percent of the estimated cost of the project for normal design services. At this base, a 100 percent markup is assumed to cover the costs of office administration and operation. Thus,

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[2]The engineering shop rate is the average cost per hour of doing work in the engineering work center (WC 421) and includes: military and civilian labor costs, bench stock materials, tools, vehicle costs, and an overhead adjustment factor of civilian pay.

3 percent is used as a starting point in determining the fee. These values are then entered into the following formula:

$$\text{Manhours} = \frac{\text{Estimated Cost} \times 3\% \times \text{Factor}}{\text{Engineering Shop Rate}}$$

to give the number of mnahours required to design the project.

The "ask-the-engineer" method is very popular. "Traditionally, time estimates are obtained by asking someone familiar with the job a question such as, 'How long will it take you to do this?' [18:65]." Most often the Chief of Design will direct this question to the design engineer. This method suffers two shortcomings: (1) the engineer may pad his estimate to be safe, and (2) the Chief of Design may not be experienced enough to know whether or not the engineer's estimate is reasonable.

The "detailed breakdown" method is a technique of determining the number of engineering design manhours based on a detailed analysis of the elements required broken down by specific discipline (11:86-89). This method provides fairly accurate estimates of the required manhours, but it is quite time-consuming. The large number of small projects handled by the average Air Force design section normally makes this method impractical.

The "computed curve" method relies on historical data which relate the total number of design manhours required for previous projects to the associated project costs. A curve is drawn to model this relationship, usually with project cost along the X-axis and total manhours along the Y-axis. By knowing the estimated cost of a new project, the Chief of Design can estimate the number of manhours required to design a project by reading the manhours where the estimated cost intersects the curve. At one base, a series of four curves have been developed: \$0 - \$10,000; \$10,000 - \$100,000; \$100,000 - \$1,000,000; and \$1,000,000 - \$10,000,000. In addition, each project is evaluated by the Chief of Design in terms of complexity and modularity. The results of this evaluation may then cause the curve to be shifted within plus or minus three standard deviations from the mean represented by the initial curve. For example, if the project rated high in modularity and very low in complexity, the curve would be shifted down approximately three standard deviations; if low in modularity and high in complexity, the curve would be shifted up approximately three standard deviations before reading the number of required manhours (6). To provide accurate estimates, this method requires several years of project data. Due to the complexity of the calculations, a computer is required for curve generating and the Chief of Design should have a background in statistical analysis.

The "matrix" method also relies on historical project manhour data related to cost and complexity to enable the Chief of Design to estimate total project design manhours. Cost ranges such as $0 - $25,000, $25,000 - $75,000, $75,000 - $150,000, and $150,000 - $400,000 are displayed vertically on the matrix. Complexity values are low, medium, and high and are displayed horizontally on the matrix. The cells of the matrix then contain the total number of manhours for project design based on an estimated cost and complexity. The matrix method requires a large data base unique to each base and does not allow for the effects of other important design variables.[3]

The "cartooning" method is a technique based on the estimated number of sheets of drawings which may be required, the amount of information or detail which should be contained on each sheet, and some knowledge of how many manhours it will take to complete each sheet. To use this technique, a Chief of Design must be experienced in all of the engineering disciplines involved in a design

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[3]Material on the matrix method was taken from course material for the "Engineering, Construction, and Environmental Planning: Management Applications Course taught at the AFIT Civil Engineering School, Wright-Patterson AFB OH.

or have experienced supervisors or senior engineers who can provide the necessary information. In addition, the Chief of Design must have established a data base on manhours per sheet of drawings.

The final method is the "one-a-month" method. The Chief of Design allows one month to complete each project unless it is considerably more difficult than the "average" project. When the inexperienced Chief of Design may not be aware of other estimating methods, the "one-a-month" method certainly provides an easy method to use, but is obviously a gross simplification of the complex interaction of many factors and probably results in an inability to efficiently manage design performance.

The American Institute of Architects (AIA) has recognized the necessity for accurately estimating the time required to design a project. They also have recognized the lack of either an adequate method or readily available data to provide such information. As a result, the AIA is currently developing the Time Data Bank, which involves gathering data on a number of well-documented case studies and sorting this data in the computer. This accumulated data can be used to provide information on time estimates for similar projects and is intended to be used to make as well as to check estimates (1:2).

Current Air Force Interest and Justification

"The Management of Engineering Design within base level CE needs improvement [5]." This blunt assessment by USAF/PREM reflects the same concern as a number of Chiefs of Design who were interviewed by the authors between 2-11 November 1977 as they attended Engineering and Construction Management Applications Course 77C at the Air Force Institute of Technology (AFIT). Air Force engineering managers who attended previous engineering and construction management applications courses identified the number one priorities on their list of engineering concerns as design productivity and meeting design schedules.[4]

Engineering manhours need to be better controlled for each individual engineer, discipline, type of work, and priority to assure efficient management of the engineer's time (8). Of primary concern in effectively controlling engineering manhours is the ability to accurately estimate the number of hours required to design a project. This research, as well as the authors' individual experiences at various bases, has shown that there is neither a generally accepted method used at base level nor any method suggested through Air Force guidance.

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[4]Extracted from AFIT/CES Engineering and Construction Management Applications Course background material on file in instructor's office.

Accurate project design manhour estimates are the basic building blocks of a valid design schedule. However, with current practices, there is no basis for what goes into the design schedule (9). Many systems are used for scheduling, but all require that initial manhour estimates be input. The estimates that are input impact the validity of the schedule, yet up to now, there is "no good way of estimating design manhours [15]." The ability to accurately estimate project design time is essential in constructing an effective design schedule and allows the Chief of Design to insure the timely completion of critical and high priority projects (3). An effective design schedule increases the probability that all projects in the current program will be designed on time. Accurate manhour estimates are essential in managing year-end or fallout money projects. In addition to providing the basis for a valid design schedule, accurate project design manhour estimates provide a forecast capability for design management. In summary, "as estimating methods become more accurate, scheduling should also become more accurate [7:4]."

Accurate project design manhour estimates can be used to forecast total annual design capability, which impacts the programming of projects, the identification of A-E requirements, design staff requirements, and design support requirements (4). Accurate manhour estimates also allow accurate forecasting of in-house design capability. This prior knowledge of the design capability lets the Chief of Design know how many projects can be included in the current program or may have to be slipped to the next fiscal year. If unforeseen changes do create a backlog of priority projects or required manhours in any discipline, this backlog can be identified early, again allowing A-E requirements to be determined and funds budgeted (5). Early identification of staff shortages or unique requirements would allow time for assistance by command or another base. Also, staff requirements in site development and administration could be addressed. Accurate design manhour estimates can help in identifying available time which could be devoted to a fallout design effort as well as identifying specific projects which might be considered for design. Finally, accurate manhour estimates allow forecasting of support requirements such as furniture, drafting tools, computational and testing equipment, reference material, film, and supplies.

Along with the ability to identify future requirements, accurate manhour estimates can be used as an indicator of the status of ongoing projects. Accurate project design manhour estimates could be used to help monitor the status of a design project. Currently, the status of a project under design is established subjectively by the engineer telling the chief the percentage of the work he thinks he has completed (8; 9; 15). A comparison of the actual number of manhours expended against the number of manhours estimated would provide some indication of the progress on the project. Additionally, this comparison would provide a management indicator of potential problem areas. For example, if the percentage of manhours that have been expended is high and the progress being reported by the engineer is low, something is wrong.

Accurate project design manhour estimates can provide a basis for evaluating the performance of the engineer as well as the design section (9; 15). On any given project, a comparison of the estimated manhours with the actual manhours required to complete the design can provide one indicator of the engineer's performance on that project. More importantly perhaps would be comparisons of an engineer's design efforts over a period of time. Projections could be made, based on project design manhour estimates, on how much design an engineer should accomplish in a year. Thus, goals might be set for annual performance and then actual performance measured against those goals. Similarly, design goals, based on project design manhour estimates, could be established for the whole design section and performance could be measured against those goals. Additionally, once target design manhours had been established and met, future goals could be set to reduce the time to complete a project design.

Accurate project design manhour estimates could help establish the government estimate for negotiating design contracts with A-Es. A method for estimating project design manhours, which is based on historical data and parameters of the specific project to be designed, provides a factual basis for negotiations. This method provides a means of analyzing possible changes in a parameter, such as cost of project. For instance, if the base has several options in the construction of the project, how would each option impact the design of the project?

The same benefits mentioned in regard to A-E design work hold true for the in-house design work. The method is visible and can serve as a basis for discussion and negotiation with the design engineer. Again it allows for analysis of options, thus serving as an aid in making design management decisions. Comparison with past performances can be used in planning future goals. Such a method also provides a basis for the Chief of Design to discuss and define his section's capability. In essence, it may provide a basis for saying "no," when "no" is the realistic reply. However, the Chief of Design cannot say "no" unless he knows what he can do and how the changes impact the design schedule and the program.

Finally, the need for an accurate and reliable method for estimating design manhours was identified by several chiefs of design because of the following recurring management situation. In private professional architectural or engineering practice, new employees fresh out of school or just entering the field are not given a job managing large numbers of design projects or a highly skilled engineering staff. These people work "on-the-boards" to gain experience, often for many years before assuming such management responsibilities. By that time, they have the in-depth experience to make design time estimates as well as to carry out other design management responsibilities. In the Air Force, however, it is not uncommon for a young officer with little or no practical experience to be assigned as the Chief of Design where he must make estimates of design time essential in formulating project design schedules. Of forty-two Chiefs of Design responding to a survey conducted in this research of CONUS engineering design sections, seven were officers and thirty-two were civilians. The remaining three did not indicate whether they were officers or civilians. The civilian chiefs had an average of 8.78 years experience as Chiefs of Design and an average of 16.44 total years of design experience. By comparison, the officers had an average of 1.14 years experience as the Chief of Design and an average of 1.71 total years of design experience. This situation is particularly true at overseas bases or smaller stateside bases and is happening more often as rated officers with five to twelve years of service spend a tour as a rated supplement in base civil engineering. These individuals have neither practical experience nor Air Force guidance to direct them in accomplishing an important part of their job (4; 12; 13).

In response to the apparent need to improve design management, the Civil Engineering School at AFIT has included a one-hour block of instruction in the Engineering and Management Applications Course 78A. The course presents a brief overview of four design manhour estimating methods currently being used. The intent is to let Chiefs of Design know what other Chiefs of Design are using.

The Air Force is planning to approach the engineering design management problem by including information in a brochure for the Chief of Design. This brochure is not to be a regulation but is intended to be colorful, readable, and simple to use (8). The brochure will address a number of management problems within the Engineering Design Section. The intention is to "offer *management techniques* for *setting targets* for . . . manhours . . . by the engineer [5]." After traveling to a number of bases, a civil engineering member of the Military Airlift Command/Inspector General team concluded that design sections do not have any valid basis for deciding what goes into the design schedule (9). At this point in time there are no methods for estimating design manhours which have been identified for inclusion in the brochure. The results of this research will be made available to the project officer for inclusion in the brochure.

In recent years, Air Force managers have been tasked to do more with fewer resources. The requirement for effective management of our present engineering resources is perhaps best summed up by the following quotation:

> The apparent shortage of engineering talent actually can be traced to a shortage of effective engineering management. A poor manager *wastes* engineering talent [17:35].

Problem Statement

Current project design manhour estimating methods vary considerably. Our research indicates that there is no method which provides accurate and reliable enough manhour estimates. Additionally, the lack of a reliable method creates an inability to effectively schedule the engineers' workload and to determine the design capability. These considerations adversely impact the effective management of the civil engineering design section resources.

Objectives

The objectives of this research are to:

1. Identify and analyze the variables which have the greatest effect on the required design time of a project,

2. Develop a model for estimating the required design time based on the most significant of the variables,

3. Establish an appropriate standard for accuracy of estimated project design time, and

4. Test the model's accuracy and reliability in estimating the required design time.

Research Questions

In order to meet the objectives, the following research questions must be answered:

1. What are the variables which directly affect the project design times?

2. What is the relationship between design time and the variables?

3. What accuracy of estimated project design time should be achieved? What accuracy is currently being achieved?

General Hypothesis

The relationships between design time and design variables will allow the Chief of Design to estimate the required design time accurately and reliably.

CHAPTER II

METHODOLOGY

This chapter is divided into two sections which describe the methodology used in this research. The first section describes the population, sample, identification and definition of variables, and data acquisition. The second section briefly describes the statistical techniques and step-by-step approach used in analyzing both nonproject and project data collected from a survey.

Population

For the purpose of this research effort, the population is defined as all construction projects, to include minor or new construction, routine maintenance, and repair, designed by engineers assigned to the civil engineering design sections of all CONUS AF CE design sections.

Sample

The sample used in this research was taken from forty-five CONUS bases and consists of data on: variables considered in estimating project design times; accuracy being achieved and desirable accuracy to be achieved in estimating project design times; the percentage of an engineer's time scheduled for project design; and on 553 completed design projects. See Appendix A for a compilation of these data. The survey instrument by which this information was gathered was sent to all eighty-seven CONUS civil engineering design sections identified in Chapter 4, Volume I of AFM 10-1, Air Force Directory of Unclassified Addresses. Of the forty-five bases responding to the survey, thirty-four provided usable project data. However, bases not providing project data did provide usable non-project data.

The survey was limited to the CONUS bases because of the ease of data collection, the accessibility for necessary coordination with the surveyed bases, and additional variables which must be considered for overseas bases (different design section configurations and manning, working with foreign nationals, less resources at their disposal, etc.). Since the sample was restricted to bases in the CONUS, the results obtained from this research effort cannot be generalized to bases outside the CONUS.

Identification and Definition of Variables

Many variables have been considered to have a potentially significant effect on the number of manhours required for a project design. These variables were identified through conversations with six current Chiefs of Design and five senior engineering managers, informal survey response from eighteen design managers attending Engineering, Construction, and Environmental Planning Management Applications courses 77-C and 78-A at the AFIT/Civil Engineering School, as well as the experience and knowledge of the authors. For each variable identified, consideration was given to the following questions: how available is the data for this variable; how readily can it be classified/quantified; how objective/subjective is the data; does this variable affect different projects to different degrees, or does it affect all projects approximately the same; and to what extent does this variable affect the number of design manhours required? These questions were used as criteria which would provide data that could be statistically analyzed and would be readily available on existing project documentation.

Dependent Variable

Project Design Manhours. The project design manhours are the number of manhours required to design a project. The number of manhours is affected by several factors which have been determined to be the independent variables. Project design is defined as the time required to: (1) review programming documents, (2) review record drawings, (3) conduct site visits to verify actual conditions, (4) conduct meetings with the using agency to insure that their functional requirements are met, (5) conduct necessary research to insure the Air Force regulations are complied with, (6) develop project drawings and specifications, (7) accomplish final coordination and approval procedures, and (8) comply with any MAJCOM/AF project review comments.

Independent Variables

Project Cost. The project cost is the estimated project cost taken from the DD Form 1391 or the Air Force Form 332.

Number of Disciplines Involved in the Design. The number of disciplines is simply the total number of different engineering disciplines involved in the design of that particular project.

Type of Project. The type of project is a nominal variable that identifies a project as minor or new construction (MC), routine maintenance (M), or repair (R).

Project Fund Category. The project fund category is a nominal variable that designates the source of money used to fund the project. The research effort will consider projects which are funded by the following sources of money: Operations and Maintenance (O&M), Nonappropriated Funds (NAF), Military Family Housing (MFH), and Hospital.

Experience of the Engineer. The experience of the engineer will be broken down into two separate variables. The first variable is defined as the total number of years of design experience for the engineer. The second variable is defined as the number of years of design experience at the present base of the engineer.

Perceived Modularity. Perceived modularity is an ordinal variable defined as repetition of specific elements within a particular design project. Modularity is subjectively determined by the Chief of Design as high, medium, or low. For example, the design of numerous sets of identical classrooms would probably be considered high modularity.

Similar Project. A similar project is one which has been previously completed and which can be substantially reused for a current project design.

Perceived Complexity. The perceived complexity of a project takes into account such factors as the amount of external coordination required, whether the project has unique design requirements, involves new technology, or requires much internal coordination among the engineers. Complexity is assigned by the Chief of Design on a scale of one to five with the very simple project being one, an average project being three, and the very complex project being five.

A number of additional independent variables were identified but were not considered for data collection. A list of these variables is presented in Appendix B-1. The main reasons for elimination of these variables were the lack of readily available data, the inability to adequately classify/quantify the data, and the necessity to limit the number of variables in order to minimize the burden of data gathering at the base and analysis of the data.

Data Acquisition

The data for these variables was collected through the use of a survey sent to all bases in the CONUS. The survey was sent directly to the Chief of Design at each base for completion. The survey was validated through an iterative process of review and revision. The final format is the result of reviews and recommendations by: civil engineering personnel at HQ USAF/PREMA; two classes of Chiefs of Design who attended Engineering, Construction and Environmental Planning Management Applications courses 77-C and 78-A and internally by research department faculty, thesis advisor, and Facilities Management graduate students.

Development of the Survey

In general the survey was designed to gather data on: the size, experience and composition of design sections; the factors the Chief of Design is looking at during his design workload planning; current and desirable estimating accuracy; and specific project information. Refer to Appendix B-2 for a copy of the survey. Following are specific thoughts and rationale for developing individual questions.

From the first page of the survey, item 2, "base and AUTOVON," was requested to allow follow-up inquiries by the researchers regarding data from that base and to allow geographical location of the base for analysis by region. Item 3, "factors considered when making estimates for project design times," was included to validate the list of independent variables previously identified and to identify any important variables which may have been overlooked. Item 4, "rank ordering the factors most often used," was included to try and reduce the many variables to a consistent and manageable few variables which may provide the most information for prediction. Item 5, "desirable estimating accuracy," was included to help establish a standard or target for estimating accuracy. This standard would then be used to test the accuracy of any developed method or model for estimating project design manhours. Item 6, "present project manhour estimating accuracy being achieved," was included to find out what accuracy bases who are measuring this are achieving and to find out how many bases are not measuring estimating accuracy. Item 7, "the percentage of the engineer's total time scheduled for direct project design," was included to compare the percentage of time scheduled with the AF target of approximately 40 percent and to determine the percentage of time we must manage using project design time estimating.

From the second page of the survey, item 1, "Engineer Number," was included to determine the size of the design staff and to provide a way to associate a particular engineer, and thus discipline and experience, with a particular project. To do the latter the engineer's identifying number(s) would be placed in item 7 of the third page, Engineers Involved. Item 2, "Rank/Grade," was included primarily to determine the military/civilian mix among the design staff and whether or not the Chief of Design was military or civilian. Item 3, "Discipline," was included to allow analysis of project design time data by discipline or combinations of disciplines. Item 4, "Design Experience," was included to determine how experience in total years or at that particular base were related to manhours required to design a project. Items 6, 7, and 8, "experience of the Chief of Design," were included: to show the range in experience levels; to allow a comparison of the variables used by more versus less experienced chiefs; and to allow a comparison of the estimating efficiency of different experience levels.

On the third data gathering page of the survey, items 1, 2, 3, and 4, "Project Information," were included to provide objective information on each project for use in analysis. In order to limit the work effort required at the base which provided the data, the number of projects was limited to fifteen. At any point in time, the number of projects of each type of work (M, R, MC) or fundings (O&M, NAF, MFH, Hospital) at each base varies considerably. Thus, a specific mix of project types and funding was not specified, and the Chief of Design was asked to select the particular projects. Projects were restricted to those which had been completed since 1 October 1976 in order to achieve some comparability in terms of project cost, i.e., the same scope project, presumably taking the same design effort, might cost much more in 1977 than in 1972. Item 5, "Perceived Modularity," was included to have the Chief of Design make a judgment from the information he had available on the modularity of the project in order to examine the relationship of modularity to project design time. Item 6, "Total Project Manhours," was included primarily to determine the actual manhours required to design each specific project. Estimated manhours were also requested if they were available in order to allow us to compare actual versus estimated manhours. Since the engineer often does his own drafting, time for engineering as well as drafting would be included in the project man-hour figures. This data helps make projects more comparable and allows some additional analysis. Item 7, "Engineers Involved," was included to determine how many engineers were involved in the design of each project; what disciplines they were; their experience level; and whether they were military or civilian. Item 8, "Perceived Complexity," was included to have the Chief of Design make a judgment of his perceived complexity of the project relative to other projects at his base. Item 9, "Similar Project," was included to determine if in the Chief of Design's judgment a recent similar project had been designed which could substantially be used or reused to design a current project.

Analysis Methods and Approach

Analysis of Nonproject Data

The analysis of nonproject data, that is, the data from the first and second page of the survey dealing with factors considered, accuracy of prediction, and the design staff, was conducted using descriptive statistics, primarily frequency distribution and arithmetic mean.[5] In general,

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[5] See Chapter 2 of Pfaffenberger and Patterson reference for additional information.

the factors selected for comparison were chosen to identify potential differences or patterns of differences. These could then provide clues to critical variables used by the design sections which estimated project design manhours more accurately. The following approach was used:

1. The frequency distribution of the bases by Major Air Command (MAJCOM).

2. The frequency distribution of the factors considered by the Chief of Design when making estimates for project design times was compiled.

3. The number of factors most used was limited to three as this was judged to be the most manageable or usable number which a Chief of Design could easily manipulate. The three most often used factors were analyzed using frequency distributions by:

a. factors selected. Additionally, the factors were examined using both weighted and non-weighted rankings. The actual weighting system used is described in Chapter III.

b. bases who indicate that they are estimating within at least 20 percent accuracy and by bases which are actually estimating within 20 percent accuracy based on the project information provided.

c. MAJCOM.

d. design staff size.

e. military/civilian ratio.

f. years of experience as the Chief of Design.

g. a military chief versus a civilian chief.

4. The desirable degree of accuracy was analyzed using frequency distribution by:

a. all respondents.

b. MAJCOM.

5. The degree of accuracy currently being achieved was analyzed using frequency distribution by:

a. responses provided by all Chiefs of Design.

b. values computed from the estimated and actual manhour project data provided.

c. MAJCOM.

6. The percentage of the engineer's total time scheduled directly for project design was analyzed using frequency distributions:

a. as indicated by Chiefs of Design.

b. by MAJCOM.

7. The experience of the Chief of Design was analyzed by:

a. mean years as Chief of Design.

b. mean years total design experience.

Analysis of Project Data

The analysis of project data, that is, the data from the third page of the survey which provided specific project data on the dependent and independent variables identified, was conducted using two statistical techniques: analysis of variance (ANOVA) and linear regression--simple and multiple (SLR and MLR). Existing computer programs contained in the Statistical Package for the Social Sciences (SPSS) were used to perform the ANOVA, SLR, and MLR analyses.

ANOVA is a parametric statistical technique used to determine comparability between two or more population means (16:364). Specific ANOVA assumptions are based on these means. The data submitted met the required assumptions (which are discussed in Appendix E-1). In this research effort, ANOVA is used to assess the comparability of bases with regard to the characteristics of the design sections. The SPSS ONEWAY-ANOVA program was used to analyze the data base for the six quantifiable varibles:

Y = the number of manhours required to complete individual project designs

X1 = the estimated cost of each project

X2 = the number of disciplines used to design each project

X3 = the number of years of design experience that each engineer has on base

X4 = the number of years of total design experience of each engineer

X8 = the perceived complexity of each project

Any variable was rejected as being not statistically significant and comparable, when the critical F statistic value, F_{prob}, was less than 0.050. This was equated to a 95 percent confidence interval at $\alpha = 0.05$ when compared with the sample F, F_s, as listed for the computer output. The following ANOVA analyses were conducted on each of the variables listed above:

1. Using the data base of all 553 projects,
2. Using the data base of 288 projects from sixteen bases remaining when non-comparable bases from the first run were eliminated, and
3. Using the data base of 424 projects from twenty-five bases remaining when variables X3 and X4 were disregarded.[6]

Linear regression analysis is a method which is used to describe a linear relationship between the dependent variable and the independent variable(s) for a set of data points. Simple linear regression analysis is used to predict the value of the dependent variable for any single given value of the independent variable. Multiple linear regression is an extension of simple regression because it takes into account the effect of more than one independent variable on the dependent

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[6] A detailed explanation of the data bases, elimination techniques, and contrast techniques are found in Chapter III, Analysis and Findings, as well as in Appendix E-1.

variable. MLR is the appropriate technique when it is desired to investigate the effects on the dependent variable of several independent variables simultaneously. (20:287) See Appendix E-2 for a more detailed explanation of MLR analysis.

Variables included in the linear regression analysis are as follows:

Y = the number of manhours required to complete individual project designs

X1 = the estimated cost of each project

X2 = the number of disciplines used to design each project

X3 = the number of years of design experience that each engineer has on base

X4 = the number of years of total design experience of the engineer

X5 = the type of project (MC, M, R)

X6 = modularity (high, medium, low)

X7 = type of funds (O&M, MFH, NAF, Hosp)

X8 = perceived complexity of the project

X9 = drafting done by the engineer (yes or no)

X10 = similar project recently completed (yes or no)

The purpose of the analysis of these variables was to develop an MLR equation.

Model Criteria. The three criteria established for testing the equation developed from the MLR analysis were accuracy, reliability, and manageability. The equation is considered to be acceptable when the level of accuracy attained is ±15 percent or less. That is, the number of manhours estimated to design a project must be within ±15 percent of the actual number of manhours required to design that project. For the equation to be considered reliable, the specified level of accuracy must be attained at least 90 percent of the time. Manageability refers to the convenience or ease of use of the equation at the working level. The equation is judged to be manageable when the number of variables providing acceptable predictive capability is limited to approximately three variables. When the equation has met the criteria, it is considered as an accurate model.

Equation Evaluation Criteria

The criterion used to evaluate the efficiency of the predictive power of this equation is derived from a subjective test on the coefficient of determination, R^2. The higher the value of R^2, the more accurate the equation is in predicting the value of the dependent variable given the independent variables. For purposes of this thesis, the commonly accepted statistical convention of a nominal R^2 value of .80 is considered sufficient to conclude that the equation has an acceptable prediction or explanatory capability. The following linear regression analyses were conducted:

1. On all 553 projects provided by thirty-four bases.

2. On 505 projects remaining when others were deleted. Others were manually deleted when manhours appeared to be inconsistent with project cost or when project cost was far beyond that normally designed at base level, for example, two projects whose estimated cost was over $1,000,000 were omitted. Manhours were generally considered inconsistent with cost when the ratio of manhours to cost (in thousand dollars) exceeded 8:1 or when the ratio of manhours to cost (in thousand dollars) was less than 1:8.

3. On all 553 projects stratified by type of work--229 MC, 229 R, and 95 M.

4. On all 553 projects stratified by total estimated cost: less than $10,000--52 projects; between $10,000 and $100,000--343 projects; between $100,000 and $200,000--88 projects; and greater than $200,000--70 projects.

5. On 363 projects identified as requiring only one discipline for design.

6. On 391 projects in which the project engineer did not do the drafting for the project.

7. On each individual base.

CHAPTER III

DATA ANALYSIS AND FINDINGS

This chapter is divided into three sections. Section one pertains to the findings related to the non-project data; section two presents the results of the analysis of variance; and section three presents the results of the multiple linear regression. The text of the chapter deals with the verbalized results/findings of the analysis. Separate appendices are utilized to present the specific numerical results of the particular methods of analysis. Appendix C provides the findings of the nonproject data analysis and Appendix D presents the results of both the analysis of variance and multiple linear regression.

Findings from Nonproject Data

Basically, the findings from the nonproject data result from frequency distributions, averages, and comparisons of data gathered on pages one and two of the survey. The organization of this findings section follows along the format of the survey. Generally, only the greatest frequencies, most striking differences, or definite patterns are highlighted in the findings. All of the data is presented in the appendixes or in figures.

MAJCOM of bases. The response of bases to the survey by MAJCOM generally agrees with the overall distribution of bases by MAJCOM. There were fifteen responses from SAC bases, eleven responses from TAC bases, and six responses from MAC bases. See Appendix C-1 for frequency of all MAJCOM.

Factors considered by Chiefs of Design. From the total range of factors considered when making estimates of project design time, four factors appeared on almost every response: the number of disciplines involved and similar project recently completed each appeared for forty-two bases; complexity of the project, forty-one; and experience of the engineer, forty. In addition, four other variables appeared at approximately 75 percent of the bases: which disciplines are involved appeared for thirty-seven bases; current design load, thirty-one; and total estimated project cost and type of design specification, each thirty. See Appendix C-2 for a complete frequency distribution of factors including those provided by the chiefs themselves.

Most often used factors and their rank order. The four most often used factors were complexity of the project, appearing nineteen times; total estimated project cost of the project, eleven; current design load, five; and number of disciplines involved, four. The five second most often used factors were: experience of the engineer appearing nine times; similar project recently done, seven; and number of disciplines involved, which disciplines involved, and current design load, each five. The four third most often used factors were: experience of the engineer, appearing ten times; complexity of the project, and similar project recently done, each four. If the three positions (first, second, and third) are given equal weighting and summed, the four most often used factors were: complexity of the project appearing twenty-nine times; experience of the engineer, twenty; estimated total cost of the project, fifteen; and current design load, fourteen. If the positions are weighted (most often used = three points, second most often used = two points, and third most often used = one point), then the ranking changes as follows: complexity of the project with seventy points still remains first; total estimated cost of the project with forty points becomes second; experience of the engineer with thirty-one points slips to third; and current design load with twenty-nine points remains fourth. See Appendix C-3 for the complete listing of the results.

The most used factors from the bases stating that they were achieving at least 20 percent accuracy in their design estimating were the same as the three most used factors in the overall findings. Also the most used factors from bases which were computed as achieving at

20 percent accuracy were similar to the overall findings. See Appendix C-4 and C-5. The frequency distribution of the three most often used factors by MAJCOM showed no unusual differences between MAJCOMs. The distribution of factors for each group of MAJCOM bases was similar to the overall findings. See Appendix C-6. The frequency distribution of the three most used factors by the size of the staff showed no unusual differences between the factors considered for small design staffs and large design staffs. See Appendix C-7.

The frequency distribution of the three most used factors by the military/total staff ratio showed that, although experience of the engineer was a consideration throughout the various ratios, it was considered more frequently as the military/total staff ratio increased. Total estimated cost of a project appeared to be considered more often in the lower military/total staff ratios. Analysis of data shows that a higher military/total staff ratio indicates a wider divergence of experience levels for the engineers, thus requiring that more consideration be given to this variable. A lower ratio indicates a greater homogeneity of experience levels, hence, greater consideration can be given to estimated project cost. Other factors were distributed evenly among the ratios. See Appendix C-8. The frequency distributions of the three most used factors by years of experience of the Chief of Design showed no unusual differences between less experienced and more experienced chiefs. See Appendix C-9. The frequency distribution of the three most used factors by military or civilian Chief of Design showed some different considerations. The thirty-two civilian chiefs considered the factors as follows: complexity of the project appeared seventeen times; experience of the engineer, fourteen; current design load, twelve; and total estimated cost of the project, eleven. The seven military chiefs considered the factors as follows: complexity of the project appeared seven times; experience of the engineer, four; and which disciplines are involved, three. For military chiefs, total estimated cost appeared once and current design load appeared twice. See Appendix C-10.

Desirable accuracy in estimating project design manhours. The frequency distribution of the desirable accuracy showed that thirty-seven out of forty-three Chiefs of Design considered accuracy within 20 percent as desirable while eleven of these thirty-seven Chiefs of Design considered accuracy within 10 percent as desirable. See Appendix C-11. The frequency distribution of the desirable accuracy by MAJCOM revealed no unusual differences from the overall desirable accuracy findings. See Appendix C-12.

Degree of accuracy presently being achieved. The frequency distribution of the accuracy presently being achieved as stated by the Chiefs of Design revealed that twenty-two out of forty-three bases did not record their accuracy. Of the remaining bases, ten indicated that they presently achieved "within 20 percent" and six "within 30 percent" accuracy. See Appendix C-13. Accuracy presently being achieved was computed for each base from the estimated and actual manhours provided on the project data. The accuracy expressed as a plus or minus percentage was computed by dividing the actual manhours by the estimated manhours. The frequency distribution of the accuracy being achieved as computed revealed that, out of the thirty bases examined, ten were achieving "within 30 percent" accuracy with a fairly normal distribution of the other accuracies. See Appendix C-14. When the two preceding distributions were placed on the same grid, as shown in Figure 3, a discrepancy was noted between the accuracy being achieved as stated by the Chiefs of Design and the accuracy being achieved as computed. The comparison indicates that adequate analysis has not been made between the actual versus estimated design manhours by the Chiefs of Design. Consequently, the actual estimating accuracy is not known.

The accuracy being achieved as computed was plotted against the number of years of experience of the Chiefs of Design. The scattergram showed generally that the greater the number of years experience, the better the estimating accuracy. See Appendix C-15.

Percentage of the engineer's total time scheduled for direct project design. The frequency distribution of the engineer's time scheduled for design showed "less than 50 percent" to have the greatest frequency at fourteen bases with all responses being normally distributed. See Appendix C-16. The frequency distribution of the engineer's time scheduled for design by MAJCOM showed some differences between commands. This may indicate that major commands place different emphasis on direct design effort relative to the other functional duties of the engineer. For SAC, the greatest frequencies were "less than 40 percent," seven responses, and "less than 30 percent," four responses. For TAC, the greatest frequencies were "less than 50 percent," five responses, and "less than 60 percent," three responses. Other commands were generally centered around "less than 50 percent" and "less than 60 percent." See Appendix C-17.

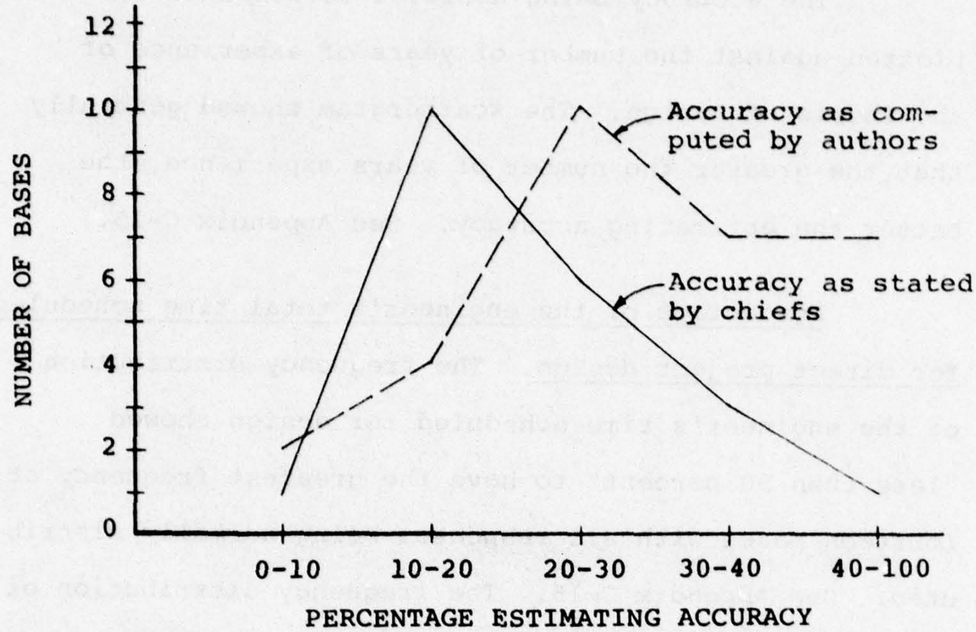

Fig. 3. Comparison of Stated Versus Computed Accuracy Being Achieved By The Chiefs of Design

Analysis of Variance

The first ANOVA run was conducted on all 553 cases from the thirty-four bases with the following results:

VARIABLE	F_s	F_{PROB}
Y	3.735	0.000*
X1	1.182	0.227
X2	4.190	0.000
X3	9.897	0.000
X4	7.374	0.000
X8	4.182	0.000

*0.000 indicates $\alpha > .001$

This run indicated that only the design variable, estimated project cost (X1), was statistically significant and the sample means were comparable for all bases. As can be seen from the analysis of subsets, in Figure 4, the number of bases with common grouped means varied with the method of analysis. The Student-Newman-Keuls (SNK)[7] analysis provided a more precise grouping of bases with regard to their means.

The SNK test indicated that the means were well grouped for the variable, design manhours (Y), except for one base. The variable, number of disciplines (X2), was also well grouped with only a few bases not contained within common subgroups. The greatest variability occurred for the variables base experience of the

[7] See Appendix E-1 for explanation of the SNK contrast test.

Scheffe Analysis

Variable	Subset 1	Subset 2	Subset 3	Subset 4
Y	34	--	--	--
X1	34	--	--	--
X2	34	--	--	--
X3	31	31	31	29
X4	31	31	--	--
X8	34	--	--	--

SNK Analysis

Variable	Subset 1	Subset 2	Subset 3	Subset 4	Subset 5	Subset 6
Y	33	1	--	--	--	--
X1	34	--	--	--	--	--
X2	29	31	26	--	--	--
X3	23	23	25	16	13	4
X4	25	26	23	23	24	1
X8	13	28	28	29	7	--

Fig. 4. Results of Sheffe and SNK Contrast Tests

engineer (X3), total experience of the engineer (X4), and complexity of the project (X8). Variables X3 and X4 showed many subset groupings. The least number of common subsets for variables X3 and X4 occurred for bases with higher mean experience levels demonstrating that some bases do, in fact, have more experienced design sections. The least number of common subsets for variable X8 occurred for a few bases with very low or very high project complexities. These few bases appear to have perceived this subjective variable, project complexity, as either lower or higher for their projects than for the other bases.

As no composite subgroup was provided by the ONEWAY-ANOVA program, a tabular plot was made for each base versus each variable and subgroup obtained from the SNK contrast test. See Appendix D-1 for the results of the tabular plot. Analysis provided a new data base containing sixteen bases and 288 projects. See Appendix D-2 for results of the analysis. All variables except base experience of the engineer (X3) were statistically significant and the sample means were comparable for all sixteen bases. As several subsets occurred for the variable total experience (X4) as well as base experience (X3), the comparability of these two variables was questioned. The experience levels of the design sections do vary considerably from base to base.

A third data base was formed containing twenty-five bases with a total of 424 projects. Neither base experience (X3) nor total experience (X4) were considered when comparing bases to each other for possible elimination. The results of this analysis are presented in Appendix D-3. This computer run produced more subset groupings, indicating more variability between the bases than for the 16-base data file. This is logical as fewer bases were eliminated due to more stringent requirements before a base was eliminated.

A more powerful technique is required to analyze the variance among projects, but analysis of variance did show that all bases may not be comparable with regard to the design sections themselves and the type of projects that they design. If this is true, an Air Force wide predictive model would not be appropriate but rather a predictive model *for each* base should be developed.

Multiple Linear Regression

General Findings

The MLR results show that a relationship does exist between project design manhours and the project design variables that were selected by the authors of this thesis effort and validated by the Chiefs of Design at the AF bases located in the CONUS. However, the relationships are neither significant nor consistent enough, at least with the current data, to provide an acceptable predictive capability with regard to accuracy and reliability.

The rank order of the project variables with adequate explanatory power and consistency is: the number of disciplines involved in the project design (X2); the perceived project complexity (X8); the estimated project cost (X1); the type of project funds (X7); and projects where the engineer did some of his own drafting work (X9). Only the variables X2, X8, and X1 demonstrated any real consistency and explanatory power. The other two variables (X7 and X9) demonstrated only marginal consistency and normally very low explanatory power (less than 2 percent). The remaining variables used in the analysis displayed no consistency and negligible explanatory power.

The explanatory power of variables X2 and X8 were as expected. In most instances, having more than one engineer working on a project will require more additional total manhours than if only one engineer did all the work. The complexity describes the relative difficulty of the job and, hence, should explain increases/decreases in required manhours as the difficulty of the project increases/decreases, respectively. The project cost, which in many respects describes the general size/scope of the project, did not illustrate as much explanatory power as was originally thought. Even stratification of the data into specified cost ranges did not appreciably affect the original MLR results.

The two variables which depicted the on base and total experience level of the engineers, X3 and X4, respectively, provided neither explanatory power nor consistency. This result is contradictory to the feelings of the Chiefs of Design at the bases surveyed. The majority said that the experience of the engineer was one of the main factors considered when estimating the total design manhours required for a given project. The results of this regression analysis show no relationship to exist.

The type of project funds variable, X7, was the largest contributing nominal (category) variable, but its contribution was too small and inconsistent to be an effective predictor.

Simple linear regression (SLR) was used to analyze what, if any, relationships exist between project design manhours and any one of the following variables: X1, X2, X3, X4, and X8. Analysis was made to determine if the relationships existed and, if so, whether they were linear, curvilinear, quadratic, exponential, etc. The scattergram plots of the different correlations displayed no apparent relationships other than a relatively weak linear relationship.

The following subsections will be used to present the results of the specific approaches accomplished to analyze the data using the MLR technique. See Appendix D-4 for a summary of the results for the different study approaches.

Masterfile. All 553 projects provided by thirty-four different bases were analyzed as a whole; the results were considered as the foundation from which other analysis approaches were made and with which their results compared. Three variables, X2, X1, and X8, with respective contributions of .258, .098, and .045 produced a total R^2 value of .401. This value for R^2 does not meet the commonly accepted statistical requirement for a nominal R^2 value of .80 before the model can be considered an accurate predictor. Therefore this model does not possess the necessary qualities to be used as an acceptable predictor for estimating project design manhours.

Representative Data File. Several of the projects contained very high manhours-low cost or very low cost-high manhour relationships. These projects were considered atypical occurrences and, therefore, were removed from the masterfile. A total of forty-eight projects were eliminated and the MLR analysis was conducted on the remaining 505 projects. As would be expected, the project cost variable, X1, had the largest contributory power of .241 with variables X8 and X2 having contributions of .146 and .060, respectively. These three variables produced a total R^2 value of .447, an improvement in R^2 of .046 over the original masterfile.

Type of Work. It was felt that the type of work (minor construction, repair, and maintenance) might have some bearing on the required number of design manhours. The masterfile was broken down into three separate files, one file for each type of work. Of the total projects, 229 were minor construction, 229 were repair, and 95 were maintenance type work. The MLR analysis provided improved results for the minor construction file but poor results for the repair and maintenance files. Four variables had acceptable contribution levels. X1 and X2 had the most significant contributions with ΔR^2 values of .290 and .124 while X8 and DV7 had lesser contributions of .035 and .018, respectively. The total R^2 value for these four variables was .467. The total R^2 values utilizing the significant contributory variables for the repair and maintenance files were .348 and .335, respectively.

Stratified by Project Cost. The masterfile data was stratified into the following files with price ranges of: less than $10,000, between $10,000 and $100,000, between $100,000 and $200,000, and greater than $200,000. This stratification was accomplished in the belief that project design manhours and project cost would not exhibit the same linear relationship for the $5,000 project as the $250,000 project. This belief was partially validated by the results of the MLR analysis on these stratified files. Variables X2, X8, and X1 played the dominant role in these results with the type of project funds (DV5, DV6, and DV7) and the engineer drafting (DV8) contributing appreciable amounts for one or more of the MLR runs. The "less than $10,000" file produced poor results (R^2 value of .125); the "between $10,000 and $100,000" file produced results that were comparable to the original masterfile results (R^2 value of .377); the "between $100,000 and $200,000" file produced considerably improved results (R^2 value of .607); and the "greater than $200,000" file produced results noticeably better results than the masterfile results (R^2 value of .474). A further breakdown of the "between $100,000 and $200,000" file into two $50,000 blocks produced even better results than the parent file. The "between $100,000 and $150,000" file produced an R^2 value of .628 and the "between \$150,000 and \$200,000" file yielded an R^2 value of .783. Likewise, a further breakdown of the "greater than \$200,000" file produced better results than the parent file. The "between \$200,000 and \$400,000" file had an R^2 value of .657 and the "greater than \$400,000" file had an R^2 value of .996. The stratification of projects with regard to cost did improve results, however, the required consistency still cannot be provided.

One Discipline Projects. Early MLR results illustrated that the experience of the engineers, both on-base experience (X3) and total experience (X4), did not have any appreciable explanatory power. Approximately 35 percent of the projects involved the use of two or more engineers. It was felt that the multiple-discipline projects did not allow for the direct influence of each engineer on the total design manhours required. Therefore all multidiscipline projects were removed, leaving only single discipline-projects where an individual engineer had sole responsibility for the number of manhours used to design the project. The results of the MLR analysis provided a low R^2 value of .298 with neither X3 or X4 variables having adequate explanatory power to be considered for inclusion into the prediction equation.

These results, along with the masterfile results, indicate that the experience of the engineer, on-base as well as total experience, have very minimal effect on the number of design manhours required.

EDR Projects Removed. Approximately 29 percent of the projects (162 out of 553) involved engineers who performed some of their own drafting work. Analysis was performed on another file containing only those projects where the engineer did not perform any of his own drafting work. This allowed concentration on those projects where actual engineering time was expended on the project. The results of this analysis produced a relatively low R^2 value of .364, which was lower than the R^2 value for the masterfile. The removal of those projects which involved drafting time did not improve the explanatory power of the equation.

Each Individual Base. MLR analysis was conducted on each of the thirty-four bases to see what relationships between the dependent variable and the independent variables exist, if any. No statistical conclusions could be drawn from each of these individual runs due to the small sample size (approximately fifteen projects per base). Variables X2, X8, and X1 showed up consistently as the largest contributors while peculiar circumstances at the different bases allowed almost all of the other variables to demonstrate appreciable explanatory power for one or more different bases. Very surprisingly and unexplainably, thirty-one of the bases had R^2 values greater than .70, twenty-nine bases were greater than .80, and twenty-one bases were greater than .90. This is very perplexing in light of the fact that, when combined into the masterfile, the R^2 value is only .414.

Selected Bases Removed. ANOVA was used to identify bases which, for a given variable, were not comparable with each other (this does not imply that the bases as a whole were not comparable). Nine bases and eighteen bases were eliminated under two different sets of subjective criteria which produced a 25-base data file and a 16-base data file. The MLR results show that X2, X1, and X8 have the largest contribution. The 16-base file produced a R^2 value of .500 which is an improvement over the masterfile results of .414. This is logical since the bases that exhibited some degree of difference from the other bases were removed, hence the resulting file should be more homogeneous. The results of the 25-base file yielded a R^2 value of .385 which is lower than that obtained for the masterfile. This result contradicts the reasoning for the improved results from the 16-base file.

One possible explanation is that the individual projects produced favorable MLR results but the means of the variables for each project from a given base were not favorable with regard to the other bases.

CHAPTER IV

CONCLUSIONS

This chapter is organized into two sections. The first section addresses the research questions and the general hypothesis set forth in Chapter I. The second section discusses general conclusions drawn from the overall research.

Research Questions Answered

1. *What are the variables which directly affect the project design times?*

While each of the Chiefs of Design considered many variables in estimating project design times, they identified the three most used variables as complexity of the project, total estimated cost of the project, and experience of the engineer.

The results of the MLR analysis show that the number of disciplines, perceived complexity, and estimated project cost were the design variables having the greatest effect on the project design manhours. The predominant variables differed slightly from one analysis approach to another, but these three variables consistently had the largest effect on the estimated project design manhours. The notable exception to the most used factors provided by the Chiefs of Design was the experience of the engineer. Neither base experience nor total experience demonstrated any appreciable influence on the estimated project design manhours. This indicates that the experience of the engineer may not be a good factor to consider for two possible reasons: (1) experience does not relate directly to manhours required for design but rather to the technical capability to design the project and (2) the more experienced engineer is assigned the more difficult or complex projects and, hence, the project takes longer to design.

2. *What is the relationship between design time and the variables?*

A consistent relationship between the design variables, number of disciplines, perceived complexity, and estimated project cost, does exist. However, this combination of variables, when introduced in MLR analysis, is only able to explain approximately 40 to 50 percent of the total variation between the estimated values of project design manhours and the actual values of project design manhours. Therefore, only a relatively weak linear relationship exists between the selected design variables and project design manhours.

3. *What accuracy of estimated project design time should be achieved? What accuracy is currently being achieved?*

Based on the responses of the Chiefs of Design as well as discussions with other experienced civil engineering managers (8; 9; 15), we concluded that any project time estimating techniques should be able to predict actual project design time with an accuracy of ±15 percent. From the stated accuracies, we were unable to conclude what accuracy is currently being achieved. First, over half of the bases responding to the survey did not directly record their estimating accuracy. While 86 percent of the responding bases stated a desirable estimating accuracy within 20 percent, 51 percent of the bases do not directly record their accuracies. It is impossible to assess your progress toward a goal if actual performance is not recorded. Second, of the bases which stated that they were achieving a certain accuracy, our computations revealed that in 9 of the 15 cases, the stated accuracy was different from that actually being achieved. In eight of the nine inaccurate estimates, the actual accuracy computed from project data was worse than the stated accuracy. We concluded that bases are actually estimating more poorly than they realize. However, computation of accuracies achieved on the projects included on the survey indicated that most bases were achieving between 20 and 40 percent accuracy.

General Hypothesis Evaluated

The relationships between design time and design variables will allow the Chief of Design to estimate the required design time accurately and reliably.

The results of the MLR analysis indicate that a sufficiently strong linear relationship does not exist between design time and the design variables to produce a model that would be acceptable for prediction. As a result, the objective to test the model's accuracy and reliability was no longer appropriate and, therefore, was not accomplished.

General Conclusions

Several general conclusions became evident during our analysis. These conclusions were made from analysis of ANOVA results, MLR results, and descriptive statistics.

The results of the Oneway Analysis of Variance showed that the only design variable, estimated project cost, could be considered as comparable between bases at the 95 percent confidence level. Design manhours was shown as comparable for all bases except one. The other design variables (number of disciplines, base experience of the engineer, total experience of the engineer, and perceived complexity) demonstrated less comparability, with the base and total experience variables showing very little comparability between the bases. The ANOVA program is unable to collapse the six variables and consider them simultaneously to determine if the bases themselves are comparable. Therefore, judgment as to the statistical comparability of bases can be made only with regard to a single design variable, but not to the comparability of the bases themselves. The results verified the contention that the experience levels of the engineers in the design sections do vary from base to base. No other conclusions can be made with the necessary degree of certainty.

MLR analysis on the masterfile (containing data from all thirty-four bases) and on each individual base produced an unexpected outcome. Individually the bases' results were very good (twenty-nine out of thirty-four bases had a R^2 value in excess of .80), while the results from the masterfile demonstrated a relatively weak relationship with a R^2 value of .414. It appears that the bases are statistically antagonistic toward each other when the data is combined. One explainable reason is that the predominant variables differ quite a lot from base to base and, when combined, apparently conflict with each other. The shifting of the predominant variables from base to base indicate that unique circumstances may exist at each base. An Air Force wide program to standardize design manhour estimating procedures could present serious problems. The apparent variability between bases prohibits a set of all-encompassing rules applicable to all bases. Only general guidelines may be acceptable. This would allow each base to tailor the estimating procedures to the particular circumstances that are pertinent to that base.

Using descriptive statistics, there was no difference in factors (variables) considered and the estimating accuracy between the different MAJCOMs. There was a little difference in the factors considered by chiefs making accurate estimates versus those making inaccurate estimates; by experienced versus inexperienced chiefs; or by military versus civilian chiefs. As might be expected, the more experience that a chief has, the more accurately he estimated project design times. An implication for the assignment of Chiefs of Design is that experience should be a consideration. Implications for an overall design management improvement program are that we must know what we are doing and how well we are doing before we can improve the management of our engineering resources and increase productivity. Currently, we do not really know what our design management performance is. Perhaps more importantly, we think we are estimating more accurately than we actually are.

In summary, if management of design resources is really as important as we think it is, then:

1. We need to identify it as a performance criteria to be measured.

2. We need to establish a satisfactory level to shoot for as a management goal.

3. We need a convenient feedback mechanism (a management information system) to provide appropriate information which will allow us to determine where we stand relative to our management goal.

CHAPTER V

RECOMMENDATIONS

This chapter is divided into two sections. The first section presents recommendations for future research efforts and the second section presents some general recommendations derived from this research effort.

Recommendations for Future Research

1. Current Air Force interest and this research have focused on design management which may require approximately 40 percent of the engineer's time. What is the engineer doing with the other 60 percent of his time? As efficient management of the engineer is based on his total time, we recommend that further study be conducted to identify those activities which comprise the other 60 percent of the engineer's time. One potential benefit of a study of this nature would be to reallocate the engineer's time to allow more time to be expended on direct design effort. As a minimum, the study will identify the pertinent activities of the engineer more precisely and allow for more efficient management of his time.

2. We recommend that a further study be made with emphasis on gathering more data from each base in order

to develop estimating models for each individual base as opposed to one model Air Force wide. The results of this research effort indicate that particular/special circumstances exist at each individual base which may make it impractical to develop an Air Force model, but which may allow each base to develop its own accurate predictive model.

3. We recommend that further research be conducted into the design estimating methods of Architect-Engineer firms/other government agencies to provide additional insight into design estimating procedures.

General Recommendations

1. We recommend that a more comprehensive data base be created to allow for future research into design management. The current data base is sufficient to identify potential relationships between the design man-hours and the design variables, but a larger data base is required to validate these relationships or discover other relationships. The large number of possible combinations of the ten design variables for each project makes a larger data base (approximately 2000-3000 projects) necessary to determine, with more certainty, what these relationships actually are.

2. We recommend that the current Base Engineer Automated Management System (BEAMS) be used to track

manhours, to monitor and manage the time of the engineer, and to help evaluate the performance of the individual engineers. Closer monitoring of project design time is a prerequisite for improved management of Civil Engineering's design resources.

3. Currently there is neither an Air Force program which disseminates information on the various estimating methods or other design management procedures nor provides any general guidelines, targets, or goals to establish general parameters within which the bases should be operating. The following three part program is recommended:

a. Include a discussion of the various estimating techniques in a brochure which Air Force is currently developing. This will make the Chiefs of Design aware of different techniques and allow them to select which method works best for their base.

b. Establish general design guidelines for the bases to operate within. Care must be exercised to ensure sufficient latitude in the guidelines to allow the bases to compensate for particular/special situations that may exist at each individual base.

c. Expand the use of the continuing education classes at the Civil Engineering School at Wright-Patterson AFB, Ohio, to present various estimating techniques in use, as well as the findings of any past research efforts which may provide the Chief of Design with new insights into design management.

APPENDIXES

APPENDIX A

PROJECT DATA MASTER FILE

The following headings identify each column of the Project Data Master File:

Line Number	10
Actual Design Manhours (Y)	60
Estimated Project Cost (X1)	48.0
Number of Disciplines (X2)	1
Years of Base Experience (X3)	1
Years of Total Experience (X4)	1
Type of Work (X5)	'R'
Modularity (X6)	'L'
Type of Project Funds (X7)	'H'
Complexity (X8)	3
Engineer Did His Drafting (X9)	'N'
Similar Project Done Previously (X10)	'N'
Numerical Designator of the Base (X11)	1

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LIST 0010,0460
  10   60   48.0  1  1  1  'R'  'L'  'H'  3  'N'  'N'  1
  20   74  280.0  1 12 16  'R'  'M'  'F'  4  'N'  'Y'  1
  30   60  130.4  1 12 16  'R'  'M'  'O'  3  'N'  'Y'  1
  40  180  146.4  4 12 16  'R'  'L'  'O'  5  'N'  'N'  1
  50   80  109.4  1  8  8  'R'  'M'  'O'  3  'N'  'Y'  1
  60   97  154.0  1  8  8  'R'  'M'  'O'  3  'N'  'Y'  1
  70   20   26.4  1 18  8  'M'  'M'  'F'  2  'N'  'Y'  1
  80   40   34.2  1 18  8  'M'  'M'  'F'  2  'N'  'Y'  1
  90   81   24.0  1  2  6  'R'  'M'  'H'  3  'N'  'N'  1
 100   45   20.3  3  8  8  'C'  'M'  'N'  3  'N'  'Y'  1
 110   80   35.0  1  1  1  'R'  'M'  'O'  3  'N'  'Y'  1
 120   30   96.0  1 12 16  'R'  'M'  'O'  3  'N'  'Y'  1
 130  124   20.1  1  2  6  'C'  'M'  'N'  3  'N'  'N'  1
 140  175   69.8  4 12 16  'R'  'L'  'H'  4  'N'  'N'  1
 150   40   27.0  2  8  8  'R'  'M'  'O'  3  'N'  'N'  1
 160   76   25.0  1  1  1  'C'  'L'  'O'  3  'N'  'N'  2
 170  117   72.0  2  3  6  'C'  'L'  'H'  5  'N'  'N'  2
 180   34  738.0  1  1  1  'R'  'H'  'O'  2  'N'  'Y'  2
 190  124   51.0  2 16 51  'R'  'L'  'O'  3  'N'  'N'  2
 200   88   49.7  1  4  4  'C'  'H'  'F'  3  'N'  'N'  2
 210   52    4.3  1  4  4  'R'  'L'  'O'  1  'N'  'Y'  2
 220   87    9.9  1  4  4  'C'  'L'  'O'  4  'N'  'N'  2
 230   98    8.0  1 16 51  'C'  'L'  'H'  2  'N'  'N'  2
 240   77    3.0  1  4  4  'C'  'L'  'H'  2  'N'  'N'  2
 250  124   79.5  2  3  6  'C'  'L'  'H'  5  'N'  'N'  2
 260   72   92.7  1  3  6  'C'  'L'  'H'  2  'N'  'Y'  2
 270   35  168.2  1  3  6  'C'  'H'  'F'  2  'N'  'N'  2
 280   52   22.5  1  3  6  'C'  'L'  'O'  2  'N'  'N'  2
 290    5   50.1  1  1  1  'M'  'H'  'O'  1  'N'  'Y'  2
 300   22   35.2  1  1  1  'M'  'H'  'O'  1  'N'  'Y'  2
 310   56   86.1  1 21 39  'R'  'M'  'O'  2  'Y'  'Y'  3
 320  135   68.7  1  2 17  'C'  'L'  'O'  3  'N'  'N'  3
 330  192  123.4  1 10 22  'R'  'M'  'F'  3  'Y'  'Y'  3
 340   48   50.0  1 21 39  'M'  'L'  'O'  2  'Y'  'Y'  3
 350  146  197.4  1  2 17  'M'  'L'  'O'  3  'N'  'Y'  3
 360   16    8.0  1 10 22  'R'  'L'  'O'  2  'Y'  'N'  3
 370   38   19.2  1 10 11  'R'  'L'  'O'  3  'N'  'N'  3
 380  115   51.5  2 10 11  'C'  'M'  'O'  3  'N'  'N'  3
 390   78   66.4  1  2 11  'C'  'M'  'O'  3  'Y'  'N'  3
 400  210   71.5  4 21 39  'C'  'L'  'O'  4  'N'  'N'  3
 410  115   50.1  1  2 11  'C'  'L'  'H'  3  'Y'  'N'  3
 420   58   10.0  1 10 11  'C'  'L'  'H'  3  'N'  'N'  3
 430  196  199.0  1 21 39  'R'  'M'  'F'  4  'Y'  'N'  3
 440   46   13.1  1 21 39  'R'  'M'  'F'  2  'Y'  'Y'  3
 450   91  158.7  2 10 11  'R'  'H'  'F'  3  'N'  'N'  3
 460  155  193.0  1  2 17  'R'  'L'  'F'  4  'N'  'N'  3

ready
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LIST 0470,0920

470  291  308.8  4  10  22  'C'  'L'  'H'  5  'N'  'N'  3
480   18  128.8  1   1   3  'M'  'H'  'O'  3  'N'  'Y'  4
490   64   40.0  2   3   3  'R'  'L'  'O'  4  'N'  'N'  4
500  200   38.0  2  23  23  'C'  'L'  'H'  4  'N'  'N'  4
510   86   51.6  3  23  23  'C'  'M'  'O'  3  'N'  'Y'  4
520  100  113.9  1  10  13  'R'  'M'  'O'  4  'N'  'N'  4
530   51  154.6  2  10  13  'R'  'H'  'O'  3  'N'  'Y'  4
540   42   76.3  1  23  23  'C'  'H'  'F'  2  'N'  'N'  4
550   21  123.0  1  10  13  'C'  'H'  'O'  2  'N'  'Y'  4
560  140  160.0  1   2   9  'R'  'L'  'O'  3  'N'  'N'  4
570   28   50.0  1  10  13  'R'  'H'  'O'  2  'N'  'Y'  4
580   25   82.0  1   1   3  'R'  'L'  'O'  3  'N'  'Y'  4
590   41   53.0  1  23  23  'R'  'H'  'F'  2  'N'  'N'  4
600  192   64.0  3  23  23  'C'  'M'  'O'  3  'N'  'N'  4
610  270   68.0  1   2  26  'C'  'L'  'O'  5  'N'  'N'  4
620  103   10.5  3  23  23  'C'  'L'  'O'  5  'N'  'N'  4
630   91  114.9  1  11  40  'M'  'M'  'O'  4  'Y'  'Y'  5
640   46   23.8  1  11  40  'M'  'H'  'O'  2  'N'  'Y'  5
650  167   93.7  1  11  40  'M'  'M'  'O'  4  'N'  'N'  5
660  114   41.0  1  11  40  'R'  'M'  'O'  3  'N'  'Y'  5
670   67   32.4  1  11  40  'R'  'L'  'O'  3  'N'  'Y'  5
680  149   44.9  2  21  30  'C'  'L'  'O'  5  'N'  'N'  5
690  228   35.2  2  21  30  'C'  'L'  'O'  4  'N'  'N'  5
700   68   19.9  1  20  27  'R'  'M'  'F'  3  'N'  'N'  5
710   67   10.7  1  21  30  'C'  'L'  'O'  4  'N'  'N'  5
720  107   45.2  1  11  40  'R'  'M'  'H'  4  'N'  'Y'  5
730   89    9.4  3  21  30  'C'  'L'  'H'  3  'N'  'N'  5
740  512   35.0  3  21  30  'C'  'L'  'N'  5  'N'  'N'  5
750  189   71.4  2  21  30  'C'  'L'  'N'  5  'N'  'N'  5
760  106  912.0  1  21  30  'R'  'H'  'F'  4  'N'  'N'  5
770  125  213.9  1  21  30  'C'  'H'  'F'  4  'N'  'Y'  5
780   98  187.0  1   3   3  'M'  'H'  'F'  2  'Y'  'N'  6
790  645  174.0  4   5  10  'C'  'L'  'H'  5  'Y'  'N'  6
800  200   26.0  3   7  15  'R'  'L'  'O'  4  'Y'  'N'  6
810  220   22.0  3   7  15  'C'  'L'  'H'  5  'Y'  'N'  6
820   90   80.0  1   3   3  'M'  'L'  'O'  2  'Y'  'N'  6
830  425   62.9  4   5  10  'C'  'L'  'O'  4  'Y'  'N'  6
840  485   74.5  4   5  10  'C'  'L'  'O'  3  'Y'  'N'  6
850   60   18.0  2   7  10  'R'  'L'  'O'  3  'Y'  'N'  6
860   85   16.5  1   3   3  'M'  'L'  'H'  2  'Y'  'N'  6
870  510  395.0  4   5  10  'C'  'L'  'H'  5  'Y'  'N'  6
880   65   53.5  1  16  25  'M'  'L'  'F'  3  'N'  'N'  6
890  430  300.0  4   5  10  'C'  'L'  'H'  5  'T'  'N'  6
900  400   74.0  4   5  10  'C'  'L'  'O'  4  'Y'  'N'  6
910   80   37.0  1   1   1  'R'  'M'  'F'  3  'N'  'Y'  6
920  180  129.0  2   3   3  'R'  'L'  'O'  4  'N'  'Y'  6

ready
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LIST 0930,1380

 930  196   70.0  2 15 23  'C'  'L'  'N'  3  'Y'  'N'  6
 940  160    6.0  1  2  6  'R'  'L'  'O'  5  'N'  'N'  7
 950   16   10.0  1  2  2  'R'  'L'  'O'  4  'N'  'N'  7
 960   72   10.0  1  2  2  'R'  'L'  'F'  4  'N'  'N'  7
 970  132   40.0  1  2  2  'R'  'M'  'F'  2  'N'  'Y'  7
 980   96   21.0  1  2  6  'R'  'L'  'O'  4  'N'  'N'  7
 990  240  140.0  1  8 28  'C'  'M'  'O'  3  'N'  'Y'  7
1000  260   79.5  1  1  1  'M'  'M'  'O'  4  'N'  'N'  7
1010  144   39.4  1  8 28  'C'  'L'  'H'  3  'N'  'N'  7
1020   72   45.3  1  2  6  'R'  'M'  'O'  1  'N'  'Y'  7
1030  136    6.9  1  8 28  'C'  'L'  'O'  3  'N'  'N'  7
1040  104    3.0  1  2  2  'M'  'L'  'O'  2  'N'  'N'  7
1050  320    5.2  1  8 28  'R'  'L'  'O'  4  'N'  'N'  7
1060  200   10.0  1  2  2  'C'  'M'  'O'  4  'N'  'N'  7
1070   56   35.0  1  1  1  'R'  'H'  'F'  1  'N'  'Y'  7
1080   32    9.6  1  1  1  'M'  'L'  'F'  3  'N'  'N'  7
1090   16    8.0  1  1  1  'R'  'L'  'O'  2  'N'  'Y'  7
1100  104   20.0  1  1  1  'M'  'M'  'O'  2  'N'  'Y'  7
1110   64  150.0  1  1  1  'M'  'H'  'F'  1  'N'  'Y'  7
1120  160   14.7  1  1  1  'M'  'H'  'F'  2  'N'  'N'  7
1130  101  140.0  2 10 20  'C'  'L'  'H'  4  'N'  'N'  8
1140  125   67.0  3 13 20  'C'  'M'  'H'  3  'Y'  'N'  8
1150   78   10.0  1 20 30  'C'  'M'  'O'  3  'N'  'Y'  8
1160   32   30.0  1 20 30  'R'  'L'  'O'  3  'N'  'Y'  8
1170   35    9.0  1 10 20  'R'  'L'  'H'  2  'N'  'Y'  8
1180   38   50.0  1  1  1  'R'  'H'  'F'  1  'N'  'Y'  8
1190   84  156.0  1 20 30  'R'  'M'  'O'  3  'N'  'Y'  8
1200   40    5.0  1  1  1  'R'  'L'  'F'  2  'Y'  'N'  8
1210  110   20.0  1  1  1  'R'  'L'  'O'  3  'N'  'N'  8
1220  130   23.0  1  1  2  'R'  'L'  'O'  4  'N'  'N'  8
1230  180   28.0  3 10 20  'C'  'M'  'O'  4  'Y'  'Y'  8
1240  225  225.0  3 13 20  'R'  'M'  'O'  4  'Y'  'N'  8
1250  170   44.0  3 13 20  'C'  'L'  'O'  3  'Y'  'N'  8
1260   45   73.0  1 20 30  'C'  'H'  'O'  2  'N'  'Y'  8
1270  195   75.0  2 13 20  'C'  'L'  'N'  4  'Y'  'N'  8
1280  650  194.7  3 11 20  'C'  'L'  'N'  5  'Y'  'N'  9
1290   49   10.5  1  1  1  'C'  'H'  'F'  2  'N'  'N'  9
1300 1337  187.0  3  4  6  'C'  'M'  'H'  5  'Y'  'N'  9
1310   95  103.3  2  2  2  'M'  'L'  'O'  2  'N'  'Y'  9
1320  187   22.0  2  2  2  'R'  'L'  'N'  3  'N'  'N'  9
1330  150   23.7  2 11 20  'C'  'M'  'O'  3  'N'  'N'  9
1340  126   43.1  2  1  1  'C'  'L'  'H'  3  'N'  'N'  9
1350  344   50.0  1  2  2  'M'  'L'  'H'  4  'Y'  'N'  9
1360  170  271.9  1  1  2  'M'  'H'  'F'  3  'N'  'Y'  9
1370   56  150.7  2  2  2  'M'  'H'  'F'  2  'N'  'Y'  9
1380  177  260.1  2  2  2  'R'  'H'  'F'  3  'N'  'Y'  9

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LIST 1390,1840

1390  132   18.4  3   4   6  'C'  'L'  'N'  3  'N'  'N'   9
1400   27   10.5  1   1   1  'R'  'M'  'N'  2  'N'  'N'   9
1410   17  149.3  1   2   2  'C'  'M'  'H'  3  'N'  'Y'   9
1420  114    9.3  1   3   3  'C'  'L'  'O'  2  'N'  'N'   9
1430   85  108.2  1  14  28  'M'  'H'  'F'  2  'N'  'N'  10
1440   64   76.0  2   3   4  'R'  'M'  'F'  3  'N'  'Y'  10
1450   36   40.0  1   3   4  'M'  'H'  'F'  2  'N'  'Y'  10
1460  100   28.9  1  14  28  'C'  'M'  'O'  3  'N'  'N'  10
1470   80  319.4  1  12  15  'R'  'L'  'O'  3  'N'  'Y'  10
1480   60   62.1  1  12  15  'M'  'M'  'O'  2  'N'  'Y'  10
1490   55   98.0  2  14  28  'C'  'M'  'O'  3  'N'  'N'  10
1500   22   39.0  1   3   4  'M'  'H'  'F'  1  'N'  'Y'  10
1510  113   48.7  2   3   4  'C'  'M'  'O'  3  'N'  'N'  10
1520   40   34.9  1   4   9  'R'  'M'  'O'  3  'N'  'Y'  10
1530   50   25.0  1  12  15  'M'  'M'  'F'  2  'N'  'Y'  10
1540   62  130.5  1   4   9  'C'  'H'  'F'  2  'N'  'N'  10
1550   44  103.0  2   4   9  'R'  'H'  'F'  3  'N'  'Y'  10
1560   24   66.9  1   3   4  'R'  'H'  'F'  2  'N'  'Y'  10
1570   50   20.4  1   1   1  'M'  'H'  'F'  2  'N'  'Y'  10
1580  190  150.0  1   2   2  'R'  'M'  'O'  2  'N'  'Y'  11
1590  200   30.0  1   1   1  'R'  'L'  'O'  3  'N'  'N'  11
1600  120   50.0  1   0   3  'R'  'L'  'O'  2  'N'  'N'  11
1610  220  150.0  1   1   1  'R'  'L'  'F'  1  'N'  'N'  11
1620  160   70.0  1   2   2  'C'  'M'  'O'  2  'N'  'Y'  11
1630  100   65.0  1   0  12  'M'  'M'  'O'  2  'N'  'N'  11
1640  260  433.0  1   2   2  'R'  'M'  'O'  3  'N'  'Y'  11
1650  240   59.0  3   1  21  'C'  'L'  'O'  4  'N'  'N'  11
1660   60   81.0  1   0   3  'C'  'L'  'O'  5  'N'  'N'  11
1670  240  233.8  1   0  12  'M'  'M'  'O'  3  'N'  'Y'  11
1680  280  380.0  1   1  21  'R'  'M'  'O'  2  'N'  'Y'  11
1690   40    3.3  1   2   2  'M'  'M'  'O'  1  'N'  'Y'  11
1700  220    5.9  1   1   8  'C'  'L'  'H'  4  'N'  'N'  11
1710  180  197.0  1   0  12  'R'  'M'  'O'  3  'N'  'N'  11
1720  156  198.0  1   4   4  'R'  'H'  'F'  3  'Y'  'N'  12
1730  490   43.0  3   4   4  'C'  'M'  'N'  3  'Y'  'N'  12
1740   36    7.6  1   2   2  'C'  'L'  'O'  4  'N'  'N'  12
1750  166   55.6  4   4   4  'R'  'H'  'F'  2  'Y'  'N'  12
1760  231   56.5  1  19  23  'R'  'L'  'O'  4  'N'  'N'  12
1770   88  122.0  1   2   2  'R'  'L'  'O'  2  'N'  'N'  12
1780   25   16.8  1   2   2  'R'  'M'  'F'  2  'N'  'N'  12
1790  197    5.0  1  10  10  'C'  'L'  'O'  1  'N'  'N'  12
1800 2015  350.7  7  19  23  'C'  'L'  'H'  4  'Y'  'N'  12
1810   56  143.1  1   2   2  'R'  'L'  'F'  1  'N'  'N'  12
1820  254   56.7  1  10  10  'R'  'L'  'N'  3  'N'  'N'  12
1830  125   88.0  1   3   3  'R'  'L'  'F'  3  'N'  'N'  12
1840  433   54.8  4  19  23  'R'  'M'  'O'  3  'N'  'N'  12

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LIST 1850,2300

1850  138    2.5  1  10  10  'C'  'L'  'O'  3  'N'  'N'  12
1860   38  198.0  1   4   4  'R'  'H'  'F'  3  'N'  'Y'  12
1870   75   99.5  1   2   7  'M'  'M'  'H'  2  'N'  'Y'  13
1880   16   43.6  1  15  22  'R'  'L'  'O'  2  'N'  'N'  13
1890  194  299.7  2  17  32  'R'  'H'  'F'  1  'N'  'N'  13
1900   70  100.0  1   1   1  'C'  'H'  'F'  1  'N'  'N'  13
1910   83   20.0  1  15  22  'C'  'L'  'O'  3  'N'  'N'  13
1920   13  160.6  1   3   3  'R'  'L'  'O'  2  'N'  'Y'  13
1930  220  136.0  1  10  20  'M'  'M'  'O'  2  'Y'  'Y'  14
1940   30   40.0  1  10  20  'M'  'H'  'F'  1  'N'  'Y'  14
1950  120  269.0  1  11  15  'M'  'M'  'O'  2  'N'  'N'  14
1960  250   82.0  1  10  20  'M'  'M'  'O'  3  'Y'  'Y'  14
1970   30   10.0  1  10  20  'M'  'L'  'N'  3  'N'  'N'  14
1980   20    7.0  1  10  20  'R'  'L'  'H'  3  'N'  'N'  14
1990   24   40.0  1   3  21  'R'  'H'  'F'  3  'N'  'N'  14
2000  250  999.9  1  11  15  'R'  'M'  'O'  3  'N'  'N'  14
2010  300   83.0  2  10  27  'R'  'L'  'O'  5  'N'  'N'  14
2020   60   62.0  1  10  27  'R'  'M'  'H'  4  'N'  'N'  14
2030   85   15.0  3  25  30  'C'  'L'  'H'  4  'N'  'N'  14
2040  380   85.0  3  25  30  'C'  'L'  'N'  4  'Y'  'N'  14
2050  300   40.0  3  25  30  'C'  'L'  'H'  5  'Y'  'N'  14
2060  290   75.0  3  25  30  'C'  'L'  'O'  5  'N'  'N'  14
2070  230   75.0  3  25  30  'C'  'L'  'O'  4  'Y'  'N'  14
2080  732  233.6  3   3   3  'C'  'L'  'H'  5  'N'  'N'  15
2090  176   50.0  1   1   6  'R'  'L'  'O'  4  'N'  'N'  15
2100   50  116.3  1   3   3  'R'  'H'  'F'  2  'N'  'Y'  15
2110  166  195.0  2   4  10  'M'  'H'  'F'  4  'N'  'N'  15
2120   12   29.4  1   1   1  'M'  'H'  'F'  2  'N'  'Y'  15
2130   12   15.3  1   1   5  'M'  'M'  'O'  3  'N'  'Y'  15
2140   52   71.2  2   4  10  'C'  'L'  'O'  4  'N'  'N'  15
2150   81  270.0  1   4  10  'R'  'L'  'H'  5  'N'  'N'  15
2160   31   33.7  1   1   5  'C'  'L'  'N'  3  'N'  'N'  15
2170  129   36.8  1   1   5  'C'  'L'  'N'  3  'N'  'N'  15
2180   40   43.6  1   1   5  'M'  'L'  'O'  4  'N'  'N'  15
2190   25   22.1  1   1   5  'R'  'M'  'O'  4  'N'  'Y'  15
2200   58   10.0  1   1   1  'C'  'L'  'O'  3  'N'  'N'  15
2210   72   26.0  2   1   6  'C'  'L'  'O'  5  'N'  'N'  15
2220   60  138.2  2   1   6  'R'  'M'  'F'  4  'N'  'Y'  15
2230  164  296.9  1  10  18  'M'  'H'  'O'  1  'N'  'Y'  16
2240   87  307.0  1   7   7  'M'  'M'  'O'  3  'N'  'Y'  16
2250  118  194.6  1   7   7  'M'  'M'  'O'  3  'N'  'Y'  16
2260  325   60.1  2   9  30  'C'  'L'  'O'  4  'N'  'N'  16
2270   29   10.0  1  10  18  'M'  'L'  'H'  1  'N'  'Y'  16
2280  268   32.7  3   9  30  'C'  'L'  'O'  4  'N'  'N'  16
2290  264   50.1  3   9  30  'R'  'L'  'O'  4  'N'  'N'  16
2300  216   15.0  1   9  30  'R'  'H'  'O'  2  'N'  'N'  16

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LIST 2310,2760

2310  844  106.3  3   9  30  'C'  'L'  'N'  5  'N'  'N'  16
2320   95   30.0  2   9  30  'C'  'L'  'H'  2  'N'  'N'  16
2330   38   30.3  1  10  18  'M'  'H'  'F'  1  'N'  'Y'  16
2340   55  112.0  1   7   7  'C'  'H'  'F'  2  'N'  'N'  16
2350   70  238.7  1  10  18  'R'  'H'  'F'  1  'N'  'Y'  16
2360  175   80.9  1   2  19  'R'  'H'  'F'  3  'N'  'N'  16
2370   24  292.6  1   2  19  'R'  'H'  'F'  3  'N'  'Y'  16
2380   44   45.0  1   5   8  'M'  'H'  'F'  1  'Y'  'N'  17
2390   30   45.0  1   4  18  'R'  'L'  'O'  2  'Y'  'Y'  17
2400   51    4.0  1   2  10  'C'  'L'  'F'  3  'Y'  'N'  17
2410   90   58.3  2   3  17  'R'  'L'  'O'  3  'N'  'N'  17
2420   49   10.0  1   6  30  'M'  'L'  'O'  2  'Y'  'Y'  17
2430  203   55.1  1   2  10  'C'  'L'  'O'  4  'Y'  'N'  17
2440  596   83.9  3   9  28  'C'  'L'  'N'  5  'Y'  'N'  17
2450   42   42.9  1   1  29  'R'  'M'  'O'  1  'N'  'N'  17
2460  151   18.6  2   5  18  'C'  'L'  'H'  4  'N'  'N'  17
2470  311  150.3  1   4  18  'R'  'L'  'O'  3  'Y'  'Y'  17
2480   52   14.0  1   2  10  'R'  'L'  'O'  3  'Y'  'N'  17
2490   10    5.5  1   3  17  'R'  'L'  'H'  2  'N'  'N'  17
2500  235   49.5  1   6  30  'M'  'L'  'O'  3  'Y'  'N'  17
2510  115   71.1  1   2  10  'R'  'L'  'O'  3  'N'  'N'  17
2520  231   44.8  1   4  18  'C'  'L'  'H'  3  'Y'  'N'  17
2530  305   28.1  1   4  18  'C'  'L'  'H'  4  'Y'  'N'  17
2540  420   95.6  4   4  28  'C'  'L'  'O'  5  'Y'  'N'  17
2550  273  153.9  1   1  29  'R'  'M'  'O'  3  'Y'  'N'  17
2560  212   51.5  2   3  17  'R'  'L'  'H'  4  'Y'  'N'  17
2570  160   50.0  3  10  20  'R'  'L'  'O'  3  'N'  'N'  18
2580  170   75.0  3  10  20  'C'  'L'  'O'  3  'N'  'N'  18
2590   85  250.0  1   2  10  'R'  'M'  'F'  3  'N'  'N'  18
2600   80  256.0  1  15  30  'M'  'M'  'F'  2  'N'  'N'  18
2610   35  193.0  1   2   4  'M'  'M'  'F'  2  'N'  'N'  18
2620   86   46.0  3  10  20  'C'  'L'  'O'  3  'N'  'N'  18
2630   35  230.0  1   2   4  'M'  'L'  'F'  3  'N'  'N'  18
2640   95   58.0  4  20  25  'C'  'L'  'O'  3  'N'  'N'  18
2650   90   64.0  3  20  25  'C'  'L'  'O'  5  'N'  'N'  18
2660  100   52.0  3  10  20  'C'  'L'  'O'  3  'N'  'N'  18
2670   50   26.0  3  10  20  'C'  'L'  'O'  3  'N'  'N'  18
2680   36   15.0  3  15  30  'C'  'L'  'O'  5  'N'  'N'  18
2690   30  200.0  1  15  30  'R'  'L'  'O'  3  'N'  'Y'  18
2700   34   12.0  2  10  20  'C'  'L'  'O'  4  'N'  'N'  18
2710  120   70.0  3  20  25  'C'  'L'  'O'  4  'N'  'N'  18
2720   12   65.0  1   2   4  'R'  'L'  'O'  2  'N'  'Y'  18
2730  118   75.0  4  10  20  'C'  'L'  'O'  4  'N'  'N'  18
2740  228  168.0  4  15  30  'C'  'L'  'O'  4  'N'  'N'  18
2750   70   32.0  2   8  22  'C'  'L'  'O'  4  'N'  'N'  18
2760   70   36.0  3  15  30  'C'  'L'  'O'  4  'N'  'N'  18

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LIST 2770,3220

2770   50   70.0  2 10 20  'R'  'L'  'O'  4  'N'  'N'  18
2780  120   55.0  3 13 17  'C'  'M'  'N'  3  'Y'  'N'  19
2790  100   74.2  4 13 17  'C'  'L'  'O'  3  'Y'  'N'  19
2800   60  200.0  1 13 17  'R'  'H'  'O'  3  'N'  'Y'  19
2810   50    5.0  1  4 21  'C'  'M'  'O'  4  'N'  'Y'  19
2820  100   73.0  3 10 22  'C'  'M'  'O'  3  'N'  'Y'  19
2830   80   29.0  1  4 21  'C'  'L'  'O'  5  'N'  'N'  19
2840   60   12.0  3 13 17  'C'  'M'  'O'  2  'Y'  'Y'  19
2850   90   24.3  2  4 21  'R'  'M'  'O'  4  'N'  'N'  19
2860   30   50.0  2 10 22  'M'  'H'  'O'  3  'Y'  'Y'  19
2870   46   34.7  2 13 17  'R'  'L'  'O'  4  'N'  'N'  19
2880   60   15.8  2  4 21  'C'  'L'  'O'  4  'N'  'N'  19
2890   30    6.1  1 22 22  'C'  'L'  'N'  2  'N'  'N'  19
2900    8   25.0  1 22 22  'R'  'H'  'F'  2  'N'  'N'  19
2910   42    4.9  1  4 21  'C'  'L'  'F'  4  'N'  'N'  19
2920   24   21.9  1 22 22  'C'  'M'  'O'  3  'N'  'Y'  19
2930  350   70.7  2  6 32  'C'  'L'  'O'  3  'N'  'N'  20
2940   40   12.9  1  2  2  'C'  'L'  'O'  3  'N'  'Y'  20
2950   50    5.3  1  1  5  'C'  'L'  'H'  4  'N'  'N'  20
2960  700  717.1  2  6 32  'C'  'M'  'O'  4  'N'  'Y'  20
2970  125   41.7  1  1  1  'M'  'L'  'O'  3  'N'  'N'  20
2980  200   98.7  1  4 15  'M'  'L'  'O'  3  'Y'  'Y'  20
2990   75   17.0  1  4 15  'C'  'L'  'O'  4  'N'  'N'  20
3000  250   68.1  1  2  2  'C'  'L'  'O'  4  'N'  'N'  20
3010   75   21.3  1  1  5  'C'  'L'  'O'  3  'N'  'Y'  20
3020  150   83.3  1  2  2  'R'  'L'  'O'  4  'N'  'N'  20
3030  350   59.3  1 19 21  'C'  'L'  'O'  5  'N'  'N'  20
3040  300  188.8  1  1  1  'R'  'M'  'O'  4  'N'  'N'  20
3050   30   15.0  1  2  2  'C'  'M'  'O'  3  'N'  'N'  20
3060   40    9.9  1  4  4  'R'  'L'  'O'  1  'N'  'Y'  21
3070   80   12.9  1  1  1  'M'  'L'  'O'  1  'N'  'N'  21
3080   40    6.6  1  1  1  'M'  'L'  'O'  1  'N'  'Y'  21
3090  120  190.1  1  2  2  'M'  'L'  'O'  3  'N'  'Y'  21
3100   40    1.9  1  1  1  'R'  'L'  'O'  1  'N'  'N'  21
3110   50    7.5  1  7 30  'R'  'L'  'O'  1  'N'  'N'  21
3120  100   40.0  1  7 30  'C'  'L'  'O'  2  'N'  'N'  21
3130  200   65.7  1  3  3  'M'  'H'  'O'  2  'N'  'Y'  22
3140  145  100.7  1  2 15  'R'  'M'  'O'  3  'N'  'N'  22
3150   75   63.7  3 16 28  'C'  'H'  'H'  3  'N'  'N'  22
3160   42   22.1  1  3  3  'M'  'H'  'O'  2  'N'  'Y'  22
3170   14    9.1  1  4 15  'C'  'L'  'O'  2  'N'  'N'  22
3180  120   20.4  1 16 28  'C'  'L'  'O'  3  'N'  'N'  22
3190  286   26.1  1 16 28  'C'  'L'  'N'  3  'N'  'N'  22
3200   41   40.0  2  2 15  'C'  'H'  'N'  2  'N'  'N'  22
3210   70   27.2  3 16 28  'C'  'L'  'O'  4  'N'  'N'  22
3220   16   22.8  1 16 28  'M'  'H'  'F'  1  'N'  'Y'  22

ready
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LIST 3230,3680

3230  128    3.9  1 16 28 'C' 'L' 'N' 2 'N' 'N' 22
3240  200   58.0  1  4 15 'C' 'L' 'O' 3 'N' 'N' 22
3250  400   75.0  2  5 10 'C' 'L' 'O' 3 'N' 'Y' 23
3260  750  377.0  4 12 15 'C' 'L' 'H' 5 'N' 'N' 23
3270  275  213.7  1  5 10 'R' 'M' 'O' 2 'N' 'Y' 23
3280  211  263.3  3 12 15 'R' 'L' 'O' 4 'N' 'N' 23
3290  575   72.4  3  5 10 'C' 'L' 'O' 2 'N' 'N' 23
3300 1659  252.3  3 12 15 'C' 'L' 'N' 5 'N' 'N' 23
3310 1181  180.5  4 12 15 'C' 'L' 'N' 5 'N' 'N' 23
3320  150  129.3  2  5 10 'R' 'M' 'O' 3 'N' 'Y' 23
3330  272  254.5  1  4  4 'R' 'L' 'O' 5 'N' 'N' 23
3340  154  211.9  1 12 15 'R' 'H' 'O' 1 'N' 'Y' 23
3350  427  231.0  3 12 15 'C' 'L' 'H' 5 'N' 'N' 23
3360  159  179.0  1  4  4 'C' 'L' 'O' 4 'N' 'N' 23
3370  100   75.9  1  2  4 'R' 'L' 'O' 3 'N' 'N' 23
3380  400   64.9  3 12 15 'C' 'L' 'O' 5 'N' 'N' 23
3390  220   36.6  3 12 15 'C' 'L' 'O' 3 'N' 'N' 23
3400   92   61.5  3 16 16 'R' 'L' 'O' 5 'Y' 'N' 24
3410   40   15.3  1 20 24 'R' 'L' 'O' 4 'Y' 'N' 24
3420  452  380.0  3 16 16 'R' 'L' 'O' 5 'Y' 'N' 24
3430  122   75.0  2  6  6 'C' 'L' 'O' 5 'Y' 'N' 24
3440  129   27.6  3  6  6 'C' 'L' 'O' 5 'Y' 'N' 24
3450   48   27.9  1 12 17 'C' 'L' 'N' 3 'Y' 'N' 24
3460  111   15.9  1  6  6 'C' 'H' 'H' 3 'Y' 'N' 24
3470   24   24.9  1 21 24 'M' 'L' 'O' 4 'Y' 'N' 24
3480  280  199.0  1 11 11 'R' 'L' 'O' 5 'Y' 'N' 24
3490  845  619.9  1 20 24 'R' 'L' 'O' 5 'Y' 'N' 24
3500  902  447.0  4 16 16 'R' 'L' 'O' 5 'Y' 'N' 24
3510  537   74.0  4 12 19 'C' 'L' 'O' 5 'Y' 'N' 24
3520  589   75.0  4 12 19 'C' 'L' 'O' 5 'Y' 'N' 24
3530  179   80.0  1 16 16 'R' 'L' 'O' 5 'Y' 'N' 24
3540  144   78.0  1 21 24 'R' 'L' 'O' 4 'Y' 'N' 24
3550  366  284.9  1  3  8 'R' 'L' 'O' 5 'N' 'N' 25
3560  612  232.5  1 12 28 'R' 'M' 'O' 5 'N' 'Y' 25
3570  415   47.0  1 12 25 'C' 'L' 'O' 5 'N' 'N' 25
3580  341  276.2  1  4  4 'M' 'L' 'O' 3 'N' 'N' 25
3590  160   23.5  1  9 10 'R' 'L' 'O' 3 'N' 'N' 25
3600  690   66.2  3 12 25 'C' 'M' 'O' 5 'N' 'N' 25
3610   60  240.1  1  1  1 'M' 'H' 'F' 3 'N' 'N' 25
3620   81    1.4  1 12 28 'M' 'H' 'F' 3 'N' 'N' 25
3630  408  175.0  1  1  1 'R' 'H' 'F' 3 'N' 'N' 25
3640   98    1.9  1  2  2 'R' 'L' 'O' 1 'N' 'Y' 25
3650   57   10.1  1  7 10 'C' 'L' 'H' 5 'N' 'N' 25
3660   36    3.0  1  7 10 'M' 'L' 'O' 3 'N' 'Y' 25
3670   15   23.9  1  7 10 'M' 'H' 'F' 3 'N' 'Y' 25
3680  511   99.4  1  2  2 'C' 'L' 'F' 5 'N' 'N' 25

ready
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AD-A061 340 AIR FORCE INST OF TECH WRIGHT-PATTERSON AFB OHIO SCHO--ETC F/G 5/1
A STUDY OF ESTIMATING PROJECT DESIGN MANHOURS.(U)
SEP 78 R N MOSS, D J MEISTER, D F RUSCHMANN
UNCLASSIFIED AFIT-LSSR-12-78B NL

2 OF 2
AD
A061 340

END
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LIST 3690,4140

3690  192   29.6  1   9  10  'C'  'L'  'H'  5  'N'  'N'  25
3700  124   41.4  1  18  22  'M'  'L'  'O'  3  'Y'  'N'  26
3710  204  154.9  1  18  22  'M'  'L'  'O'  2  'Y'  'N'  26
3720  115   13.7  1   2   2  'R'  'L'  'N'  2  'N'  'N'  26
3730  156  152.2  1  18  22  'R'  'M'  'O'  3  'Y'  'N'  26
3740  260  291.3  3   5   5  'R'  'L'  'O'  4  'Y'  'N'  26
3750  160   73.3  2   5   5  'C'  'L'  'O'  4  'N'  'N'  26
3760   94   44.7  1  18  22  'M'  'H'  'F'  1  'Y'  'N'  26
3770  104   93.1  1  18  22  'R'  'M'  'F'  2  'Y'  'N'  26
3780  124  161.5  1  18  22  'M'  'L'  'F'  2  'Y'  'N'  26
3790   70   31.7  1   5   5  'M'  'L'  'F'  1  'N'  'Y'  26
3800  104   90.0  1   5   5  'M'  'L'  'F'  2  'N'  'Y'  26
3810  148  282.5  1  18  22  'R'  'M'  'F'  2  'Y'  'Y'  26
3820   96   32.8  1   5   6  'R'  'L'  'F'  2  'N'  'N'  26
3830   82   16.8  1  18  22  'C'  'H'  'F'  2  'N'  'N'  26
3840   82   70.0  1   5   6  'R'  'L'  'O'  3  'N'  'N'  26
3850  130   73.4  3   3   5  'C'  'L'  'O'  3  'N'  'N'  26
3860  140   30.0  2   3   5  'R'  'L'  'O'  2  'N'  'N'  26
3870  123  110.0  2   9   9  'R'  'L'  'O'  4  'Y'  'N'  27
3880   40   80.0  2   4   4  'R'  'L'  'O'  3  'Y'  'N'  27
3890   87   96.0  1   1   1  'R'  'M'  'O'  3  'Y'  'N'  27
3900  324  194.0  3   8   8  'C'  'L'  'O'  4  'Y'  'N'  27
3910  114  240.0  1  15  15  'R'  'H'  'F'  2  'Y'  'N'  27
3920  212  514.0  3   9   9  'R'  'M'  'O'  3  'Y'  'N'  27
3930   86  110.0  1   8   8  'C'  'H'  'F'  2  'Y'  'N'  27
3940  538  307.0  2   7  13  'R'  'M'  'O'  3  'Y'  'N'  27
3950  391  260.0  4   9   9  'R'  'M'  'O'  3  'Y'  'N'  27
3960  226   95.0  1   4   4  'R'  'L'  'O'  4  'Y'  'N'  27
3970  124   72.0  2   3   7  'C'  'M'  'O'  3  'Y'  'N'  27
3980  380   61.0  3   8   8  'C'  'L'  'O'  5  'Y'  'N'  27
3990   46   52.0  1   4   4  'M'  'M'  'F'  3  'Y'  'N'  27
4000   67   20.0  1   6   6  'C'  'L'  'N'  3  'Y'  'N'  27
4010   38    8.0  1   7  13  'C'  'L'  'N'  2  'Y'  'N'  27
4020  108  120.3  1   2   4  'M'  'L'  'O'  3  'N'  'N'  28
4030   89  195.0  1  13  17  'R'  'L'  'O'  4  'N'  'N'  28
4040   52   52.0  1  13  14  'M'  'H'  'F'  1  'N'  'Y'  28
4050   94  118.0  1   2   4  'R'  'M'  'O'  3  'N'  'N'  28
4060   38   35.0  1  13  17  'M'  'H'  'O'  3  'N'  'N'  28
4070   94  260.8  1   2   4  'R'  'H'  'F'  3  'N'  'N'  28
4080   76  231.1  1   2   4  'R'  'H'  'F'  3  'N'  'N'  28
4090   78  198.1  1   3   3  'R'  'H'  'F'  3  'N'  'N'  28
4100   46   11.9  1  13  17  'C'  'L'  'O'  2  'N'  'N'  28
4110   61   73.2  1   2   4  'R'  'H'  'O'  2  'N'  'Y'  28
4120   98   42.9  1   3   3  'R'  'L'  'O'  4  'N'  'N'  28
4130   56   25.0  1   2   4  'R'  'L'  'O'  3  'N'  'Y'  28
4140   51    6.5  1   2   4  'R'  'L'  'O'  3  'N'  'N'  28

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LIST 4150,4600

4150  116  177.2  1   1   1  'R'  'M'  'O'  3  'N'  'N'  28
4160   54  150.0  1   3   3  'R'  'H'  'F'  3  'N'  'Y'  28
4170  300  980.0  1   3  10  'R'  'H'  'F'  3  'N'  'Y'  29
4180  200   24.0  2   5  32  'C'  'L'  'O'  4  'N'  'N'  29
4190  400   15.0  2   5  32  'C'  'L'  'O'  3  'N'  'N'  29
4200   54   86.0  1   3  10  'M'  'M'  'O'  2  'N'  'N'  29
4210   71   25.0  1   1   1  'R'  'M'  'O'  4  'N'  'N'  29
4220   30    4.0  1   1   1  'C'  'H'  'N'  2  'N'  'Y'  29
4230   49   28.0  1   1   1  'C'  'H'  'O'  3  'N'  'Y'  29
4240  160   11.0  1   2   2  'R'  'L'  'O'  3  'N'  'N'  29
4250  120   18.0  1   1   2  'R'  'L'  'O'  2  'N'  'N'  29
4260   60    2.0  1   1   2  'R'  'L'  'O'  1  'N'  'N'  29
4270   40    9.0  1   1   2  'M'  'L'  'H'  2  'N'  'N'  29
4280  610   98.0  3   5  32  'C'  'L'  'N'  4  'N'  'N'  29
4290   30    2.0  1   2   2  'C'  'L'  'O'  1  'N'  'Y'  29
4300   94   42.0  2   5  32  'C'  'L'  'O'  3  'N'  'N'  29
4310  320   74.0  2   5  32  'C'  'L'  'H'  4  'N'  'N'  29
4320   87   21.4  1   3  10  'C'  'M'  'F'  2  'Y'  'Y'  30
4330  180   74.6  4   6   0  'C'  'L'  'O'  3  'Y'  'N'  30
4340  200   64.0  2   3  30  'C'  'L'  'O'  4  'Y'  'N'  30
4350   47   34.0  1   5   0  'R'  'L'  'H'  2  'Y'  'Y'  30
4360   45   45.6  2   3  10  'R'  'L'  'O'  4  'Y'  'N'  30
4370   30   39.4  1   1  10  'R'  'L'  'O'  3  'Y'  'Y'  30
4380  180   23.0  1   1   6  'C'  'L'  'O'  4  'Y'  'N'  30
4390  170  420.0  4   3  30  'C'  'L'  'N'  4  'Y'  'N'  30
4400   47  110.0  1   5   0  'M'  'H'  'F'  2  'Y'  'Y'  30
4410   60   22.5  2   7   0  'C'  'L'  'H'  4  'Y'  'N'  30
4420   74   97.0  2   5   0  'R'  'L'  'O'  3  'Y'  'N'  30
4430   20   42.0  1   3  10  'C'  'L'  'O'  3  'Y'  'N'  30
4440  105   71.7  4   3  10  'C'  'L'  'O'  3  'Y'  'N'  30
4450  104   98.0  4   3  10  'R'  'L'  'O'  3  'Y'  'N'  30
4460  158   32.5  4   3  30  'C'  'L'  'O'  3  'Y'  'N'  30
4470  144  276.2  1  11  11  'M'  'M'  'O'  3  'N'  'Y'  31
4480  121   38.0  1  29  29  'C'  'M'  'O'  3  'N'  'Y'  31
4490   48   20.0  1  11  11  'M'  'L'  'O'  3  'N'  'Y'  31
4500   80  220.0  1   5  17  'R'  'L'  'O'  2  'N'  'Y'  31
4510   81   33.0  1  11  11  'R'  'L'  'N'  4  'N'  'N'  31
4520  331   75.0  1   2   2  'C'  'L'  'O'  4  'N'  'N'  31
4530   35   16.0  1   2   2  'C'  'L'  'F'  2  'N'  'N'  31
4540   27   11.0  1  11  11  'R'  'L'  'F'  3  'N'  'Y'  31
4550  738  340.0  1   5  17  'R'  'M'  'O'  3  'N'  'Y'  31
4560   88   30.0  1   2   2  'C'  'L'  'O'  3  'N'  'Y'  31
4570   33   85.8  1   2   2  'M'  'H'  'F'  2  'N'  'Y'  31
4580  104   18.0  1   2  18  'R'  'L'  'O'  3  'Y'  'N'  32
4590  120   20.4  1   1   1  'R'  'H'  'O'  3  'Y'  'N'  32
4600  150   10.0  1   4  13  'C'  'L'  'O'  3  'Y'  'N'  32

ready
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LIST 4610,5060
4610  158   87.5  1  8 17 'R' 'H' 'O' 4 'N' 'N' 32
4620  243  200.0  1  3  9 'R' 'H' 'O' 2 'N' 'Y' 32
4630  126   33.0  1 12 20 'R' 'L' 'O' 4 'Y' 'N' 32
4640  174    9.4  2  4 13 'C' 'L' 'O' 4 'Y' 'N' 32
4650  154   10.0  2  2 10 'R' 'L' 'H' 3 'Y' 'N' 32
4660  284  140.0  1  2 29 'R' 'H' 'F' 2 'N' 'Y' 32
4670   71    6.2  2  1  1 'C' 'L' 'O' 3 'Y' 'N' 32
4680   66    7.0  1  2 10 'C' 'L' 'O' 2 'Y' 'N' 32
4690  326   19.8  1  6  8 'C' 'L' 'H' 4 'N' 'N' 32
4700  211  116.1  1  6  8 'R' 'H' 'O' 2 'N' 'Y' 32
4710  231  265.1  1  6  8 'R' 'H' 'O' 2 'N' 'Y' 32
4720  262   22.1  4  4  5 'C' 'L' 'O' 4 'Y' 'N' 32
4730  407   70.2  3  2  3 'C' 'L' 'H' 5 'Y' 'N' 32
4740   84    5.0  3  9 12 'C' 'L' 'O' 4 'Y' 'N' 32
4750  607  321.0  1  2 29 'R' 'L' 'H' 3 'Y' 'N' 32
4760  447  100.0  2  3  9 'C' 'M' 'H' 3 'Y' 'N' 32
4770  121   14.1  1  2  3 'C' 'L' 'O' 4 'Y' 'N' 32
4780   57    4.2  2  9 12 'C' 'M' 'F' 2 'Y' 'N' 32
4790   90   75.0  1  9 12 'M' 'H' 'F' 1 'N' 'Y' 32
4800   15   10.0  1  4 13 'R' 'L' 'O' 1 'Y' 'N' 32
4810   76   12.0  1  1  5 'C' 'L' 'O' 2 'N' 'N' 32
4820   94  274.0  1  4 13 'C' 'L' 'H' 1 'N' 'N' 32
4830   95   30.0  1  4 13 'C' 'L' 'N' 3 'Y' 'N' 32
4840   25    3.0  3  2  3 'C' 'L' 'H' 4 'Y' 'N' 32
4850  110   25.0  1  4 13 'R' 'H' 'F' 1 'Y' 'N' 32
4860   99    8.0  1  3  9 'R' 'L' 'F' 2 'Y' 'N' 32
4870   71   25.0  1  6  8 'M' 'H' 'F' 2 'Y' 'Y' 32
4880  169   50.0  1  4 13 'C' 'H' 'O' 4 'Y' 'N' 32
4890   60    6.5  3  2 29 'R' 'L' 'O' 3 'Y' 'N' 32
4900   47   50.0  1  2 29 'R' 'L' 'O' 3 'Y' 'Y' 32
4910  118   10.0  1  4 13 'R' 'L' 'O' 3 'Y' 'N' 32
4920 1048  215.0  3  4 13 'R' 'L' 'O' 5 'Y' 'N' 32
4930  532   64.0  2  4 13 'R' 'L' 'O' 5 'Y' 'N' 32
4940  280   89.9  2  4 13 'C' 'L' 'O' 5 'Y' 'N' 32
4950   31   15.0  2  2  3 'R' 'L' 'O' 2 'Y' 'N' 32
4960   39   50.0  1  2  3 'C' 'M' 'O' 3 'Y' 'N' 32
4970   84   25.0  1  2 10 'R' 'L' 'O' 2 'Y' 'N' 32
4980   23   25.0  1  4 13 'R' 'H' 'F' 2 'Y' 'N' 32
4990   38  111.0  1  4 13 'C' 'H' 'F' 2 'Y' 'Y' 32
5000  103  163.0  1  4 13 'R' 'L' 'O' 4 'Y' 'N' 32
5010  204   70.0  1  6  8 'C' 'M' 'O' 4 'Y' 'N' 32
5020  155   30.0  1  2 10 'C' 'H' 'F' 2 'Y' 'N' 32
5030  375  116.0  2  9 25 'R' 'L' 'F' 4 'Y' 'Y' 32
5040  257   44.0  2  9 25 'C' 'L' 'F' 4 'Y' 'N' 32
5050  534  205.0  1  2 29 'R' 'H' 'O' 4 'Y' 'Y' 32
5060   90   50.0  1  3  9 'C' 'L' 'O' 3 'Y' 'Y' 32

ready
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LIST 5070,5530

5070   53   30.0  1   4  13  'M'  'H'  'F'  2  'N'  'Y'  32
5080  131  199.0  1   6   8  'R'  'H'  'O'  2  'N'  'Y'  32
5090   17   25.0  1   4  13  'R'  'H'  'F'  2  'Y'  'Y'  32
5100   43    4.0  1   3   9  'C'  'L'  'N'  3  'N'  'N'  32
5110   43   10.0  1   1   1  'R'  'H'  'O'  2  'Y'  'N'  33
5120   46   45.1  1   1   1  'M'  'L'  'O'  3  'Y'  'N'  33
5130  134  186.2  1   1   1  'M'  'M'  'O'  3  'Y'  'Y'  33
5140   60  147.0  1   1   1  'R'  'H'  'F'  2  'Y'  'N'  33
5150   38    6.9  1   1   1  'R'  'L'  'O'  3  'Y'  'N'  33
5160  225   99.0  2  12  30  'R'  'L'  'O'  5  'Y'  'N'  33
5170   40   33.0  1   1   1  'M'  'H'  'O'  2  'N'  'N'  33
5180   41   70.0  1  15  21  'R'  'H'  'F'  3  'Y'  'N'  33
5190   44   35.0  1   1   1  'R'  'H'  'F'  3  'N'  'Y'  33
5200   20   19.7  1   2   2  'C'  'L'  'O'  2  'Y'  'N'  33
5210  216   29.0  1   3   5  'R'  'L'  'O'  4  'Y'  'N'  33
5220  272  235.1  1  12  30  'R'  'M'  'O'  4  'N'  'N'  33
5230  197  165.6  2   2   3  'C'  'L'  'O'  3  'N'  'Y'  33
5240  255  360.0  1  12  30  'R'  'M'  'O'  4  'N'  'Y'  33
5250  100  187.0  1   2   3  'R'  'M'  'F'  3  'N'  'N'  33
5260  250  125.0  2   1   2  'C'  'L'  'N'  3  'N'  'N'  34
5270  370  103.0  2   5  11  'R'  'M'  'F'  3  'N'  'N'  34
5280  216   15.0  3   6  17  'C'  'L'  'H'  3  'N'  'N'  34
5290  544  295.0  3   4   5  'R'  'H'  'F'  3  'N'  'N'  34
5300  406  131.0  3   4  30  'C'  'L'  'H'  5  'N'  'N'  34
5310  364  215.0  2  12  12  'R'  'L'  'O'  4  'N'  'N'  34
5320   50   19.0  1  11  27  'M'  'M'  'O'  1  'N'  'Y'  34
5330  268  150.0  3   2   8  'R'  'H'  'F'  3  'N'  'Y'  34
5340  170  200.0  2   5  15  'R'  'L'  'O'  2  'N'  'N'  34
5350  240   66.0  2  12  12  'C'  'L'  'O'  4  'N'  'N'  34
5360  180   68.0  3   4  30  'C'  'L'  'O'  3  'N'  'N'  34
5370  320  133.0  1  12  12  'M'  'L'  'O'  3  'N'  'Y'  34
5380  890  243.0  4   3   7  'C'  'M'  'O'  4  'N'  'N'  34
5390  400   34.0  2   4   5  'C'  'L'  'O'  3  'N'  'N'  34
5400   60   33.0  1  11  27  'C'  'M'  'O'  2  'N'  'Y'  34
5410   98   45.0  2   2   8  'R'  'L'  'O'  5  'N'  'N'  34
5420  100   29.0  1   4   5  'C'  'M'  'O'  3  'N'  'N'  34
5430  312   68.0  3   2   8  'R'  'H'  'F'  2  'N'  'N'  34
5440  235   96.0  3   4   4  'R'  'H'  'F'  3  'N'  'Y'  34
5450   60   90.0  1  11  27  'M'  'M'  'O'  3  'N'  'Y'  34
5460  520   73.0  3  12  12  'C'  'L'  'O'  3  'N'  'N'  34
5470  540  280.0  2   6  17  'C'  'M'  'F'  3  'N'  'N'  34
5480  180   68.0  2   2   8  'R'  'L'  'O'  4  'N'  'N'  34
5490   50   22.0  1  11  27  'M'  'M'  'O'  1  'N'  'Y'  34
5500  440   82.0  2   5  15  'R'  'L'  'O'  4  'N'  'N'  34
5510  640   75.0  3   4  30  'C'  'L'  'H'  3  'N'  'N'  34
5520  100   30.0  1   4  30  'R'  'L'  'H'  4  'N'  'N'  34
5530  240   82.0  3   5  15  'C'  'L'  'O'  3  'N'  'N'  34

ready
```

APPENDIX B

DESIGN SECTION SURVEY

APPENDIX B-1

Variables Considered but Not Selected

a. Scope

b. Security Problem Requirements (Secure Area, Entry Control)

c. Location of Project Site on Base

d. Availability of Drafting/Surveying Support

e. Manning Level

f. Engineer Working Within his Discipline

g. Speed of the Engineer

h. Unique or Innovative Project; new State-of-the-Art; Test Case

i. Engineering Productivity

j. Weather or Season

k. Reference Material Available (Sweet's Catalogue, VSMF)

l. Availability of Record Drawings

m. Accuracy of Record Drawings

n. Standard Specifications Available

o. Adequacy of Programming Information

p. Environmental Problem

q. Geographical Location

r. Size of Base

s. Higher Headquarters Review and Approval

t. Amount of Coordination Required

u. Number of Using Agencies Involved

v. Fiscal Year Cycle (Near End of Fiscal Year)

w. Military or Civilian Designer

x. Priority of Project or Urgency

y. Time Available to Accomplish Project (as for a Specified Obligation Date)

APPENDIX B-2

Project Design Manhour Estimating Survey

DEPARTMENT OF THE AIR FORCE
HEADQUARTERS UNITED STATES AIR FORCE
WASHINGTON, D.C.
20330

REPLY TO ATTN OF: AFIT/LSG

24 APR 1978

SUBJECT: Project Design Manhour Estimating Survey

TO: Chief of Engineering Design Section (DEEE), Civil Engineering (CONUS)

1. The attached survey was prepared by a research team at the Air Force Institute of Technology, Wright-Patterson AFB, Ohio. The purpose of the survey is to acquire data concerning current project design manhours and estimating methods. The data will be used to identify and analyze design factors which affect design time estimating accuracy.

2. You are requested to provide data for each section. Your responses to the survey will be held confidential.

3. Please remove this cover letter before returning the completed survey. Your cooperation in providing this data will be appreciated and will be beneficial for improving current project manhour estimating methods. Please return the completed survey in the attached envelope within two weeks of receipt.

FOR THE CHIEF OF STAFF

GEORGE E. ELLIS, COL, USAF
Chief, Operations and Maintenance Div
Directorate of Engineering and Serv

2 Atch
1. Questionnaire
2. Return envelope

Survey Information Page

1. The purpose of this survey is to collect data on the procedures currently used to estimate project design times. This information will be used to assess the effectiveness of current estimating procedures and to develop a predictive model designed to improve the accuracy and reliability of project design time estimates. We believe that this model can be a valuable tool for the Chief of the Design section to use in preparing and implementing efficient design schedules.

2. This survey is being sent to the Chief of the Design section of each CONUS installation. All information provided will be treated confidentially and will be used only to analyze factors affecting project design time. No attempt will be made to evaluate a specific base, engineer, or Chief of the Design section.

3. To establish a common terminology for this survey, project design time is defined to be the number of manhours required for engineers to: (a) review existing programming documents, (b) review record drawings, (c) make site visits, (d) attend project design meetings, (e) research regulations and product information, (f) develop specifications and drawings, (g) obtain base and command level coordination and approval, and (h) comply with project review comments from command, the using organization, and procurement.

4. If there are any questions, please call any one of the following: Capt. Don Meister, Capt. Richard Moss, or Capt. Dave Ruschmann (AUTOVON 785-6513).

PROJECT DESIGN MANHOUR ESTIMATING

1. Major Command ____________________

2. Base ____________________ AUTOVON ____________________

3. Circle the following factors which you consider when making estimates for project design times. If you consider other factors not shown on the list, add them to the list.

a. Total estimated cost
b. Number of disciplines involved
c. Which discipline(s) involved
d. Adequacy of program documents
e. Similar project done recently
f. Type of design specifications
g. Availability of record drawings
h. Accuracy of record drawings
i. Fund source (O&M, NAF, MFH)
j. Current design load
k. Type of work (M, R, MC)
l. Experience of the engineer
m. Security requirements
n. Complexity of the project
o. Number of coordinating agencies
p. ____________________
q. ____________________

4. From the above list, select the three factors which you most often use and rank order them.

a. Most often used ____________
b. Second most used ____________
c. Third most used ____________

5. What accuracy would you consider desirable in estimating design manhours for scheduling?

a. Within 10% ____________
b. Within 20% ____________
c. Within 30% ____________
d. Within 40% ____________
e. Within 50% ____________
f. No opinion ____________

6. What degree of accuracy do you presently achieve in estimating design manhours for scheduling? If you do not directly record this information, indicate this rather than estimating your accuracy for this question.

a. Within 10% ____________
b. Within 20% ____________
c. Within 30% ____________
d. Within 40% ____________
e. Greater than 40% ____________
f. Do not directly record this ____________

7. What percentage of the engineer's total time is scheduled for direct project design?

a. Less than 20% ____________
b. Less than 30% ____________
c. Less than 40% ____________
d. Less than 50% ____________
e. Less than 60% ____________
f. More than 60% ____________

Instructions for Completing This Page

Column 1. This provides an identifying number for each engineer. Enter information for each engineer next to the line number.

Column 2. Enter the actual grade or rank of the engineer.

Column 3. Enter the discipline for the engineer by his assigned manning position. Check the appropriate column for: A=Architect, C=Civil, E=Electrical, M=Mechanical, and O=Other.

Column 4. Enter the total years of actual design experience (federal and civilian) for the engineer (to the nearest year).

Column 5. Enter the years of design experience that the engineer has on the base (to the nearest year).

Columns 6, 7, and 8. Enter the total years of design experience, the total years of experience as Chief of Design, and the years of experience as Chief of Design at your base (to the nearest year).

(1) Engineer Number	(2) Rank/Grade	(3) Discipline					(4) Design Experience	(5)
		A	C	E	M	O	Total Years	Years on Base
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								
17								
18								
		(6) Total Years Design Exp.					(7) Experience as Chief of Design Total Years	(8) Years on Base
Chief of Design								

Instructions for Completing the Next Page

Information provided from this part will be used to create a data base for estimating project design manhours. Information should be available on time sheets, DD Forms 1391, monthly design schedules, and the MAREMIC reports.

Columns 1 to 4. Select and list approximately fifteen projects (excluding service contracts) designed in-house since 1 October 1976, to include projects from M=Maintenance, R=Repair, and MC=Minor Construction type work. Please include several fund sources, such as O&M, HOSP, NAF, and MFH. In Column 1, list an abbreviated title for the project. In Column 2, enter the total estimated cost of the project to the nearest thousand dollars (as entered on DD Form 1391). In Column 3, enter the fund source for the project. In Column 4, check under the appropriate heading for maintenance, repair, or minor construction.

Column 5. Enter whether a project is modular in design. If one set of specifications is used for work repeated on many facilities, say such as thirty family housing units, then the project is highly modular (H). If one set of specifications is used for work on several facilities, even though separate drawings may be required for each facility, then the project is moderately modular (M). If one set of specifications is good for only one or two facilities, then the project has low modularity (L).

Column 6. Enter the total project manhours that were estimated *and* the actual manhours used by the engineers for the project. Only project manhours directly charged to an engineer should be used (this should exclude administrative and site development personnel manhours). If an engineer does his own drafting and the manhour figure includes this drafting time, place a check in the column labeled "EDr."

Column 7. Enter the engineer's identifying number (from the previous work page) for each engineer who worked on this project.

Column 8. This column indicates the complexity of the project as it relates to the average project that you design. The scale ranges from 1 to 5, with the very simple project being 1, an average project being 3, and the very complex being 5. Complexity takes into account such factors as the amount of coordination required, whether the project has unique design requirements, is new technology involved, and is much coordination required among the engineers.

Column 9. This column indicates whether a similar project has been previously completed, which can also be substantially reused for this design. Check the appropriate column for *YES* or *NO*.

(1) Project Information	(2)	(3)	(4) Type			(5) Modular			(6) Total Project Manhours			(7) Engineers Involved	(8) Complexity					(9) Similar Project	
Title	Cost in Thousands	Fund Source	M	R	MC	H	M	L	Estimated	Actual	EDr.		1	2	3	4	5	Yes	No
1																			
2																			
3																			
4																			
5																			
6																			
7																			
8																			
9																			
10																			
11																			
12																			
13																			
14																			
15																			
16																			
17																			
18																			
19																			
20																			
21																			

APPENDIX C

NONPROJECT DATA ANALYSIS

APPENDIX C-1

MAJCOM of Bases Responding the the Survey

MAJCOM	Number of Bases Responding	Not Responding
ADC	3	0
AFA	1	0
AFLC	3	3
AFSC	1	4
ATC	4	10
MAC	6	6
SAC	15	10
TAC	11	7
	44	40

One base was included with another base which actually accomplished its design work. Two bases had been closed.

APPENDIX C-2

Design Factors and Their Frequencies

Factor	Frequency
a. Total Estimated Cost	30
b. Number of Disciplines Involved	42
c. Which Disciplines Involved	37
d. Adequacy of Program Documents	21
e. Similar Project Done Recently	42
f. Type of Design Specification	30
g. Availability of Record Drawings	24
h. Accuracy of Record Drawings	19
i. Fund Source (O&M, NAF, MFH)	7
j. Current Design Load	31
k. Type of Work (M, R, MC)	16
l. Experience of the Engineer	40
m. Security Requirements	16
n. Complexity of the Project	41
o. Number of Coordinating Agencies	21
p. Command Interest	1
q. Using Agency Changes	1
r. Imposed Funding Levels	1
s. How Well Project is Defined by the Approval Document	1
t. Type of Facility Involved	1
u. Drafting Time	2

Factor		Frequency
v.	Experience of the Technician	1
w.	Other Base and Headquarters Priorities	1
x.	Funding Status	1
y.	Present and Anticipated Manning	1
z.	Amount of Surveying Required	1
aa.	Workload of Disciplines	1
bb.	Leave, TDY, Extra Duties, Mobility	1
cc.	Environmental Assessments and Statements	1
dd.	Extent of Cut-and-Paste That Can be Done	1
ee.	Site Location in Relation to Existing Utilities	1
ff.	Modularity	1
gg.	Location of Project	1
hh.	Repetitive Nature	1
ii.	Weather Factor for Construction	1
jj.	Special Interest of Headquarters, Wing, or Base	1
kk.	Required 100% Designed Date	1
ll.	Size or Scope of Project	1
mm.	Base or Command Approval/Review	1
nn.	Working Pace of Engineer	1
oo.	Military or Civilian Engineer	1

APPENDIX C-3

Three Most Used Factors with Non-Weighted and Weighted Rankings

Factor	Non-Weighted					Weighted				
	1st	2nd	3rd	Total	Rank	1st	2nd	3rd	Total	Rank
a	11	3	1	15	3	33	6	1	40	2
b	4	5	2	11	5-tie	12	10	2	24	5
c	2	5	3	10	7	6	10	3	19	6
d	1	0	2	3		3	0	2	5	
e	0	7	4	11	5-tie	0	14	4	18	7
f	1	2	2	5		3	4	2	9	
h	1	1	0	2		3	2	0	5	
i	1	1	0	2		3	2	0	5	
j	5	5	4	14	4	15	10	4	29	4
k	1	1	1	3		3	2	1	6	
l	1	9	10	20	2	3	18	10	31	3
n	19	3	7	29	1	57	6	7	70	1
t	0	1	0	1		0	2	0	2	
aa	0	0	1	1		0	0	1	1	
bb	0	0	1	1		0	0	1	1	
ff	0	0	1	1		0	0	1	1	
kk	0	0	1	1		0	0	1	1	
ll	0	0	1	1		0	0	1	1	
nn	0	0	1	1		0	0	1	1	

APPENDIX C-4

Factors Considered by Bases Indicating Accuracy Within 20 Percent

Factor	First	Second	Third	Total
a	4	1	-	5
b	2	1	1	4
c	-	2	1	3
e	-	2	1	3
h	-	1	1	2
j	1	1	2	4
k	-	-	1	1
l	-	2	1	3
n	4	-	1	5
kk	-	-	1	1

APPENDIX C-5

Factors Considered by Bases Computed as Achieving Accuracy Within 20 Percent

Factor	First	Second	Third	Total
a	2	2	-	4
b	1	-	-	1
c	2	-	-	2
d	-	-	1	1
h	1	-	-	1
j	1	3	-	4
k	-	1	1	2
l	-	1	3	4
n	1	-	2	3

APPENDIX C-6

Three Most Often Used Factors by Bases in the Different Major Commands

Factor	MAJCOM							
	MAC	SAC	TAC	ATC	AFLC	ADCOM	AFSC	USAFA
a	4	3	5	-	1	-	1	1
b	1	5	1	3	1	-	-	-
c	1	5	2	-	1	1	-	-
d	-	2	1	-	-	-	-	-
e	2	4	2	1	-	1	-	1
f	-	-	1	1	1	2	-	-
h	-	2	-	-	-	-	-	-
i	-	1	-	-	-	-	-	-
j	1	5	5	1	1	-	-	1
k	-	1	2	-	-	-	-	-
l	2	5	5	3	1	3	1	-
n	5	11	5	3	2	2	1	-
t	-	-	-	-	1	-	-	-
aa	1	-	-	-	-	-	-	-
bb	-	-	1	-	-	-	-	-
ff	-	-	-	-	1	-	-	-
kk	-	1	-	-	-	-	-	-
ll	-	1	-	-	-	-	-	-
nn	1	-	-	-	-	-	-	-

APPENDIX C-7

Three Most Often Used Factors by Size of Design Staff

Factor	Size of Staff 5	6	7	8	9	10	11	12	14	18	19	30
a	-	3	4	2	-	-	2	2	-	-	2	-
b	1	2	1	4	1	1	-	-	-	-	-	1
c	-	3	2	3	1	-	-	-	-	1	-	-
d	1	-	1	-	-	-	-	1	-	-	-	-
e	-	3	1	1	1	1	2	-	-	-	1	-
f	1	3	-	-	-	-	-	-	-	-	1	-
h	-	1	-	-	1	-	-	-	-	-	-	-
i	1	-	-	-	-	-	-	-	-	-	-	-
j	2	1	5	3	-	-	1	1	-	1	-	-
k	-	1	1	-	-	-	-	1	-	-	-	-
l	1	5	3	4	2	1	-	2	1	1	-	-
n	2	8	4	5	3	-	1	2	1	-	2	1
t	-	-	-	-	-	-	-	-	-	-	-	1
aa	-	-	-	1	-	-	-	-	-	-	-	-
bb	-	-	1	-	-	-	-	-	-	-	-	-
kk	-	-	-	-	-	-	-	-	1	-	-	-
ll	-	-	-	1	-	-	-	-	-	-	-	-
nn	-	-	1	-	-	-	-	-	-	-	-	-

APPENDIX C-8

Three Most Often Used Factors by Military/Total Staff Ratio

Factor	Military/Total Staff Ratio 0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7
a	2	4	3	3	-	1	1	-
b	1	1	2	2	2	2	1	-
c	3	-	1	1	2	3	-	-
d	1	-	-	-	2	-	-	-
e	1	-	2	2	1	4	1	-
f	1	1	1	-	1	1	-	-
h	-	-	1	-	-	1	-	-
i	-	-	-	-	1	-	-	-
j	2	1	2	3	4	1	1	-
k	1	1	-	1	-	-	-	-
l	2	2	3	-	4	1	1	-
n	3	5	6	3	1	6	4	1
t	-	1	-	-	-	-	-	-
aa	1	-	-	-	-	-	-	-
bb	-	-	-	1	-	-	-	-
ff	-	1	-	-	-	-	-	-
kk	-	-	-	-	-	-	-	1
ll	-	-	-	-	-	-	1	-
nn	-	1	-	-	-	-	-	-

APPENDIX C-9

Three Most Often Used Factors by Years of Experience as Chief of Design

Factor	Years of Experience															
	1	2	3	4	5	7	8	9	10	11	12	13	15	20	21	23
a	2	2	-	1	-	1	-	1	1	1	2	1	1	-	-	-
b	1	1	-	1	-	1	-	1	1	-	2	-	1	1	-	-
c	3	-	-	-	1	1	-	-	-	-	1	-	1	-	-	1
d	-	-	1	1	-	-	-	-	-	-	1	-	-	-	-	-
e	1	2	1	-	-	1	1	-	1	-	-	-	1	-	1	-
f	-	1	-	-	-	1	1	-	1	1	-	-	-	-	-	-
h	-	-	-	-	-	-	-	-	1	-	-	-	-	1	-	-
i	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-
j	2	-	1	1	1	1	-	1	2	-	2	-	1	-	1	1
k	-	-	-	-	-	1	-	-	-	-	1	1	-	-	-	-
l	6	1	1	2	1	-	1	1	1	-	-	-	3	-	-	1
n	8	4	1	2	-	2	-	1	3	1	1	1	1	1	-	-
t	-	-	-	1	-	-	-	-	-	-	-	-	-	-	-	-
aa	-	-	-	-	-	-	-	1	-	-	-	-	-	-	-	-
bb	-	-	-	-	-	-	-	-	-	-	-	-	-	-	1	-
ff	-	-	-	-	-	-	-	-	-	1	-	-	-	-	-	-
kk	-	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-
nn	1	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

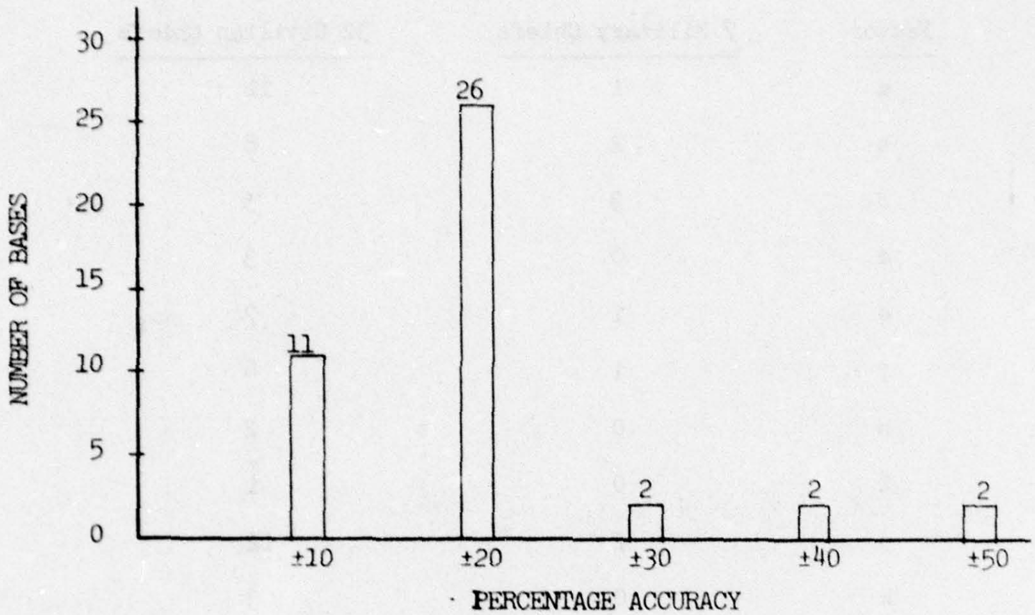
APPENDIX C-10

Three Most Often Used Factors by Military or Civilian Chief of Design

Factor	7 Military Chiefs	32 Civilian Chiefs
a	1	11
b	2	8
c	3	5
d	0	3
e	1	7
f	1	4
h	0	2
i	0	1
j	2	12
k	0	3
l	4	14
n	7	17
aa	0	1
bb	0	1
ff	0	1
nn	1	0

APPENDIX C-11

Desirable Degree of Accuracy as Indicated
by Chiefs of Design



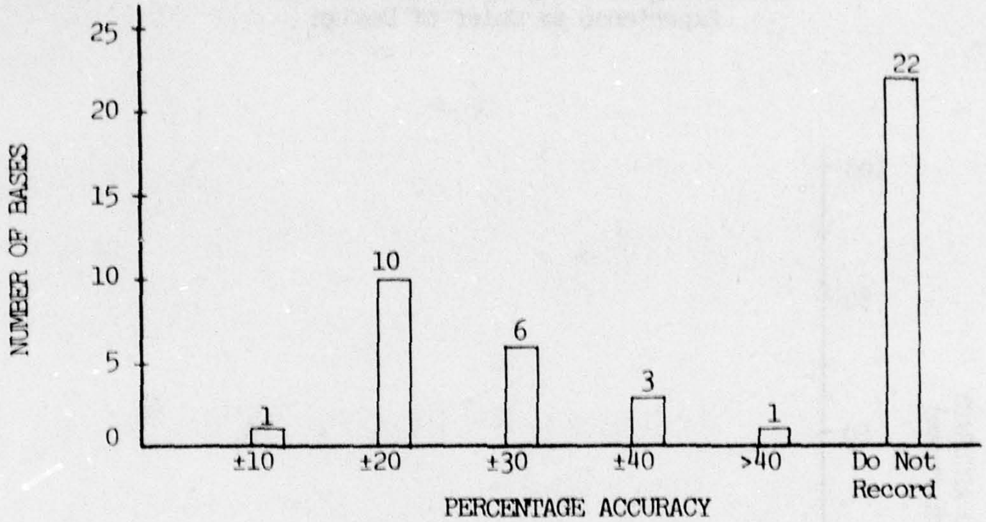
APPENDIX C-12

Desirable Degree of Accuracy as Indicated
by Bases in Different Major Commands

Accuracy	MAJCOM							
	MAC	SAC	TAC	ATC	AFLC	ADCOM	AFSC	USAFA
± 10%	1	3	4	1	2	-	-	-
± 20%	4	10	7	2	1	1	-	1
± 30%	1	-	-	-	-	1	-	-
± 40%	-	-	-	1	-	-	1	-
± 50%	-	1	-	-	-	1	-	-

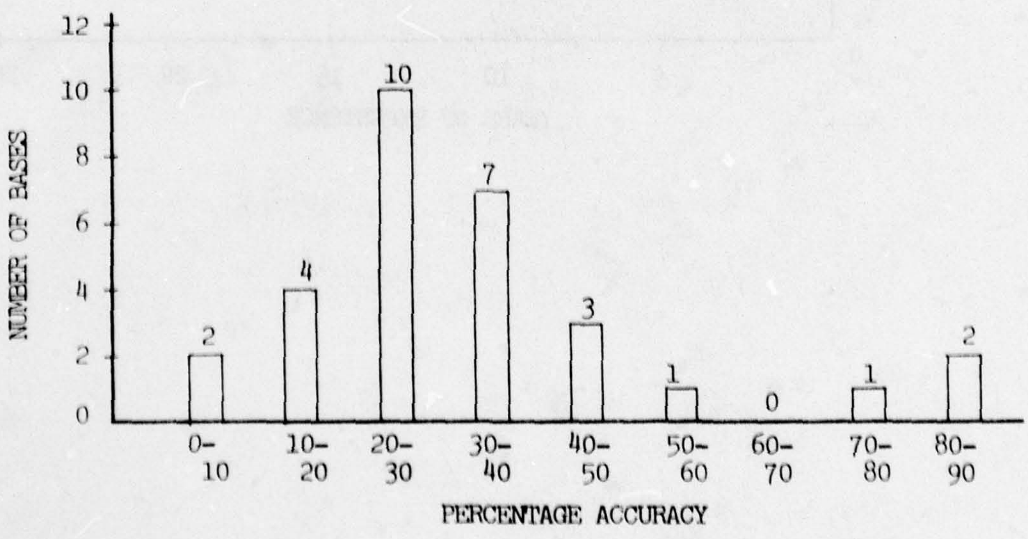
APPENDIX C-13

Degree of Accuracy Presently Being Achieved
as Stated by *Chiefs of Design*



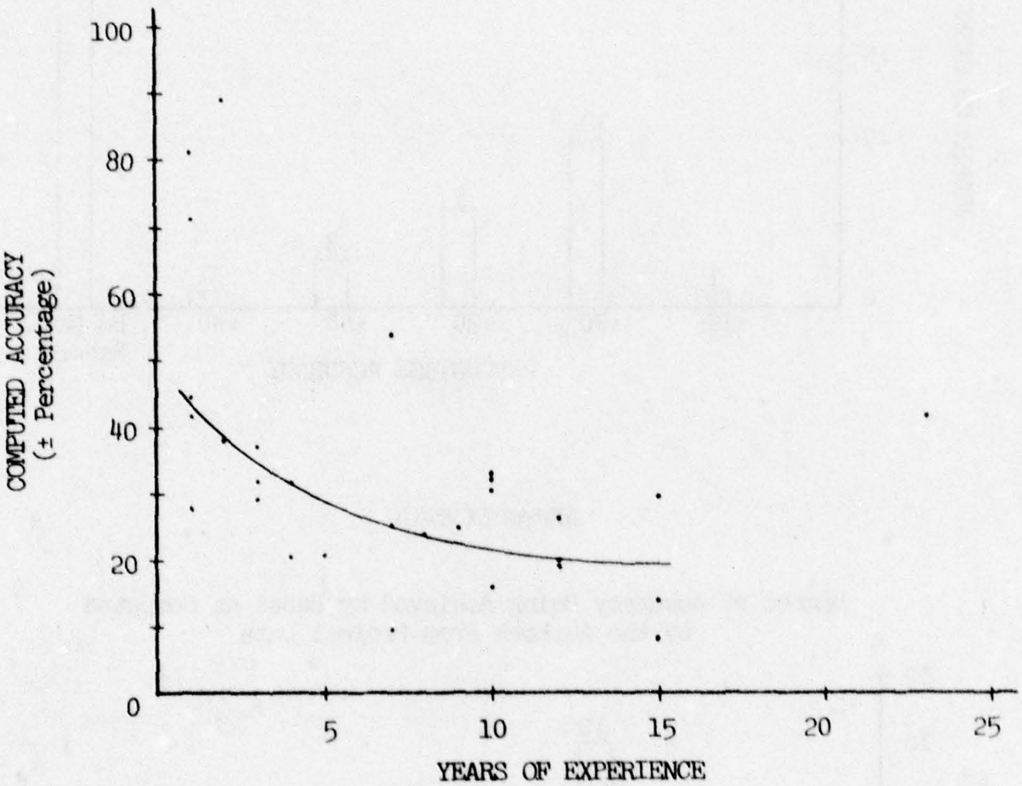
APPENDIX C-14

Degree of Accuracy Being Achieved by Bases as Computed
by the Authors From Project Data



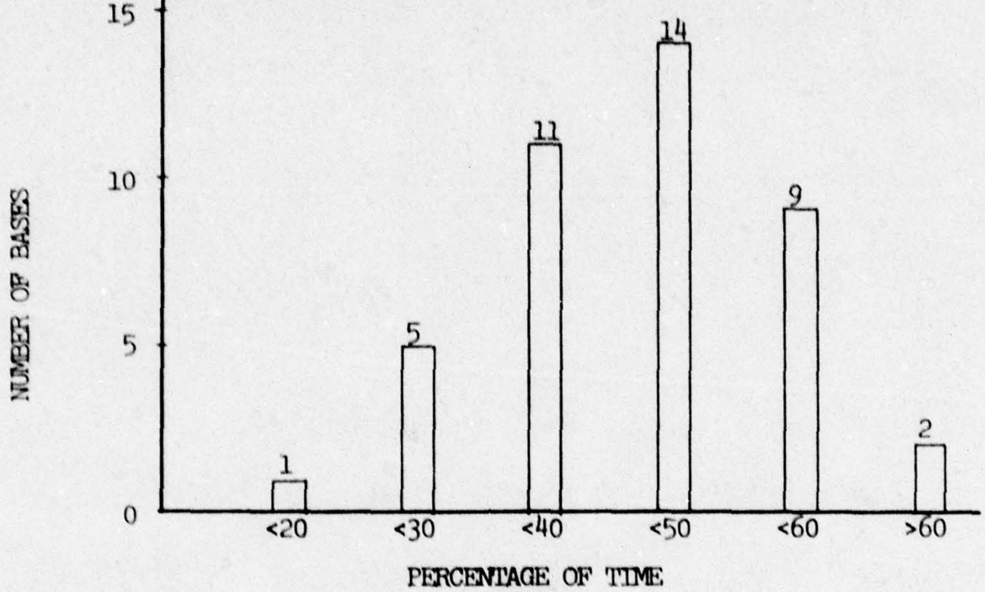
APPENDIX C-15

Estimating Accuracy by Number of Years of Experience as Chief of Design



APPENDIX C-16

Percentage of the Engineer's Total Time Scheduled For Direct Project Design by Base



APPENDIX C-17

Percentage of the Engineer's Total Time Scheduled For Direct Project Design by Major Command

Percentage	MAJCOM							
	MAC	SAC	TAC	ATC	AFLC	ADCOM	AFSC	USAFA
<20%	-	1	-	-	-	-	-	-
<30%	-	4	1	-	-	-	-	-
<40%	-	7	2	-	1	-	1	-
<50%	4	1	5	2	2	-	-	-
<60%	-	1	3	2	-	3	-	-
>60%	1	-	-	-	-	-	-	1

APPENDIX D

PROJECT DATA ANALYSIS

APPENDIX D-1

Subset Groupings from Student, Newman, Keuls Contrast Tests

Base	Variables with Subsets: Y		X1	X2			X3						X4						X8				
	1	2	1	1	2	3	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5
1	X		X	X	X	X		X	X	X	X		X	X	X	X				X	X	X	
2	X		X	X	X	X	X	X	X				X	X	X	X	X		X	X	X	X	
3	X		X	X	X	X			X	X	X						X			X	X	X	
4	X		X	X	X	X				X	X	X	X	X	X	X	X			X	X	X	
5	X		X	X	X	X						X						X				X	X
6	X		X			X	X	X	X				X	X	X	X	X			X	X	X	X
7	X		X	X			X	X					X	X					X	X	X	X	
8	X		X	X	X	X			X	X	X			X	X	X	X			X	X	X	
9	X		X	X	X	X	X	X					X							X	X	X	
10	X		X	X	X	X	X	X	X	X			X	X	X	X	X		X	X	X		
11	X		X	X	X		X						X	X					X	X	X	X	
12	X		X	X	X	X	X	X	X	X			X	X	X				X	X	X	X	
13	X		X	X	X	X	X	X	X	X	X		X	X	X	X	X		X	X			
14	X		X	X	X	X					X	X					X			X	X	X	
15	X		X	X	X	X	X						X								X	X	X
16	X		X	X	X	X	X	X	X	X						X	X		X	X	X	X	
17	X		X	X	X	X	X	X	X					X	X	X	X			X	X	X	
18	X		X			X			X	X	X					X	X			X	X	X	
19	X		X	X	X	X			X	X	X				X	X	X			X	X	X	
20	X		X	X	X		X	X	X				X	X	X	X	X			X	X	X	X
21	X		X	X	X		X	X	X				X	X	X	X	X		X				
22	X		X	X	X	X		X	X	X	X			X	X	X	X		X	X	X	X	
23		X	X		X	X	X	X	X	X	X		X	X	X	X	X				X	X	X
24	X		X	X	X	X					X	X	X	X	X	X	X						X
25	X		X	X	X		X	X	X	X			X	X	X	X	X					X	X
26	X		X	X	X	X			X	X	X		X	X	X	X	X		X	X			
27	X		X	X	X	X	X	X	X	X			X	X						X	X	X	
28	X		X	X	X		X	X	X				X	X					X	X	X	X	
29	X		X	X	X	X	X	X	X				X	X	X	X	X		X	X	X	X	
30	X		X		X	X	X	X	X				X	X	X	X	X			X	X	X	
31	X		X	X	X		X	X	X	X	X		X	X	X	X	X		X	X	X	X	
32	X		X	X	X	X	X	X	X				X	X	X	X	X			X	X	X	
33	X		X	X	X		X	X	X				X	X	X					X	X	X	
34	X		X		X	X	X	X	X				X	X	X	X	X			X	X	X	

APPENDIX D-2

Results from Analysis of Variance
(16 Base Data File)

Variable	F_s	F_{prob}
Y	1.172	0.247
X1	0.392	0.999
X2	1.349	0.109
X3	1.895	0.003
X4	1.355	0.102
X8	0.758	0.829

APPENDIX D-3

Results from Analysis of Variance
(25 Base Data File)

Variable	F_s	F_{prob}
Y	1.879	0.003
X1	0.657	0.929
X2	1.924	0.002
X3	5.768	0.000
X4	4.006	0.000
X8	1.320	0.115

APPENDIX D-4

Results from Linear Regression Analysis

The following list of variables is provided for use in examining the results of each multiple linear regression analysis:

X1	Estimated Project Cost
X2	Number of Design Disciplines
X3	Years of Base Experience of the Engineer
X4	Years of Total Experience of the Engineer
DV1	Minor Construction Project
DV2	Maintenance Project
DV3	Medium Modularity Project
DV4	High Modularity Project
DV5	Hospital Fund Project
DV6	MFH Fund Project
DV7	NAF Fund Project
X8	Perceived Complexity of the Project
DV8	Engineer Did His Own Drafting Work
DV9	Similar Project Has Been Accomplished Previously

MASTER FILE(553 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X2	0.2584	0.2584
X1	0.3562	0.0977
X8	0.4010	0.0448
DV7	0.4144	0.0133
DV5	0.4191	0.0047
X3	0.4213	0.0022
X4	0.4243	0.0029

REPRESENTATIVE DATA(505 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X1	0.2413	0.2413
X8	0.3870	0.1456
X2	0.4465	0.0595
DV8	0.4530	0.0065
DV1	0.4585	0.0055
X3	0.4614	0.0028
X4	0.4698	0.0084

NO ENGINEER DRAFTING PROJECTS(391 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X2	0.2020	0.2020
X1	0.2838	0.0818
X8	0.3281	0.0442
DV7	0.3637	0.0355
X3	0.3706	0.0069
X4	0.3770	0.0064
DV1	0.3804	0.0033

SINGLE DISCIPLINE PROJECTS(363 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X8	0.1617	0.1617
X1	0.2747	0.1130
DV6	0.2880	0.0133
DV8	0.2984	0.0103
X4	0.3032	0.0047
X3	0.3139	0.0107
DV9	0.3164	0.0024

REPAIR PROJECTS(229 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X1	0.1682	0.1682
X8	0.2775	0.1093
X2	0.3368	0.0593
DV8	0.3481	0.0112
DV6	0.3519	0.0038
X3	0.3554	0.0034
X4	0.3715	0.0160

MINOR CONSTRUCTION PROJECTS(229 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X1	0.2903	0.2903
X2	0.4147	0.1243
X8	0.4494	0.0346
DV7	0.4669	0.0175
DV9	0.4701	0.0032
DV3	0.4730	0.0028
DV5	0.4755	0.0025

MAINTENANCE PROJECTS(95 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X1	0.1776	0.1776
DV6	0.2600	0.0824
X8	0.3047	0.0446
DV8	0.3351	0.0304

LESS THAN 10,000 DOLLARS(52 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X8	0.0916	0.0916
X4	0.1252	0.0336

10,000-50,000 DOLLARS(198 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X2	0.1426	0.1426
DV9	0.2037	0.0610
DV1	0.2337	0.0300
X1	0.2609	0.0272
X8	0.2789	0.0180
DV7	0.2867	0.0077
DV5	0.2972	0.0104

50,000-100,000 DOLLARS(145 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X8	0.2378	0.2378
X2	0.3318	0.0940
X3	0.3495	0.0176
DV7	0.3729	0.0233
X4	0.3825	0.0095
DV1	0.3871	0.0046
DV6	0.3936	0.0064

100,000-150,000 DOLLARS(41 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
DV7	0.3180	0.3180
X4	0.4970	0.1790
X2	0.5791	0.0820
X1	0.5963	0.0172
DV4	0.6157	0.0193
X3	0.6279	0.0122

150,000-200,000 DOLLARS(47 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X2	0.4293	0.4293
DV5	0.5641	0.1347
DV7	0.7718	0.2077
X8	0.7827	0.0109
DV3	0.7893	0.0065

200,000-400,000 DOLLARS(60 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X2	0.4757	0.4757
DV7	0.6291	0.1533
DV6	0.6463	0.0171
DV8	0.6574	0.0110
X4	0.6640	0.0065
X3	0.6868	0.0228

GREATER THAN 400,000 DOLLARS(10 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X8	0.6249	0.6249
DV7	0.7476	0.1226
X3	0.9114	0.1638
DV6	0.9518	0.0403
X1	0.9720	0.0202
DV8	0.9960	0.0239
DV3	0.9994	0.0034

10,000-100,000 DOLLARS(343 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X2	0.2281	0.2281
X8	0.3187	0.0906
X1	0.3644	0.0456
DV1	0.3774	0.0130
DV7	0.3872	0.0098
X3	0.3948	0.0075
X4	0.4051	0.0103

100,000-200,000 DOLLARS(88 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X2	0.3734	0.3734
DV7	0.4739	0.1005
DV5	0.5394	0.0654
DV8	0.5735	0.0341
X1	0.5911	0.0175
DV3	0.6072	0.0161

GREATER THAN 200,000 DOLLARS(70 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X2	0.4068	0.4068
X8	0.4467	0.0399
DV6	0.4611	0.0143
DV7	0.4740	0.0129

25-BASE DATA FILE(424 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X2	0.2598	0.2598
X1	0.3471	0.0873
X8	0.3854	0.0382
DV5	0.3927	0.0073
DV8	0.3976	0.0048
DV7	0.4025	0.0049
X4	0.4060	0.0034

16-BASE DATA FILE(288 PROJECTS)

VARIABLE	R SQUARE	R SQUARE CHANGE
X2	0.3658	0.3658
X1	0.4491	0.0833
X8	0.4803	0.0312
X4	0.4998	0.0195
DV7	0.5059	0.0060
DV8	0.5094	0.0035
DV5	0.5122	0.0028

APPENDIX E

DISCUSSION OF STATISTICAL METHODS

APPENDIX E-1

Analysis of Variance (ANOVA)

Analysis of variance is a statistical technique which can compare the mean of a sample to either the overall population or other sample means. As there is no recorded population of Air Force projects, analysis was conducted between sample means. The SPSS program ONEWAY-ANOVA compares sample data means based on the hypothesis:

$$H_0: \mu_1 = \mu_2 = \cdots \mu_n$$

$$H_A: \text{ at least one } \mu_i \neq \mu_n$$

where the μ_n are defined as the dependent variable sample means for n independent variables (i.e., thirty-four bases).

The following assumptions must be met to allow use of analysis of variance.

1. The dependent (response) variable is normally distributed for each sample group.

2. The distributions of the dependent variable are normally distributed.

3. The error terms are independent random variables.

Analysis of variance by the ONEWAY-ANOVA program allows input of all variables for each quantifiable variable class. The computer then separately examines each quantifiable variable class by grouped mean and standard deviation. Each group mean is then entered into an analysis of mean differences calculation, which provides an F-ratio statistic, F_s.

The test for statistical significance is conducted with the F-statistic. The quantifiable variable is considered statistically significant at the specific confidence level $(1-\alpha)$, when F_s is less than a critical value of F, F_{crit}. The F_{crit} value depends on the degrees of freedom between groups and within groups at the specified α level. When $F_s < F_{crit}$, we are unable to reject the null hypothesis and must conclude that the variable's means are equivalent.

The ONEWAY-ANOVA program performs contrast tests for rejected variables and produces subsets of bases. These bases have equivalent means when compared by differences between paired sample means at the established confidence level. The contrast tests are the Student-Newman-Keuls (SNK) and Scheffe. The SNK test compares ranges of simple pairwise differences on group means of different sizes, whereas the Scheffe test comparison uses one range based on the largest group size. The SNK test is more powerful for unequal sized data groups.

APPENDIX E-2

Linear Regression Analysis

Linear regression analysis is a method which is used to describe whether a linear relationship exists between a dependent variable and the independent variable(s) for a set of data points. Multiple linear regression (MLR) takes into account the effect of more than one independent variable on the dependent variable. Utilizing MLR, with project design manhours as the dependent variable, a model may be obtained which would predict project design manhours as a function of a number of independent variables.

The MLR model will be in the form of the following equation:

$$Y = B_0+B_1X_1+B_2X_2+...+B_iX_i$$

where:

Y = Project design manhours.

X_i = Parameters based on descriptive data pertaining to the project or the base where the project is being designed.

B_i = The coefficients of regression.

The following assumptions are necessary if multiple linear regression is to be an appropriate method to establish the linear relationship between the dependent variable and the independent variables.

1. The expected value of the error term (value of Y minus the estimated value of Y) for each conditional distribution of Y given X_i is zero.

2. The error terms of each conditional distribution of Y given X_i are uncorrelated.

3. The variance of the error terms for each conditional distribution of Y given X_i is constant.

4. The error terms of each conditional distribution of Y given X_i are normally distributed.

5. The sample observations are linearly independent.

The analysis uses the Regression Subprogram of SPSS which computes a sequence of linear regression equations in a stepwise manner. The computer enters independent variables in single steps with the variable that explains the greatest amount of variance in the dependent variable being entered first (14:345). When enough regressors (independent variables) have been added so that further significant reduction in the residual variance is either not possible or specified criteria have been met, the calculation stops (20:306).

Variable Significance

Once the model has been created, the coefficients of the variables in the equation must be tested for their statistical significance. When a variable is considered statistically significant from zero at a specified confidence level, for example 95 percent, it can be said that one is 95 percent confident that there is a linear relationship between the dependent variable and the independent variable. If a linear relationship exists, then that variable can be considered as a predictor of the dependent variable.

The test for statistical significance is conducted on both the overall equation and the individual independent variables. The overall equation test of significance is used to determine whether or not the equation can be considered as a good predictor of the dependent variable. Each individual independent variable is tested for its contribution to the overall equation and shows whether or not a particular independent variable is a predictor of part of the value of the dependent variable. It is possible for one or more of the individual independent variables to fail to be statistically significant, while the overall equation can be statistically significant, and hence a good predictor of the dependent variable. This occurrence results from a phenomenon called multicollinearity, which, very simple stated, means that there exists an interrelationship among the independent variables themselves. These independent variables, none of which are statistically significant, may "combine" to act like one statistically significant variable and would then be included in the overall equation.

The tests for statistical significance will be conducted at the 95 percent confidence level. The overall equation will be tested for its significance in accordance with the procedures shown below.

H_0: $\beta_1 = \beta_2 = \ldots = \beta_i = 0 \quad \alpha = .05$

H_A: At least one $\beta_i \neq 0$.

<u>Test Statistic</u>	<u>Critical Statistic</u>
SPSS	
F_0 = Computed Figure	$F_c = F\alpha;\ p-1,\ n-p$

If $F_0 > F_c$, reject H_0. Conclude that the overall regression is statistically significant at the selected α level.

If $F_0 \leq F_c$, fail to reject H_0. $Y = \beta_0 + e$, and we might as well use $\hat{y} = \bar{y}$.

The criteria used to evaluate the efficiency of the predictive power of the model is derived from a subjective test on the coefficient of determination (R^2). The coefficient of determination is calculated using the formula:

$$R^2 = \frac{\text{Explained Variation Due to Regression}}{\text{Total Variation}}$$

The higher the value of R^2, the more accurate the model is in predicting the value of the dependent variable given the independent variables. An R^2 of approximately 0.80 is normally considered to be sufficient to conclude that the model has an acceptable prediction capability.

Research Assumptions

1. Data on the independent variables have been compiled accurately.

2. Multiple linear regression is an appropriate method for analysis and creation of the prediction model.

Limitations

The model resulting from this research effort will be valid only for predicting future project design manhours for the bases included in the sample. Inferences to enlarged or similar populations must be based on subjective evaluation and logical argument.

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