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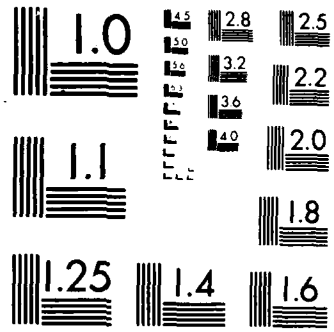

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CONTRACT MODIFICATIONS PROCESSING PROCEDURES: A GENERALIZED STOCHASTIC MODEL II

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This thesis demonstrates the use of computer simulation to model the U.S. Army Corps of Engineer's construction change order processing procedures. A generalized stochastic network based on the SIMSCRIPT II.5 discrete event simulation programming language is presented. The use of the Ramberg-Schmeiser percentile probability distribution and regression analysis to model network activities as well as a sensitivity analysis of the simulation model is featured.

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THESIS ABSTRACT

THE OHIO STATE UNIVERSITY
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DEPARTMENT: CIVIL ENGINEERING DEGREE: MASTER OF SCIENCE

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This thesis demonstrates the use of computer simulation to model the U.S. Army Corps of Engineer's construction change order processing procedures. A generalized stochastic network based on the SIMSCRIPT II.5 discrete event simulation programming language is presented. Use of the Ramberg - Schmeiser percentile probability distribution and regression analysis to model network activities as well as a sensitivity analysis of the simulation model is featured.

The principle conclusion of the research is that computer simulation can effectively be utilized to solve construction management problems provided adequate expert supervision is available. A simulation model building methodology is also discussed.

Richard E. Larew

Advisor's Signature

CONTRACT MODIFICATIONS PROCESSING PROCEDURES:

A GENERALIZED STOCHASTIC NETWORK MODEL II

A Thesis

Presented in Partial Fulfillment of the Requirements

for

the degree Master of Science in the

Graduate School of the Ohio State University

by

CPT Donald R. Curtis Jr., B.S.

* * * * *

The Ohio State University

1986

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PREFACE

EXECUTIVE SUMMARY

This thesis demonstrates the use of computer simulation to model the U.S. Army Corps of Engineer's construction change order processing procedures. A generalized stochastic network based on the SIMSCRIPT II.5 discrete event simulation programming language is presented. This experiment springs from an original study conducted at the U.S. Army Construction Engineering Research Laboratory in 1977. Change orders are tracked from their inception through their final approval. From this an understanding of the contract process is gained and recommendations for process improvement are made.

The five basic research steps were: development and verification of the simulation model, obtaining data on the actual process, data analysis and regression model development, model-data synthesis, and sensitivity analysis. Models were constructed in a succession from a skeletal model used to check the process flow control structure, to a data-based model that was used to study the actual process. The Ramberg-Schmeiser percentile probability distribution was used to model all process activities and linear regression models were developed to assist in the construction of the final simulation model as well as serving as a means of verifying the credibility of the simulation output. The last stage of the experiment involved conducting a sensitivity analysis of the simulation model to get a feel for its robustness.

Conclusions consisted of the determination that computer simulation could indeed be used to effectively model construction processes such as the processing of change orders, the conclusion that such problems are best attacked by a combined team with expertise in key problem areas, the realization that with a developed model, the actual simulation gaming process was quite simple to execute and finally it was found that Resident Contracting Officer approval authority set at the $50,000 level might result in overall process time savings. Research recommendations consisted of the need to examin the relationship between change order processing time and overall project cost and the relationship between regression and simulation model results. A recommendation to persue more user friendly simulation and data base programs was also offered. The final conclusion was that computer simulation can effectively be utilized to solve construction management problems provided that adequate model development and supervisory expertise is made available. At present, simulation does not appear to be a tool that is easily used by the layman.

CHAPTER I

INTRODUCTION

1.1 Backround

The research reported in this thesis uses one new technology, computer simulation, to investigate construction time reductions which might be realized by changing staffing and/or policies concerning contract modifications. No stone should be left unturned in searching for ways to reduce the time and cost of constructing new military facilities.

> The Army of the 1980's and 1990's will require modernization of an aging physical plant (in excess of 30 years) and new facilities to support much more complex technical systems. New facilities to be provided and existing facilities to be upgraded have created a backlog of needed facilities. Increased funding is currently programmed to meet this backlog; however, the rate at which this can be accomplished is constrained by high construction costs and the time required to deliver the new facilities.
>
> New facility planning, design, construction and construction management technologies are needed to increase the Corp's [U.S. Army Corps of Engineers] productivity and reduce the time needed to deliver new facilities (Department of the Army, 1985).

Since most of the facilities mentioned above will be constructed through the use of fixed-price construction contracts and since those contracts will typically require modifications to insure that the facilities function properly and meet user needs, it seemed logical to experiment with the Army Corps of Engineer's current contract modification processing procedures to see where time and money could be saved (O'Connor 1977, p. 7). Because of the long term nature and the large dollar values involved in the modifications process, direct experimentation was considered to be impractical. Computer simulation however, provided a suitable alternative approach to the problem and in 1977 an initial study was conducted by the U.S. Construction Engineering Research Laboratory (CERL) under the In-house Laboratory Research Program.

The original study was entitled Modifications Processing Procedures: A Generalized Stochastic Network Model (O'Connor, 1977). That study was a first-pass, best estimate attempt to examine the Army Corps of Engineers' contract modifications processing procedures using computer simulation (O'Connor 1985). Change Order processing under Contract General Provisions Clause 3--Changes (GP-3) of the U.S. Army Corps of Engineer's Construction Contract was modeled to demonstrate how mathematical modeling could be applied to Corps of Engineers' operations (O'Connor 1977, p. 11). As good as the original study was, its scope was limited due to budget constraints and it was felt that given additional resources, refinements in the areas of model sensitivity and real data validation should be attempted. Using the original study as the starting point, the research project reported in this thesis was undertaken.

1.2 Problem Definition

The major question to be addressed in this thesis is as follows: "Can the U.S. Army Corps of Engineers procedures for processing contract modifications, specifically Change Orders, be reliably modeled using computer simulation so that leaders can use the simulation to develop policy decisions that reduce the overall time and cost of fixed-price construction contracts?"

1.3 Nomenclature

As this research deals with a military processing system as well a computer simulation language, both of which involve many terms that are used in an unusual context, certain key terms and and common acronyms are defined at this point for the reader's benefit. Other terms with a more local significance will be defined in their appropriate sections.

CERL Model: Constant reference will be made to the original simulation, conducted in 1977. This model will henceforth be referred to as the CERL model (O'Connor, 1977).

New Model: This was the simulation model which was developed by the author as a result of this research.

AMPRS: This acronym stands for the Automated Management and Progress Reporting System. This was the database from which much of the research data was obtained (Perine, 1986).

SAS: This acronym stands for the Statistical Analysis System which was used to perform most of the AMPRS data analysis as well as multiple linear regression analysis(SAS Institute, 1982).

BMDP: This was another statistical analysis package used by Bio Medical Engineers to perform nonlinear regression analysis (Dixon, W.J, 1981).

SIMSCRIPT II.5: This is the name of the simulation language used to model the modifications processing procedure on the IBM Systems 370 mainframe computer

(Kiviat, 1983).

RS Distribution: This is the abreviation used by the author when referring to the Ramberg-Schmeiser percentile probability distribution, which was used to model the many random variables found in the simulation program (Dudewicz, 1979).

Change order: A construction contract modification which requires the contractor to accomplish work different from that required by the existing contract documents where changed work requirements fall under the general scope of the contract and within the physical limits of the construction site(Department of the Army, 1976). In this case the dollar value of change orders was limited to less than $100,000. Throughout this thesis the terms modification and change order are used interchangably.

Activity: The term Activity refers to any of the various processing stages of a change order. Normally activities will take the form of a random variable in the simulation model.

Process/Process Routine: A process represents an object and a sequence of actions it experiences throughout its life in the model and a process routine may be thought of as a sequence of interrelated events separated by lapses in time (Russell 1983, p. 2-3). In the simulation model the change orders along with the procedures used to prepare them, may be thought of as a "process." The simulation program uses several process routines which embody the logic description for processing change orders (Russell 1983, p. 2-8). In other words, they control what "activities" are to be performed at any given time throughout the simulation program.

Sensitivity (Analysis): This term will commonly be used by the author in reference to the degree of model response to the changes of simulation model parameters.

Field Change/Staff: Field changes include all changes identified and/or initiated by the project Resident Office staff or contractor. The Resident Office is located on or near the actual project site and is under the supervision of the Resident Engineer (RE) (O'Connor 1977, p. 13).

District Changes/Staff: These are all changes initiated by the District Office staff or by the potential user of the facility being constructed. The District Office is the headquarters under which the Resident Offices receive command guidance. The District Engineer is the individual who has actual contracting authority and serves as the Contracting Officer (CO) for the Corp District (O'Connor 1977, p. 13).

1.4 Objectives

Given the major question stated above (Problem Definition), the following specific objectives were established to help this research:

1. Update the CERL model, using AMPRS data, to model the various activities involved in change order processing as random variables and compare the results obtained with those based on the original set of assumptions (O'Connor 1985);

2. Conduct a sensitivity analysis on the new model to obtain a measure of the model's robustness (O'Connor 1985); and

3. Based on the research, offer comments to the U.S. Army Corps of Engineer's pertaining to contract modifications and claims procedures and management of the AMPRS data base.

1.5 Scope

As with the original CERL study, this thesis will "illustrate the capability of generalized stochastic network models to realistically model the critical features involved in the processing of modifications and claims. It does not include all activities required for processing modifications and claims; however, it does contain enough activities to exemplify the omitted activities and the structural relationship between those activities"(O'Connor 1977 p. 11). In contrast to the original study, this thesis will be confined to process cycle time rather than approximating process cost. This will not seriously diminish the study's utility as it could be effectively argued that the costs associated with change order processing could be modeled as a function of cycle time.

CHAPTER II

METHODOLOGY

2.1 Introduction

Having discussed the backround for this research, the basic problem and the research objectives, it is now time to examine the approach to the research - the methodology. Since the development of the simulation model was such a complex undertaking, the research was divided into several phases, each containing its own action sequence. The five basic steps were: development and verification of the simulation model, obtaining data on the actual process, data analysis and regression model development, model-data synthesis, and sensitivity analysis. These steps are presented in the order of their occurrence along with an overview of their execution.

2.2 Development and Verification of the Simulation Model

In order to insure that the simulation model did indeed perform as expected, the model evolved through a process of incremental refinement and verification. This was necessary, as it became clear early on in the research that it was possible to write a simulation program which, on the surface, appeared to be adequate, yet upon further scrutiny was found to be extremely flawed. The procedure stated briefly consisted of starting with a deterministic model patterning the process control structure, followed by a model of the stochastic processes involved the RS distribution, then a model used to duplicate the CERL experiment and finally the construction of the new model based on actual data. At each development stage a series a verification checks were made to insure that the model was operating properly. An overview of each development stage will now be presented.

The first simulation model constructed was designed to model all of the various processing flow patterns that a change order could undergo. In other words, it was used to check the logic of the main process routine used in the simulation program. Instead of modelling the activities encompassing change order processing as random variables, the activity durations were held constant at their respective mean values. The only random processes allowed to occur were those which allowed for alternative processing flow. For example, it was possible for a change order proposal to be accepted with or without negotiation between the field staff and the contractor. Each branch had an associated probaility of occurence and depending on the value of a random number called up by the program, the change order would follow one of two possible routings. A listing of this program is contained in appendix A.

Verification of this program was conducted by printing out the results of each change order processed, along with all of the characteristics assigned to that particular change. These characteristics, such as base price, lead time, and type, are known as process attributes and will be discussed in chapter three. (Process attributes are similar to subscripted variables assigned to each change order and carry its key information throughout the program.) This printout technique was used to insure that important program information was not being destroyed until its need was ended. The printout was then cross checked using a flow chart used to calculate possible outcomes, thereby seeing if the final results were logical. No queuing was involved so any final cycle time was a sum of the mean values of the activities present in the model along a given processing flow path.

In the second stage of model development, a simulation program subroutine, used to model the RS distribution, was installed. Actually, the subroutine handled all of the random variables used in the program and this subroutine served as the heart of all stochastic processes in the simulation. Given its importance, it was necessary to make absolutely sure that this subprogram was properly called up for use and that its outputs were correct. The use of the RS distribution to model the various activities in the model will be covered in detail in chapters three and four. For now, it is only necessary to understand that the constant values previously used to model activities were replaced by a subroutine and several sets of distribution parameters and then verification checks were performed on the revised model.

Verification of the second stage model was again accomplished through the use of specialized printouts. A copy of this program and a sample output is provided in appendix A. Basically, the test consisted of causing the output of every RS distribution, labeled RS1, RS2, RS3, etc., to be printed as it occurred in the program. This way, the distribution values could be checked for reasonableness and the call order of the subroutine could be verified. Along with these items, the change order attributes were also printed so that a complete picture of program operation was generated.

After the simulation program control structure and probability distribution subroutine were verified, the next logical step was to pick up where the CERL research ended. It was necessary to insure that the results obtained using the new simulation model would closely approximate those of the CERL model and therefore, the CERL model was duplicated using the RS distribution subroutine and the SIMSCRIPT II.5 programming language. A listing of this program is provided in Appendix A and the results of this step are covered in Chapter V. All six of the original experiments were run on the computer and the results were compared.

The final stage was the development of the data based program which the author refers to as the new model. It was constructed by substituting RS distribution parameters, based on AMPRS data, into the stage three model. There were actually two versions of this program, differing only by the final printed output produced. Both programs are listed in Appendix A along with their sample outputs. One version provided a complete printout of change order attributes as each change order was completed. This output was too extensive to have printed for a high number of simulation iterations so the other version printed only simple descriptive statistics on cycle time and queuing. As an additional check to see that the output received was reasonable, use of the special histogram generating feature of SIMSCRIPT II.5 was incorporated (Larew 1986). This model was then used for all other experimentation.

2.3 Obtaining Data on the Actual Process

The data for this research was obtained from the U.S. Army Corps of Engineers Baltimore District, Capitol Area Office, located at Fort Belvoir, Virginia. The data was contained in both office files and the area office's AMPRS data base. Both of these sources were crossmatched to insure that any key punch errors were caught. Also, both sources were required to get a complete list of all items needed to model the activities of the modifications process. Files were drawn at random, certain information was extracted and then the AMPRS data base, stored on a personal computer, was accessed and the same modifications were called up. Information common to both sources was checked for agreement and items with discrepancies were rechecked to obtain the most accurate data possible. All data was then loaded into the Statistical Analysis System (SAS) for future reference. A listing of the data used in this research is provided in Appendix B.

2.4 Data Analysis and the Regression Models

Data analysis was conducted using SAS and BMDP for two reasons. First, the univariate analysis was necessary to find the mean, standard deviation, skewness and kurtosis of all data items which corresponded to either process attributes or change order activity durations. The central moments, listed above were necessary to find the parameters used in each activity's RS probability distribution. Secondly, the author decided to conduct a parallel analysis of this problem using regression techniques to provide both increased insight into the problem itself as well as to provide a cross check for the simulation model. The steps used in conducting the data analysis are listed below.

The first step was to obtain simple descriptive statistics on all of the items in the data set, which will be referred to as model variables. This information provided a general feel for the potential input items for the simulation as well as identifying potential independent variables for regression analysis, in terms of their respective frequency distributions. Next, scatterplots of each combination of model variables were plotted, to see if any obvious trends appeared to exist and once that was done a correlation matrix was constructed using SAS to see if there was evidence of multicolinearity.

Once the above steps were completed the author tried to model total change order processing time using simple linear regression (SLR). The three models showing the best potential, based on the author's opinion, were run and compared. From SLR, further regression analysis was conducted using automatic model selection procedures including forward selection, backward elimination and stepwise methods. Next, the SAS RSQUARE-CP procedure was used to examine all model combinations in terms of their respective R^2 and Mallow's CP statistic values. The author then calculated values for adjusted R^2 values and constructed a rank ordering matrix, to determine the single best model for predicting total processing time.

Given the results of the previous steps, variable transformations, particularly inverse and log transforms were applied to selected variables and the automatic search and RSQUARE-CP procedures were again conducted.

From all of this a final linear model was derived using SAS. As a double check, the author used the same independent variables and performed nonlinear regression analysis using BMDP to see if any differences in the final model were evident. The final regression model was then complete and ready for use in comparison checks with the simulation model.

2.5 Synthesizing the Simulation Model With Actual Data

As mentioned in the previous section, the central moments of all model variables were obtained and were used in deriving the RS distributions for selected model variables. Each model variable, which corresponds to some activity conducted in change order processing, was screened for potential use in the simulation and its skewness and kurtosis were used to select the four parameters that determined its particular RS distribution. Next, those parameters along with an RS subroutine call statement were inserted into the simulation program and all together they comprised the complete model for one random variable in the simulation program.

It is important to note at this point that the data used to duplicate the CERL model using the RS distribution was not obtained from the Baltimore District set that has been referred to but from the original report itself. All probability distributions shown in the report were converted to histograms, the moments were calculated from the histograms and RS distribution parameters were obtained. From there, the RS distributions and the original distributions were overlaid to insure that a proper fit was achieved. Then those sets of RS distribution parameters were loaded into the simulation program. In the case of both the duplication and the new model, once the RS distribution parameters were loaded, the simulation program was run on the computer and the results were

2.6 Conducting the Sensitivity Analysis

The sensitivity of the simulation model was measured for changes in the following items: the number of total iterations of the simulation, warm up time, the mean arrival rate of change orders, RCO authority level, probabilities of the various activities that govern change order processing flow, and the shapes of the various probability distributions. The order of the list above is also the sequence used in the actual sensitivity tests. Combinations of changes were not checked per sae however, the manner in which the evaluation was performed actually demonstrated this effect to a limited degree. This will become clearer to the reader in Chapter V. No results will be presented at this time as these are covered in Chapter V.

The first sensitivity test performed was an experiment to find out how the number of iterations i.e., the number of change orders processed in the simulation, affected the final results. This eventually lead to an attempt to find the minimum amount of simulation needed to obtain solid results. The histogram feature of SIMSCRIPT II.5 was used to gather data on the output distribution for change order processing time to determine how many iterations were necessary to adequately model the tail values of the cycle time probability distribution (Larew 1986). Once this minimum number of iterations was determined, it was used throughout all remaining experiments.

The next step in the sensitivity analysis was to see the effects of"warm-up" (Russell 1983, p. 4-22) on the simulation model. The concept of warm up is that initially, all queues are empty and the first changes orders processed will experience little or no wait time before being serviced and have low cycle times as compared with those processed when all queues have reached steady state. Since the author was interested in analyzing change order processing in a steady state environment, it was important to find out where all model warm up ended and reset all statistical counters so that only results occurring during steady state were recorded.

The rate at which the simulation program generated change orders was the next area examined. The author selected to model change order arrival rates using a Poisson probability distribution which will be explained in Chapter III. The Poisson distribution is governed by a single parameter, lambda, which represents the mean rate at which change orders are generated (are ready for processing). As this test progressed the author also sought the lambda value which was applicable over the widest possible range, since there was no data from which to estimate the actual value. This value was used in all successive tests.

RCO authority level is the dollar ceiling beyond which a change order must go to a higher authority for processing. Levels over a wide range were tested and the results were recorded. Once again, a value for this item was sought that would be applicable in a wide range of situations and that value was used in successive tests.

There are many activities in the processing of change orders that equate to decisions governing processing flow. These flow branches were mathmatically modeled by assigning a probability to each route and routing items at random, accordingly. Each of these branches was varied to obtain a feel for overall model impact. In a similar manner the shapes of the probability distribution functions was varied from J-shaped tail right, to normal, to J-shaped tail left, to uniform to see the respective effects on overall change order processing time.

This concludes the methodology overview and begins the detailed discussion of this simulation experiment. The next two chapters will examine the steps covered in this chapter, but in greater detail. Chapter III concentrates on the steps most closely related to the simulation program itself, while Chapter IV will emphasize the data collection and analysis steps.

CHAPTER III

DETAILED EXAMINATION OF THE SIMULATION

3.1 Introduction

In this chapter, the simulation model and its development is presented. Starting with a brief backround discussion, highlighting the differences between the new and CERL models, this chapter takes the reader through the model building process, from an examination of the modifications procedure through the verification of the data synthesized model. Many concepts related to both the simulation program and the modifications procedure will be presented and a great deal of reader attention is required to sort through all of the details. For this reason, more subparagraphing is used to aid reader comprehension. This becomes particularly important while reading the section on the construction of the detailed model and its assumptions.

3.2 Backround

As stated in Chapter I, in 1977 the Construction Engineering Research Laboratory (CERL) conducted the original research on this subject, using the GASP IV programming language and took a best estimate approach to the problem. For example, many of the random variables representing the various activities in the modifications processing procedure were modeled using mathematical transformations in which, activity durations were considered to be a function of change order base price and a normally distributed variation term. Also, the beta distribution model, common to that used in the Program Evaluation Review Technique (PERT) with its shape determined by minimum, maximum and most likely values, was used extensively in the CERL model. These techniques carried strong assumptions with them that, although satisfactory for a first effort, probably would not have stood up to close inspection. The author of the CERL study (O'Connor) desired to perform more detailed model experimentation, particularly in the area of sensitivity analysis, but was unable due to budget limitations.

This study differed from the original in two ways. First, very few mathmatical transformations were used and the concept of activity durations calculated as a function of base price was down played except in one instance. Most activities were modeled using RS probability distributions derived from actual data, thereby operated more like the random variables they represented. Secondly, The SIMSCRIPT II.5 programming language, as opposed to GASP IV, was used. Although SIMSCRIPT II.5 is also a discrete simulation programming language it uses several different concepts, such as the notion of the process routine, to accomplish its results. These programming differences required one to approach simulation modelling in a slightly different way.

3.3 The Contract Modifications Processing Procedure

The guide for the Corps of Engineers contract modifications processing procedures is Engineer Pamphlet (EP) 415-1-2, "Modifications And Claims Guide - Fixed Price Construction Contracts," dated October 1976. Appendix F of this pamphlet contains a modifications and claims flow chart and this flow chart, as it appears in appendix E of this thesis, was modified to encompass those activities that were modeled in the simulation. Basically , the flow chart shows that the once the availability of funds for a contract modification, in this case meaning a change order as opposed to other possible forms of modifications, were established, processing of the modification was modeled through either a tentative agreement on a bilateral modification, or the issuance of a unilateral modification (O'Connor 1977, p. 11). Detailed information on the individual activities depicted in Appendix E will be covered later in this chapter.

The procedures established by EP 415-1-2 are general guidelines and in actual practice, differences are possible. In the Baltimore District, Capitol Area Office slight differences were evident, requiring the simulation model to be altered. For example, EP 415-1-2, in its description of the flow chart activities, refers to the establishment of a suspense of ten days for contractor proposal submission. In practice, suspenses were based on change scope and although this was quite logical, it required the model for late proposal submission in the simulation program to be altered significantly as compared to the CERL study. The impact of differences in the procedures used will become evident later in this chapter.

3.4 The SIMSCRIPT II.5 Programming Language

Before getting into the details of the simulation program itself, it is appropriate to cover some of the key features of the simulation programming language itself. SIMSCRIPT II.5 is a discrete-event, general purpose, simulation programming language that is marketed by CACI, Inc-Federal. One of the advanced features of the language is its use of the "process" concept, which simplified model construction greatly. Other special features that made the language well suited to this problem was the ability of the user to access several different random number streams at a time, control random number stream seed values, the ability reset all data counters after allowing for a model warm up period, and particularly important in this particular application, it allowed the user to insert a specialized probability distribution, such as the one developed by Ramberg and Schmeiser. Also, the programs were executed on the mainframe computer in a matter of seconds.

As stated above, this was a discrete-event simulation. Discrete simulations differ from continous-time simulations in that a discrete-event simulation describes a system in terms of logical relationships that cause changes of state at discrete points in time rather than continuously over time (Russell 1983 p. 1-3). Because of this "the passage of time between events need not accurately be followed; rather the passage of simulation time is driven by the sequence of events, [in this model - the process] advancing always to the time of the next significant event (Kiviat 1983, p. 325)." Since the primary focus of this problem was to discover ways to improve overall modifications processing time and since the contract modifications process is inherently discrete, a discrete simulation was therefore appropriate.

A SIMSCRIPT II.5 model contains three primary elements (Russell 1983, p. 2-5):

1. A preamble which is purely declarative and is used to identify all modelling element (processes and resources) along with the declaration of other items such as data structures, changing backround conditions, and performance measurements.

2. A main routine which is used to create and initialize all resources, which are items required by a process in order to proceed with its execution, and statements used to start the simulation and print its final output.

3. A process routine for each process declared in the preamble (see the nomenclature section for the definition of process routine).

3.5 Detailed Model Description and the Simulation Program

Having discussed the general research backround, methodology, and programming language, the program details will now be discussed. The basic program structure is simple. It contains a preamble, a main routine, two process routines and one subroutine. As stated in Chapter I, this simulation model was a simplification of the Corps of Engineers' modifications and claims processing procedure but did contain sufficient detail to reflect the key elements of the system. This is not unusual and as Edward C. Russell (1983, p.1-8), the author of "Building Models With SIMSCRIPT II.5 states, "A model is a simplified representation of a system, and it should incorporate only those features of the system that are important for the user's purposes." This guideline was adhered to in model development. The specific details of the simulation model are now discussed.

The program preamble declared two processes named Generator and Mod. Generator, as its name implies, was used to generate the initiation of the modifications processing procedure and could be loosely thought of as creating individual change orders. The second process, Mod, controlled the logic for processing change orders through all of their various stages. Several process attributes associated with the process Mod, were declared in the preamble, those being: base price, lead time, proposal preparation time, general estimate, notice to proceed, type, initiation time and two part indicator. The process attributes served as global simulation variables containing the key information describing a particular change order and were used much like a set of subscripted variables. The details of each of these processes will be discussed later. A single "resource," called Staff Officer, was declared and the following performance measures with repect to this resource were tallied: Average queuing time, maximum queuing time and percent busy. In addition to these performance measures the mean and standard deviation of all change order cycle times were calculated and a histogram describing the frequency distribution of change order cycle time was requested. One subroutine called RS was declared.

The Main routine of the program initialized the resource Staff Officer and set the number available for use by the process Mod. This routine was also used to start the simulation and upon its completion, print out all performance measures declared in the preamble. Special statements were added to the Main routine to allow for a print out of the frequency histogram. Finally, the activation statement for the process Generator was installed in the Main routine.

Process Generator was simply a DO LOOP control structure that activated the process Mod, waited a for a Poisson distributed time period and looped back to its own begining to repeat the entire process again. The Poisson distribution was selected to describe the random waiting time between change order initiation because its primary assumptions fitted this general situation quite well. First, a change order could have occured at random at any point in time. Second, the occurrence of a change order in any given time interval was independent of that in any other nonoverlapping time interval and finally, the occurrence of two or more change initiations in a given time interval was negligable (Ang and Tang 1975, p.114).

Before covering the details of the process Mod, which will be quite extensive, the following explanation of program execution is provided to enhance reader understanding. The main routine started the simulation and called up the process generator. Process generator then activated process Mod which carried out all of the logical steps in change order processing, until the number of iterations specified in the DO statement were completed. Process Mod continued its operations until all of the calls for process activation by process generator were complete. After this point, there were no more calls for process activation and the simulation terminated. The Main routine then assumed program control and printed the output of all performance measures stored in memory during program execution, including the histogram.

The process Mod was the key component of the simulation in that it was within Mod that the actual modifications processing procedure was modeled. To describe this process, the same format as used in the original CERL study will be followed (O'Connor 1977). This will facilitate reader comparison of the two models if such comparison is desired. Each activity of the procedure flow chart, listed in Appendix E, will be referenced and then an explanation of the model, used to approximate the behavior of the actiivity, will follow. The following convention will be used to describe the parameters of activities modeled with the RS distribution: RS(mean, standard deviation, lambda1, lambda2, lambda3, lambda4). The term lambda is used to describe the four parameters of the RS distribution. So for example, if the author wishes to describe an activity modeled with an RS distribution, with a distribution mean of 25, a standard deviation of 5 and lambda parameter values 1-4 of 1,1,1 and 1 respectively he will state, "this activity was modeled using RS(25,5,1,1,1,1)." Also for each activity modeled in this way, a graphical presentation of the activity's cummulative distribution function will be provided. This presentation will show the RS distribution, referred to simply as "RS", superimposed upon the cummulative distribution of the actual data, referred to as "REAL." This will allow the reader to quickly compare the two. In the event where the RS distribution was used to model the beta or normal distributions of the original study, the RS distribution will be labelled "RSMOD", and superimposed upon it will be the CERL model distribution, called "MODEL."

3.5.1 Change Order Initiation and Attributes

Upon initiation of the process Mod by process Generator, the first modelling step was to establish those key information elements, known as attributes, taylored to the execution of that particular process call. In the new model the first attributes set were a set of Ø/1 state variables. That is, the variables were set at zero until the state had changed and then their values were set to one. The variables in this category included Notice to Proceed (NTP), General Estimate (GE), and Two Part Change (PART). For example, initially the value of NTP was set at zero meaning no notice to proceed with the change had been given by the Corps of Engineers to the contractor. Once such notice had been given, the state variable value was set at one and the change was processed from then on with that information encoded. Next, the "type" of change was established. Changes were categorized as either field or district changes, with seventy five percent being district changes. This was the same percentage as used in the CERL model and it should be noted that the data sample taken was remarkably close to the estimated value, with seventy six percent of the changes generated in the field and twenty four percent generated at the district level. The variable used to record this information, TYPE, was set to a value of one for field changes and a value of two for district changes.

The next series of attributes were set to values determined by their respective RS distributions. The reader is referred to figures 3.1 through 3.6 for a graphic presentation of the cummlative distribution functions of these variables. Change order base price (BASE.PRICE) was set to a value of RS(5.92, 6.33, 1.311, .4415, 4.3993, .309) for field changes and RS(14.6, 14.29, .773, .5008, 5.5245, .85032) for district changes. Change order proposal preparation time (PROP) was set to a value of RS(9.644, 10.85, 1.577, .3644, 19.983, .60731) for field changes and RS(10.083, 35.72, -.381, .5732, .8965, 2.2392) for district changes. The lead time, used to determine the critical start date of the changed construction work, was calculated by adding the proposal preparation time to the current simulated time value, known in SIMSCRIPT II.5 as TIME.V. This was done because a study of actual office practices revealled that contractors tended to submit their proposal for changed work as slow or as fast as they needed to, in order to prevent themselves from

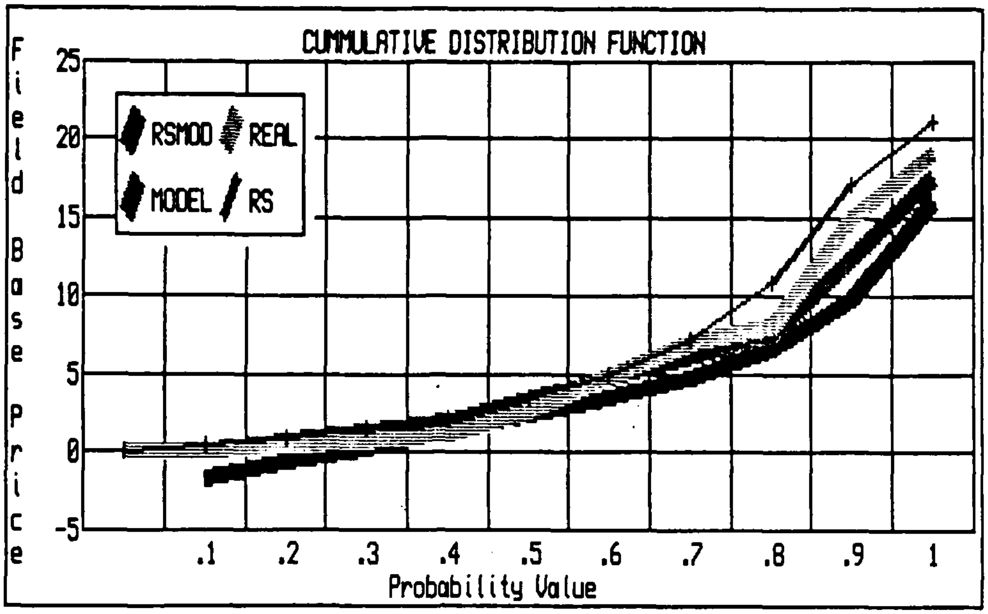

Figure 3.1 Field Base Price Probability Distribution

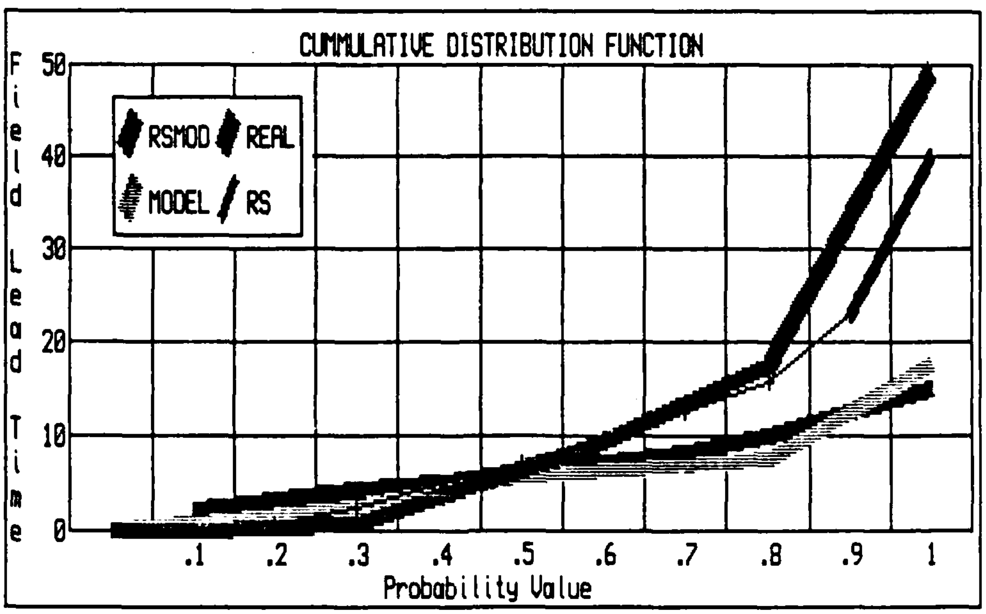

Figure 3.2 Field Lead Time Probability Distribution

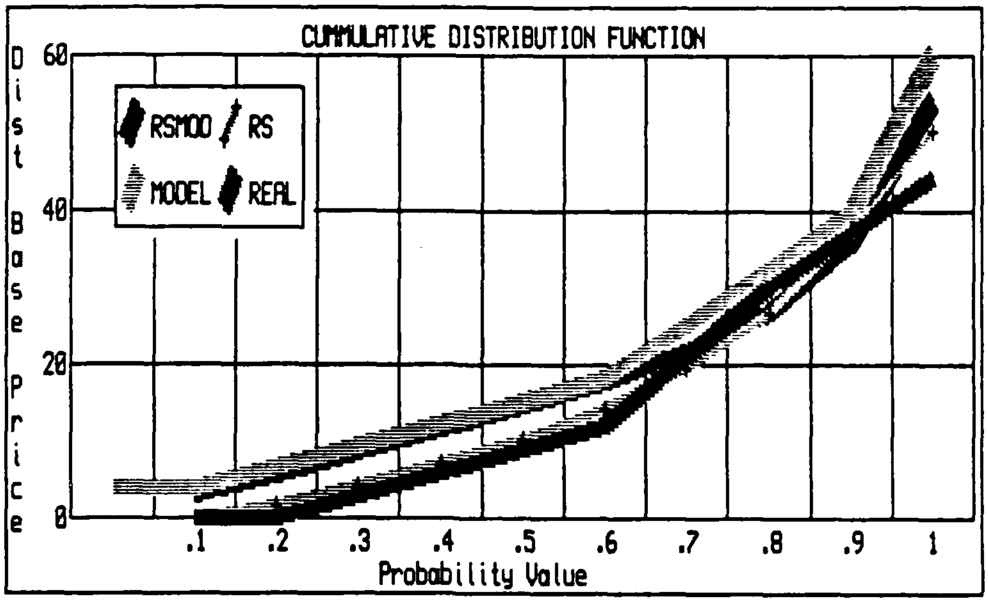

Figure 3.3 District Base Price Probability Distribution

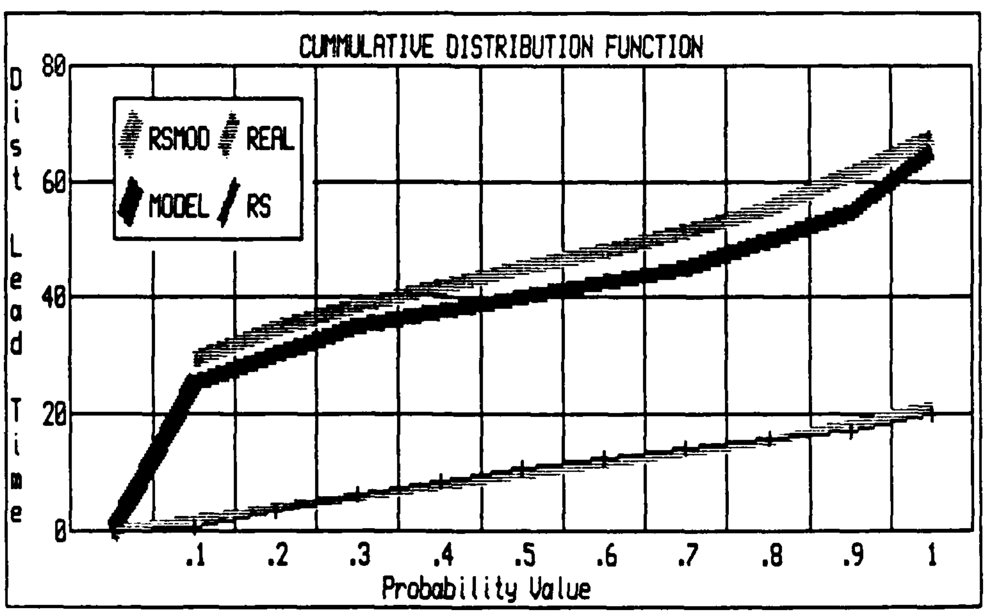

Figure 3.4 District Lead Time Probability Distribution

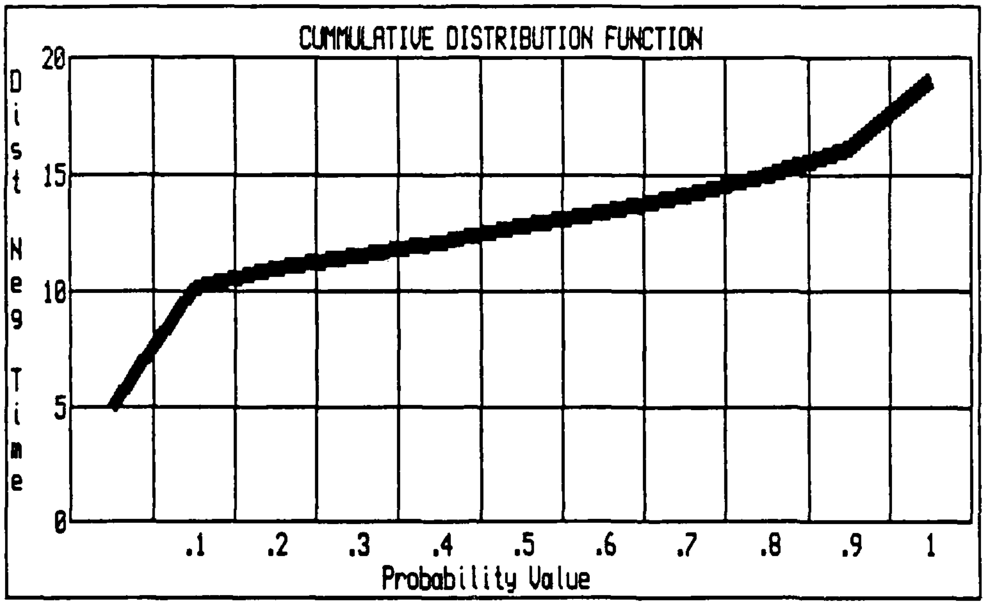

Figure 3.5 District Negotiation Time Probability Distribution

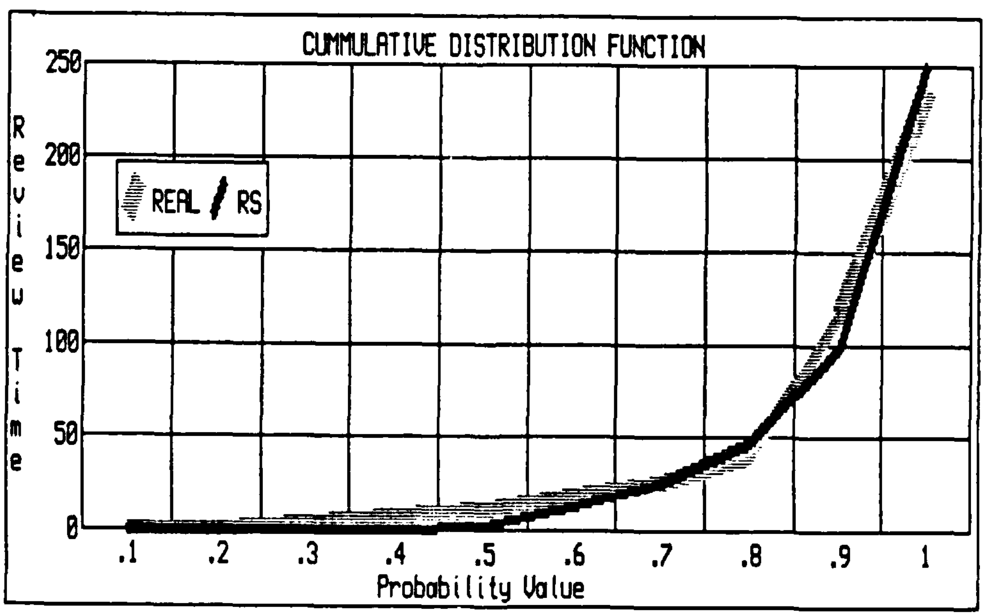

Figure 3.6 Combined Review Time Probability Distribution

encountering the negative cost impacts for unchanged work. Finally, the initiation time of the change order was set at the current value of *TIME.V*. From this point all changes were routed to activity 413 for processing.

3.5.2 Activity 413: Assemble Descriptive Change

The duration (the actual amount of productive effort to perform the activity) of activity 413 was assumed to depend on the complexity of the change order and whether or not the change was initiated in the field or the District. The base price of the change order was used as a measure of complexity (O'Connor 1977, p. 15). The duration of activity 413 was then, calculated by multiplying a factor times BASE.PRICE. The factors used were .25 for field changes and .125 for district changes. In contrast with the original study, a varation term utilizing a normal distribution with a range of plus or minus the transform value was not used. It was felt that the relative impact of such a term was insignificant when compared to the total processing times created by the model. This pattern will show up again in the calculation of the durations of the detailed general estimate, activities 416 and 422, well as activities as in activities 424/425 and 440/441. The total impact of this model modification was only a matter of hours relative to change orders taking days to process. Optimally, these activities would have been modeled using mathematical models derived from data but data, in any readily usable form, was not available in the AMPRS data base. Also, as discussed in Chapter IV, it was found that the corellation between base price and the durations of actitivties, such as proposal preparation time and review time was not very strong. In contrast to the CERL study, each of these items was modeled as a random variable from which a total activity processing time was derived with no queuing being initiated. All changes were routed to activity 414 for further processing.

3.5.3 Activity 414: NTP Before Agreement?

Activity 414 routes change orders requiring an NTP before agreement to activity 421 (activities 417 thru 420 were excluded from the model since only change orders under $100,000 were involved) and change orders not requiring an NTP before agreement to activity 415. The need for an NTP was based on the expected time to reach agreement and the time remaining until beginning the modifications became critical. The expected time to reach agreement is equal to the time required to issue the Request for Proposal (RPF), plus the time the contractor needs to prepare his proposal, plus the minimum amount of time required after the receipt of the contractor's proposal to negotiate and reach agreement. The time required to issue the RPF was assumed to be one hour if the change order was within the RCO's approval authority and was assumed to average five days if the change order was beyond the RCO's authority ... An NTP was issued if the expected time to reach agreement exceeded the time remaining until the start of the changed construction work became critical (O'Connor 1977 p. 15). If an NTP was issued, variable NTP was assigned a value of one.

3.5.4 Activity 415: Issue RPF

As in the CERL model, this activity was assumed to have a constant duration of one hour and all change orders were routed to activity 416 upon their completion.

3.5.5 Activity 416: Prepare a Detailed Government Estimate

Detailed Government Estimates (GE) were assumed to be required for all change orders exceeding the RCO's authority. The actual duration to prepare GE's was established in the same manner as the actual durations for activity 413. All change orders not requiring a GE were immediately routed to activity 430: the remainder were routed to activity 430 upon completion of activity 416 (O'Connor 1977, p. 17) . The value of variable GE was set to one for those change orders requiring a general estimate.

3.5.6 Activity 421: Issue RFP/NTP

This activity, as in the original study, was assumed to require a constant duration of one hour for all change orders; however, the date on which the RPF/NTP was issued deppended on whether the RCO or CO issued it. If the change was within the RCO's approval authority, it was issued immediately. If the CO had to issue the change then a delay of RS(5, 2, -.725, .2527, .0775, .3422) was incurred. This was in contrast with the original study, which assumed a beta distribution with mode, maximum and minimum values of 5, 10 and 1 days respectively. All change orders were routed to activity 422 upon completion of activity 421 upon completion (O'Connor 1977, p. 17) .

3.5.7 Activity 422: Prepare a Detailed Government Estimate

The duration of this activity was calculated in the same way as for activity 416. All changes not requiring a GE were routed immediately to activity 423 and those requiring the estimate had their respective GE variables set to one and after completion of activity 422, were routed to activity 423.

3.5.8 Activity 423: Two-Part Change?

The probability of a two part change was calculated using the formula PROB TWO PART = 1/150 x BASE.PRICE (3-1) and as in the original study, the probability varied from almost zero to 0.50 for a $75,000 change. If the random probabilty called by the program was less then or equal to this probability, then the variable PART was set equal to one and the change order was routed to activity 424; all others were routed to activity 430 (O'Connor 1977, p. 18).

3.5.9 Activity 424/425: Revalidate Funds & Issue Part One

The combined duration for activites 424 and 425 was established in the same manner as that for activity 413, with the average combined duration equal to 1/8 times the base price for all change orders. All change orders were routed to activity 43Ø (activiies 426 through 429 were excluded from the model since they are only of minor significance) upon completion of activity 424/425 (O'Connor 1977, p. 18).

3.5.1Ø Activity 43Ø: Receive Contractor's Proposal?

This activity represents the delay, if any, incurred while waiting for the contractor's proposal. These durations were based on the value of the attribute PROP, set when each change order was initiated. From actual data analysis it was found that there was no evidence of delays incurred from missing established suspense dates. Therefore the probability of occurence was reduced to one percent and there was no differentiation made between changes which received an early NTP and those which did not. Change orders for which a proposal had been received were routed to activity 431 upon receipt of the proposal. The others, which the contractor refused to submit in a timely manner, were routed to activity 448 after waiting ten days (O'Connor 1977, p. 19).

3.5.11 Activity 431: Is Proposal Breakdown Satifactory?

Ninety percent of the change orders were assumed to have satisfactory breakdowns and were routed to activity 438; the remaining 10 percent were assumed unsatisfactory and were routed to activity 432. The duration of activity 432 was assumed to be 1 hour for all change orders (O'Connor 1977, p.18).

3.5.12 Activity 438: Review Contractor's Proposal

The duration for this activity was established using RS(43.1, 50.78, 1.863, .3195, 12.398, .3429). Since the duration was total review flow time rather than staff processing time, no queues were activated by the simulation program. Upon completion of activity 438, all change orders were routed to activity 439 (O'Connor 1977, p.20).

3.5.13 Activity 439: Proposal Acceptable?

Twenty-five percent of all change orders were assumed to have acceptable proposals and were routed to activity 465; the remaining 75 percent were assumed to be unacceptable and were routed to activity 440 (O'Connor 1977, p. 20).

3.5.14 Activity 440/441: Negotiate and Revise

The duration for these activities were calculated as per activity 413 and upon completion processing was continued by activity 442.

3.5.15 Activity 442: Agreement Reached?

Ninety percent of the negotiations were assumed to be successful and routed activity 460. The remaining changes were routed to activity 443.

3.5.16 Activity 443/444 NTP Before Agreement? & Two-Part?

The criticality of starting the changed construction work was checked in the same manner as in activity 414. Critical change orders for which an NTP had not previously been issued were routed to 421 and subsequently to activity 423; these had the same probability, as described for activity 423, of warranting two-part change order. Noncritical Change Orders were routed to activity 445 (O'Connor 1977, p. 20).

3.5.17 Activity 445: Negotiate Further?

In contrast to the CERL model, further negotiations were assumed to be warranted ninety nine per cent of the time versus eighty per cent.

3.5.18 Activity 448: Has NTP Been Issued?

Change orders with a previosly issued NTP were routed to activity 450, with all others routed to 449.

3.5.19 Activity 449: NTP Before Agreement?

The modelling procedure was the same as for activity 414. Critical change orders were routed to activity 421, with all others routed to 450.

3.5.20 Activity 450: Review/Prepare Detailed GE

All calculations were the same as activity 416. Changes for which a GE were prepared were routed to activity 452, with all others routed to activity 452.

3.5.21 Activity 452: Forward to District

The duration for this activity was assumed to be a constant of one hour, with follow on routing to activity 453.

3.5.22 Activity 453: District Meets With Contractor

This activity was modeled using RS(13, 5, -.725, .2527, .0775, .3422), with follow on routing to activity 454.

3.5.23 Activity 454: Bilateral or Unilateral?

District negotiations were assumed to have resulted in a bilateral agreement ninety nine per cent of the time, with the remaining one percent being unilateral agreements. This was in contrast with the CERL model which assumed that ninety percent of all district negotiated changes would be bilateral. All Change Orders were then routed to activity 465 (O'Connor 1977, p. 20).

3.5.24 Activity 465: Is Change Unilateral?

Unilateral changes were routed to activity 478; bilateral changes were routed to activity 466.

3.5.25 Activity 466: Issue NTP (If Not Already Done)

All change orders incurred a one hour processing delay for final administrative processing. Bilateral change order processing ended at this activity.

3.5.26 Activity 478: Prepare Findings of Fact

The duration for this activity followed the same procedure as activity 413 with the factor of .125 used. Follow on routing was to activity 479.

3.5.27 Activity 479: Issue Unilateral

A constant one hour duration was applied to all change orders reaching this point. All processing was completed at this point.

The RS distribution subroutine consisted of a random number call for a probability value (p) to be used in the formula (Larew 1976):

$$X(p) = \text{mean} + \text{std. dev.} \times (L1+(p^{L3}-(1-p)^{L4})/L2) \quad (3\text{-}2)$$

Where std. dev. is the distribution standard deviation and L1-L4 represent the four lambda parameters of the RS distribution. The value of X was the value of the random variable being requested, such as time or base price. Since it was possible for this function to provide negative values, which would cause simulation difficulties since use of negative time was not acceptable, a programming provision which set all negative values equal to zero, was installed. This had an impact on such items as change order base price, which could actually be negative. This was not a serious problem as one simply assumes all base prices to be absolute values.

3.6 Verification of the Model

To conclude this chapter, it is appropriate to briefly return to the subject of verification and relate it to the discussion provided up to this point. One of the most powerful verification procedures available to the model builder is the "walk through" (Russell 1983, p. 1-11). For this reason, an annotated program listing is provided in Appendix F and it was developed to help the author tie together the activities depicted in the modifications procedure flow chart and those sections of the actual program, which represented those activities. To the left of each section of the program code for the process Mod is its flow chart activity number. This check helped the author to find and correct any errors in the coding of the model. For example, in the early stages of program development the author found that although all of the code was written to allow for the time necessary to prepare the change proposal, the specific statement calling for the simulation to wait that duration, was omitted. It took only seconds to correct the error, but without such a check, one of the key variables of the program would have been left out. The reader is reminded also of the verification procedure explained in Chapter II.

3.7 Summary

In this chapter, the simulation model, simulation programming language and verification steps were discussed. This phase of the research was particularly difficult in terms of the large amount of attention to detail required in its performance. Having examined the particulars of the simulation model, Chapter IV will now focus on the data input aspect of the simulation experiment. Strict attention should be paid to the relationship between the simulation and regression models, as well as the raw data from which they were both derived.

CHAPTER IV

ANALYSIS OF BALTIMORE DISTRICT (CAPTITOL AREA OFFICE) DATA INCLUDING THE DEVELOPMENT OF ACTIVITY DISTRIBUTIONS AND REGRESSION MODELS

4.1 Introduction

In this chapter the focus is on obtaining actual data on the contract modifications process, its synthesis with the simulation model using the RS distribution and the development of regression models used to cross-check the simulation. As stated in Chapter II the data used in this research was obtained from the U.S. Army Corps of Engineers Baltimore District, Capitol Area Office and a date listing is provided in Appendix B. At first glance, the data sample, which consists of sixty five observations, may appear to be small, but the data is of a high quality, in terms of the amount of validation conducted in extracting it from its computer data base and source files. Also, a comparison study of data on processing the design changes for an 852 megawatt power plant, conducted by Liu and Chang (1986) revealed suprisingly similar distributions for analogous activities, from an unrelated data base. That data base consisted of over four hundred observations and when compared to this research data sample tends to substantiate that, though small, the Baltimore District data captures the basic features, such as distribution shape, that were necessary to describe the actual process.

4.2 Modelling Activities With the RS Distribution

The four parameter, percentile distribution developed by Ramberg and Schmeiser was the primary tool used to model the random variables found in the modifications processing procedures simulated. As stated earlier, the procedure used consisted of finding the four central moments of the activity to be modeled, using the skewness and kurtosis values to find the corresponding RS distribution lambda parameters, and using those parameters in conjunction with the activity mean and standard deviation in EQN 1 to find X(p). In chapter III, while covering the simulation model an entire series of cummulative distribution functions, used to model the various activities was presented. At this time, a single case from that set will be examined in detail to provide the reader with a clear understanding of the entire procedure.

The particular example covered here was the activity which was called District Delay in the CERL model and did not show up in the new model as the product of actual data as did most of random variables modeled, but was derived by using a histogram overlay of the CERL model for this activity. The histogram data was fed into SAS and the data on the mean, standard deviation, skewness, and kurtosis, which were 5, 1.6, Ø and 3 respectively, were calculated. The skewness and kurtosis were used to find the four lambda parameter values from available tables (Larew 1976). RS(5, 1.6, Ø, .1975, .1349, .1349) was then used to model this activity in the duplication of the CERL model. To demonstrate the ability of the RS distribution in fitting data, a series of the graphic presentations are provided in figures 4.1 through 4.3. Note that in contrast to chapter three the probability distribution is provided in both line (figure 4.1) and histogram approximation form (figure 4.2). This is done fpr those readers who prefer to visualize probability distributions in this format. In actual practice, the cummulative distribution function was used for the simulation and it too is provided in figure 4.3 to demonstrate how well the RS model overlays the CERL model over the majority of the probability range.

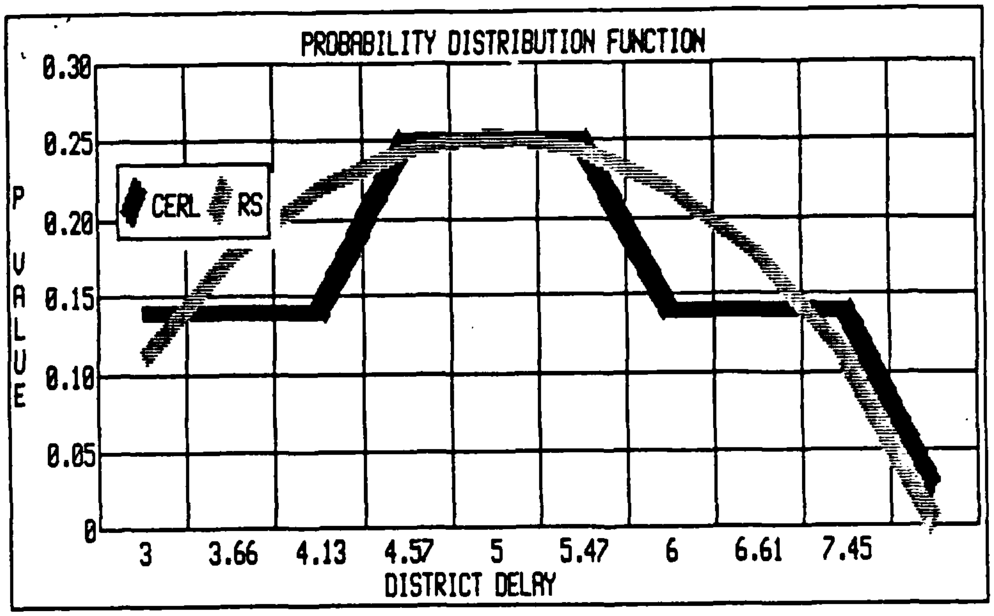

Figure 4.1 District Delay Probability Distribution Function

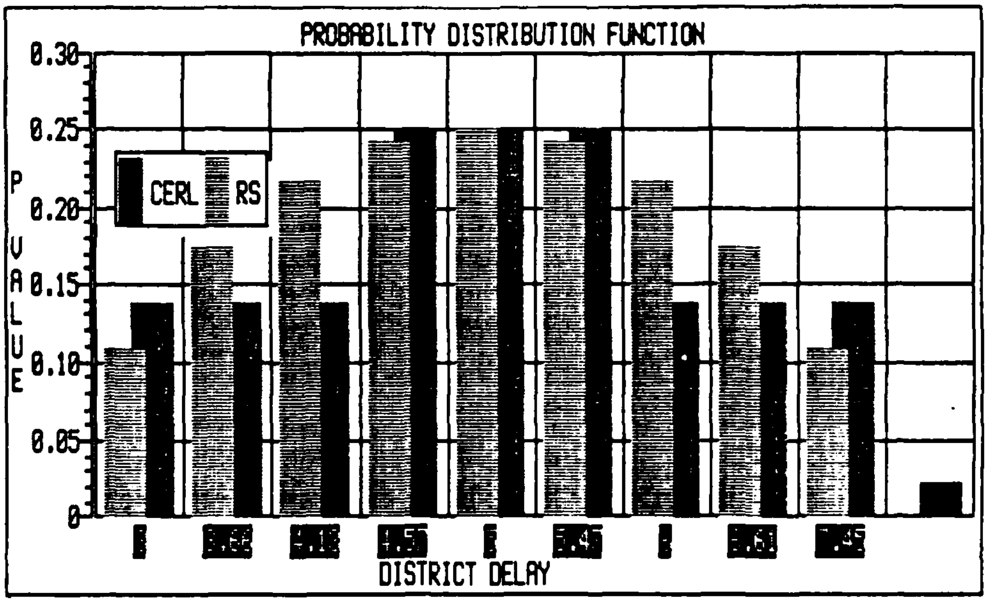

Figure 4.2 District Delay Probability Histograms

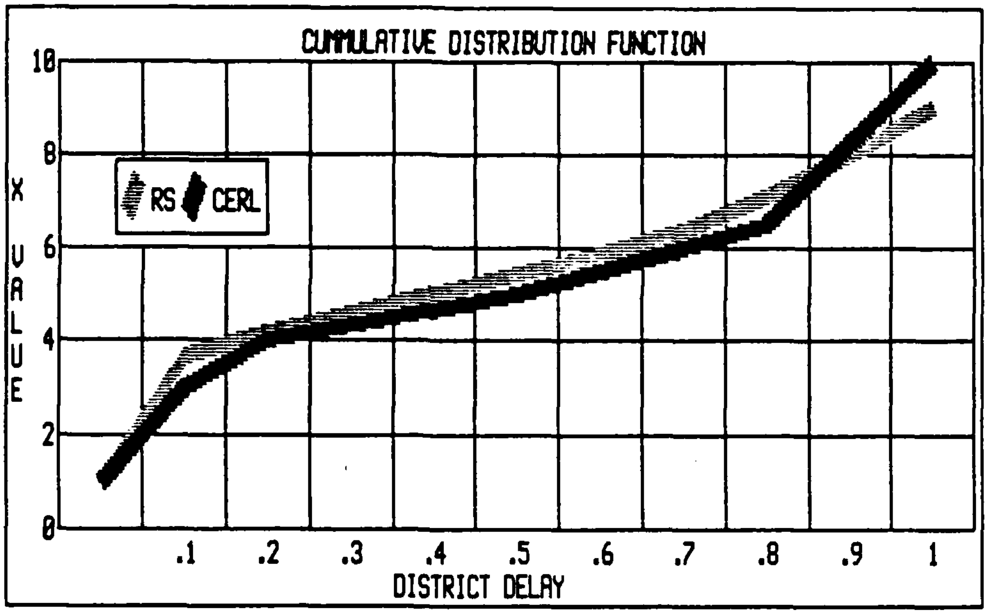

Figure 4.3 District Delay Cummulative Distribution Function

4.3 Development of a Prediction Model Using Regression Analysis

One of the important steps in simulation is validation of the model results (Russell 1983, p. 1-14). For this research, the author decided that one possible technique was to develop a prediction model using regression analysis and compare it with the simulation results obtained within the same policy environment as that from which the data, used in the regression analysis, was obtained. In this way, two reasonable approaches to the same problem could be compared, and any major discrepancies could be detected. Also, the results of regression analysis were used to find out which dependent variables might be of primary importance in determining overall model output during sensitivity analysis (Notz 1986). From this perspective the regression analysis results will now be discussed.

The initial steps in the data analysis such as the univariate analysis, scatterplots and simple linear regression (SLR) models have been discussed in Chapter II. At this point, the results of the automatic search procedures will receive primary attention. The reader should note only that no SLR model was well suited as a prediction model and multiple variable models, particularly with the inverse transformation of Percentage of Total Contract Cost (TPERC), were best suited to model total processing time (TOT). The best prediction model based on linear regression analysis, performed on SAS, was as follows:

TOT=.97+.8(REV)+.88(PREP)+.12(DTC)+.86(TPERC), (4-1),

where: REV = Contract Proposal Review Time;

PREP = Change Order Proposal Preparation Time;

DTC = Days to Complete the Construction Contract;and

TPERC = 1/PERC or the inverse of the Percentage of total contract dollars that the Change costs.

The variables used in this model consistently surfaced in the forward selection, backward elimination, and stepwise procedures, as well as with the RSQUARE-CP procedure in SAS. The corellation value (R^2) for this model was .6536, with adjusted R^2 and Mallows CP statistic values of .6293 and 3.Ø5Ø respectively. As a further check of the model's appropriateness, nonlinear regression analysis on these same variables was run, freeing all variables to take on exponent values, if required.

The nonlinear model, as fed into the BMDP package, was:

$$TOT=C_1+C_2(REV^{e1})+C_3(PREP^{e2})+C_4(DTC^{e3})+C_5(TPERC^{e4}), (4-2),$$

where C1-C5 were constants and e1-e4 were exponents. The resulting nonlinear model was:

$$TOT=1.03+.8(REV)+.88(PREP)+.116(DTC)+.86(TPERC). \quad (4-3)$$

This model compares favorably with the linear model calculated using SAS and was interpreted as meaning that there was a minimum amount of processing for any change approximately equal to one day and the remaining time attributed to the additive effects of the time it took to prepare and review the change order proposal. The DTC term was operant when the change order was initiated in the early stages of the contract, thus allowing more slack time in processing, and the TPERC term provided for the long delays experienced when changes were a very small percentage of the total contract dollars.

The results of the correlation matrix demonstrated a high value of .8654 between the change order base price and TPERC variables. This was to be expected as the base price of a given change was a fairly good predictor for the percentage of total contract dollars that the change would encompass. The correlation matrix is listed in Appendix C

4.4 Synthesizing the Simulation Model With the Actual Data

This model was useful because once the author fixed the mean values of REV, PREP, DTC and TPERC, a reasonable prediction of the total time it took to process a change, was provided. This value was then compared to the average processing time for changes in a similar policy environment (see chapter V for the results of this check). This was particularly important since model validation became more difficult at each successive stage and once the model reached this stage of development i.e., it contained no syntax errors and the walkthrough examination and hand calculations seemed reasonable, there was little comparitive basis for error detection. The regression model provided one more cross reference to insure that all was as it should be.

The other important aspect of data-simulation synthesis has been discussed in detail already, that being the data based RS distributions used in the new model. Up to that point, the model was based mostly on expert esimates. Though good, as compared with a layman's guess, the expert opinions used in the CERL model tended to overestimate processing speed and did not take into account the differences between the regulatory guidance and actual office implimentation.

4.5 Summary

In this chapter the use of data as input in both the simulation and regression models was discussed. With respect to the simulation, the data was used to form the RS probabilty distributions that modeled the various procedure activities. As a parallel problem approach and simulation cross-check for the simulation, data was also used to derive regression models of the modifications process. This research phase provided the author with a great deal of problem insight.

CHAPTER V

RESULTS OF THE SIMULATION AND MODEL SENSITIVITY DISCUSSION

5.1 Introduction

Up to this point, discussion has centered around the mechanics of putting the experiment i.e., the simulation model together. This chapter will now shift the reader's attention to the results obtained. The first section will cover the duplication of the CERL experiment, followed by the results of the new model. Next model sensitivity will be discussed and a results summary will be presented in order to tie all discussion up to this point together.

5.2 Duplication of the Original Experiment

The results of the duplication of the original experiment are shown in table 1 below. Also, to provide a comparison between the CERL and new models, the same experiment was run using the new model and its results are listed in the far right column. Overall, the comparison between the duplication, using the RS distribution along with the SIMSCRIPT II.5 programming language in the new model, was favorable. The reader should note that in both cases (the CERL model and the new model duplication) there was a noticable drop in mean processing time between the staffing at levels three and four, while no appreciable change occurred between levels four and five, regardless of authority level. Also, there was a slight drop in mean change order processing time with increased RCO authority level. This aspect will be covered in more detail later. Overall then, the results were considered to be generally the same and the new model structure used in the duplication experiment, became the standard program, from which all successive models, were based.

TABLE 1

COMPARISON OF SIMULATION RESULTS

STAFF	ORIGINAL EXP.	USING RS DIST	NEW MODEL
	RCO AUTHORITY <= $10000		
3	37.0	37.5	52.9
4	22.1	24.7	53.1*
5	20.1	22.7	52.0
	RCO AUTHORITY <= $25000		
3	35.2	33.4	50.8
4	20.5	22.1	50.3
5	18.8	21.5	50.6*

*Note: Although it appears that the mean cycle time increased the average queue times and percent busy figures dropped significantly. A better interpretation of these figures is that the difference in mean cycle time is negligable. In the model based upon real data, the significant gains derived from larger staffs is an increase in time available for other work. (see the table below)

TABLE 2

A CLOSER LOOK AT REAL DATA MODEL

RCO AUTHORITY <= $25000

	CYCLE TIME		QUEUING INFORMATION		
STAFF	MEAN	STANDARD DEV	AVERAGE QUEUE	MAXIMUM QUEUE	% BUSY
3	50.82	59.48	.34	14	48.91
4	50.25	58.11	.07	9	36.51
5	50.63	58.88	.01	4	29.63

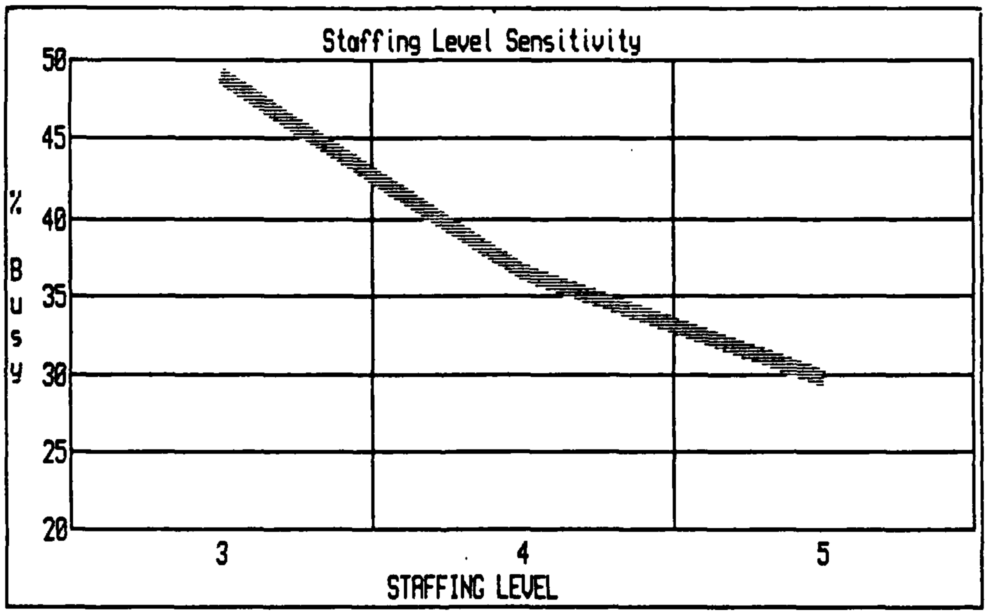

Figure 5.1 Staffing Level Impact on Percent Business

5.3 Results of the Synthesized Model

The results of the same experiment for the new model, using data based probability distributions, showed significantly different results in terms of both, mean processing time and sensitivity to staffing level. There was a fifty percent increase in the mean change order processing time for both authority levels, although the general trend of decreasing processing time for increased authority level still held true. The data based model also showed less sensitivity due to staffing level changes, with mean processing time remaining relatively constant; however, one had to look at other aspects, such as staff officer percent busy rates to see what was really happening. Table 2, shows the impact on queuing, especially staff business, in the new data based model with a $25,000 RCO authority level. Notice how figure 5.1 shows a continual decrease in business. It should also be noted that the average time in the queue, as well as maximum queuing time observed decreased.

In comparing the results of the synthesized model and those of the prediction model, a reasonable closeness was found. The prediction model was fed the mean values, as derived from the data, for its four variables. The following inputs were used: PERC = 2.3, DTC = 191, PREP = 1Ø, and REV = 34. The predicted processing time, based on EQN 2 was 59.6 days. This compares favorably with the 5Ø - 53 day time range resulting from the simulation model.

5.4 Simulation Model Sensitivity

Before getting into the specific comments on each of the many sensitivity experiments, a general overview is in order. The ranges over which parameters were varied were based on what the author believed were acceptable, practical limits. For example, in the case of the percentage of unilateral changes, the author felt it was unreasonable to assume that more than thirty percent of all change orders processed would be unilatteral, therefore the parameter range limit was set accordingly. This should not pose too great of a problem for the reader as most of the ranges should appear reasonable. Secondly, in the many graphical presentations to follow, no attempt was made to fit curves to data. The radical shifts should not be interpretted as exact, but rather, the reader should concentrate on the general trends that are evident.

Another general area requiring comment is that of the progression used in the conduct of the sensitivity analysis. This was covered in chapter II and will not be repeated here except to say that the order of tests was important and that refinements were incorporated into successive experiments. Finally, single parametric variations were made versus combinations of changes. For the most part, such changes would result in an additive effect that could be predicted by the reader from an analysis of single parameter changes. The vast number of combinations possible made detailed analysis in this area impractical.

5.4.1 Number Of Iterations

The number of iterations in the simulation, which could be thought of as the number of change orders processed, was the first sensitivty test made. This test was performed first because it was important to know the number of iterations needed to obtain a clear picture of the processing output distribution. Tests of 500, 2000, 5000, and 7000 iterations were run. A higher number of iterations was not conducted due to computer computation time constraints. The staffing level was fixed at four and the RCO authority level was held at $10,000. All seeds were fixed as were the number streams. The repective mean processing times for 500, 2000, 5000 and 7000 iterations were 48.73, 50.85, 52.74, and 52.35 days. More significant than the mean processing time results, were the results of the histogram outputs of the processing time distributions, which were very close and are shown in figures 5.2 through 5.4. Overall, any number of iterations beyond 2000 was suitable for detailed analysis purposes and 2000 was used for all further experimentation.

5.4.2 Warmup (Reset) Sensitivity

The next series of tests performed was designed to examin how sensitive the simulation results were to the effects of model warm up. Warm up is a concept which explains the initial climb of processing time as the simulation model's queues reach their steady state levels. In this test, the counters which accumulated simulation performance data, were reset after a given number of iterations so that only steady state data was contained in the development of final model output. The resets were initiated at 50, 100, and 200 iterations and as is shown in table 3, most of the effects of warmup could were effectively removed by initiating a

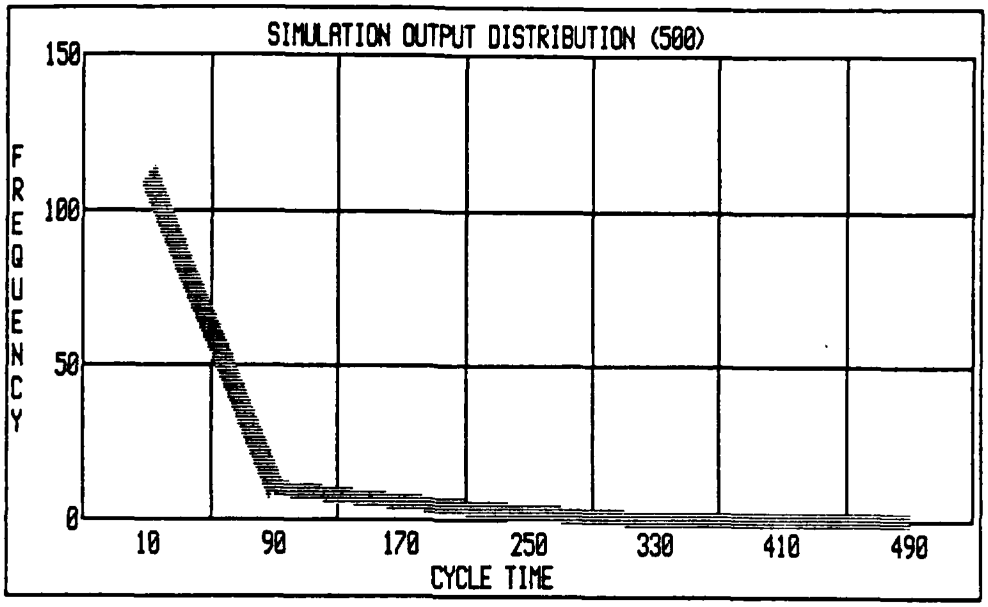

Figure 5.2 Simulation Output With 500 Iterations

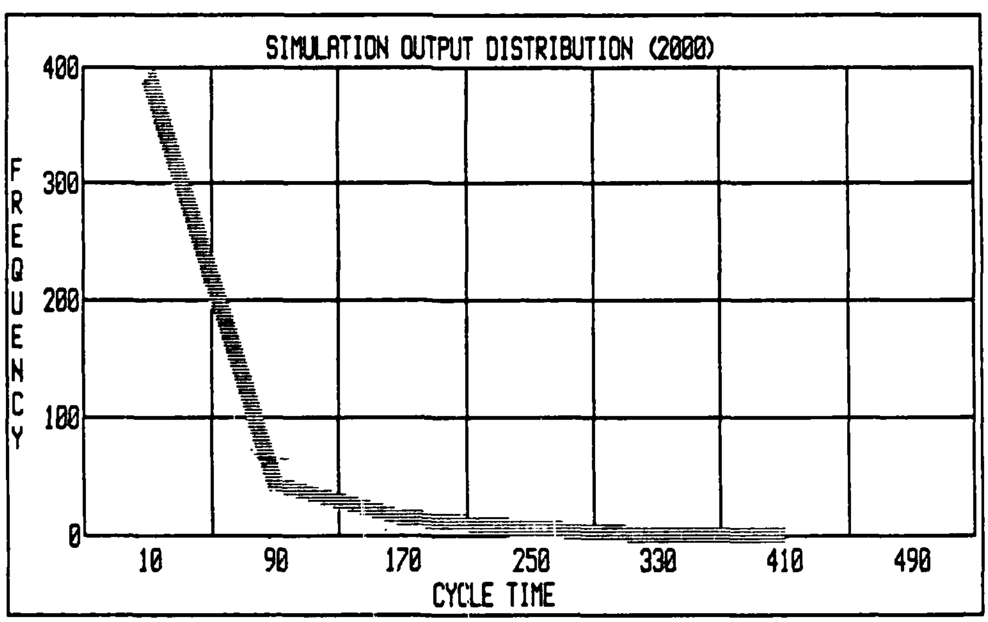

Figure 5.3 Simulation Output With 2000 Iterations

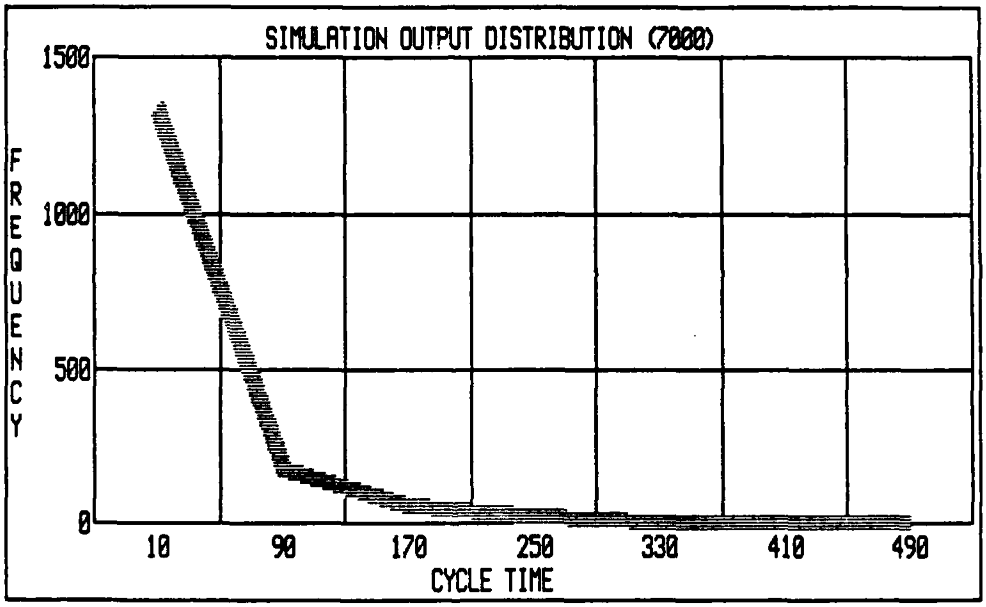

Figure 5.4 Simulation Output With 7000 Iterations

simulation counter reset after iteration 100.

TABLE 3

Comparison With No Reset (%Change)

	Number of Iterations		
	50	100	200
Processing Time			
Mean	1	2	2
Standard Deviation	.5	1	1
Queuing Information			
Average Wait	0	0	6
Maximum Wait	0	0	0
% Busy (staff)	.1	-.3	-.5

5.4.3 Poisson Lambda Parameter Sensitivity

After establishing a feel for the sensitivity of the number of iteration and warm up, and after having installed reasonable settings to account for each, the next step was to examine the sensitivity of change order generation rate. The generation of change orders was modeled using a Poisson probability distribution and this distribution's single parameter, lambda, established the mean arrival rate, or in this case, generation time, of change orders. Lambda, was varied from one to eight, and the results are depicted in figures 5.5 through 5.9. Each of the five performance measures, mean processing (cycle) time, processing time standard deviation, queuing average wait time, queuing maximum wait time, and staff business (%), were plotted. The reader should note that this convention will be used throughout the next three subsections of this thesis. The most noticeable trend was that the model is not sensitive to values of lambda beyond two. Tests on lambda values less than one were not conducted as they were not accepted by SIMSCRIPT II.5. Given this information, all further tests were run with lambda equal to two.

5.4.4 Sensitivity of RCO Authority Level

This next test was performed to see the impact of the RCO approval authority on change order processing time. Basically, this authority determined when a change order had to go to district level for processing or when a detailed estimate had to be performed. The net effect

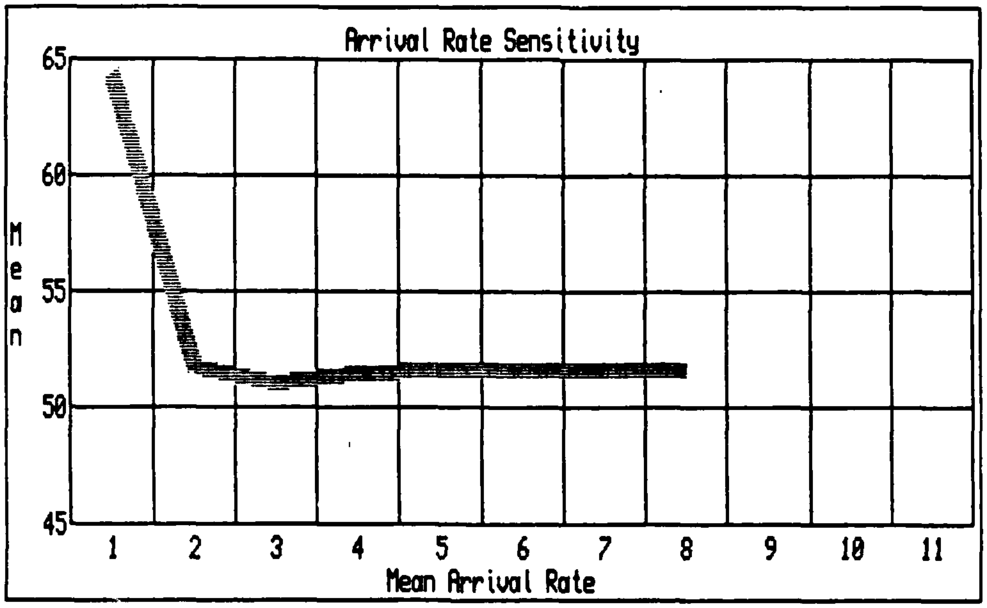

Figure 5.5 Arrival Rate Sensitivity - Mean Processing Time

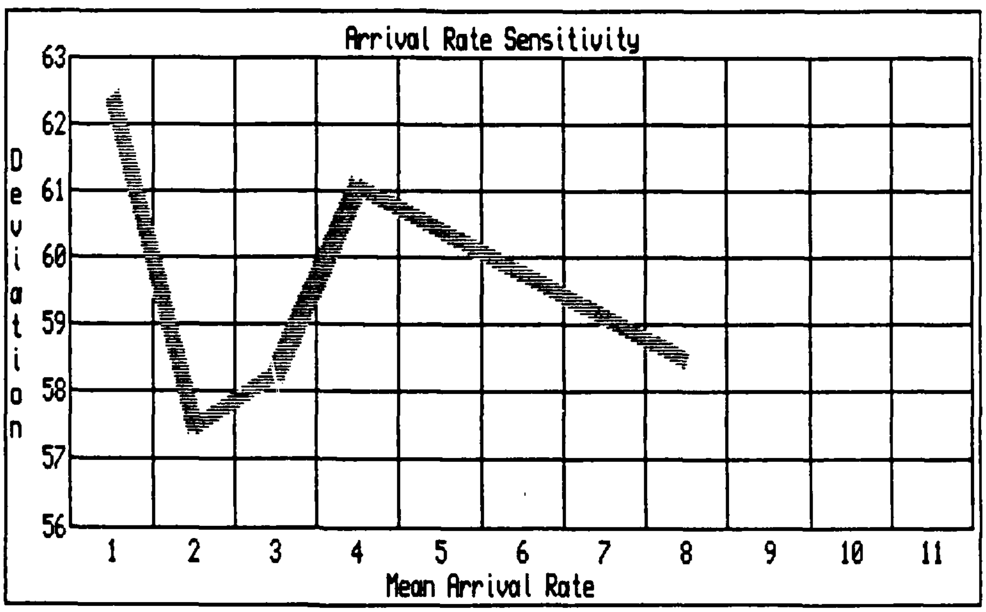

Figure 5.6 Arrival Rate Sensitivity - Processing Time Standard Deviation

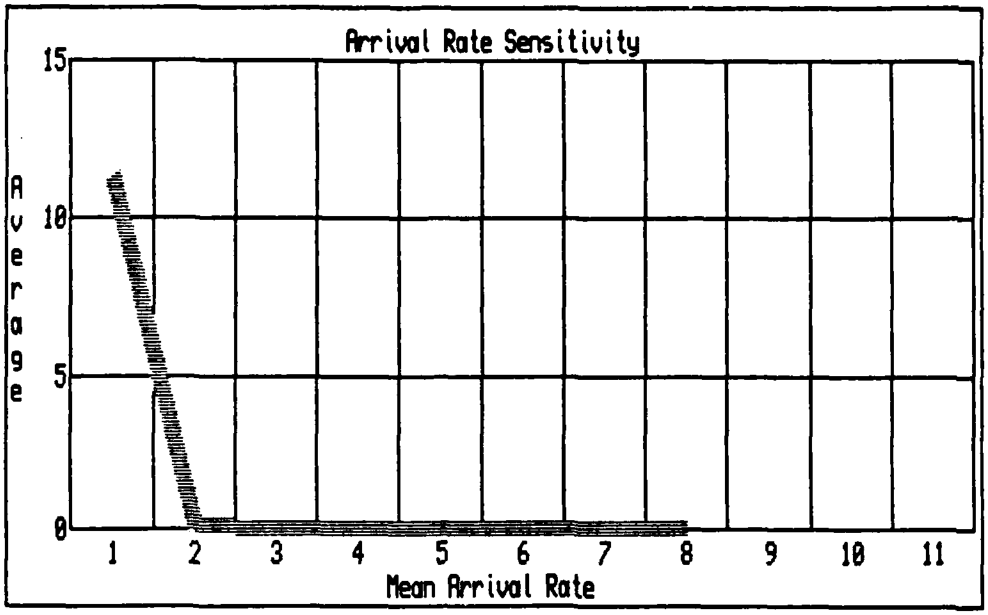

Figure 5.7 Arrival Rate Sensitivity - Average Queuing Time

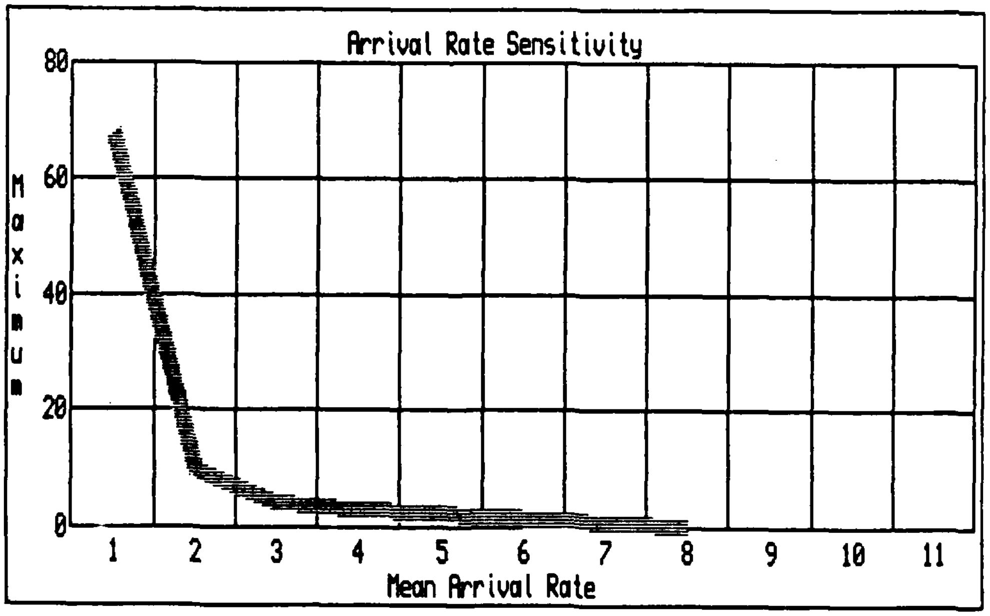

Figure 5.8 Arrival Rate Sensitivity - Maximum Queuing Time

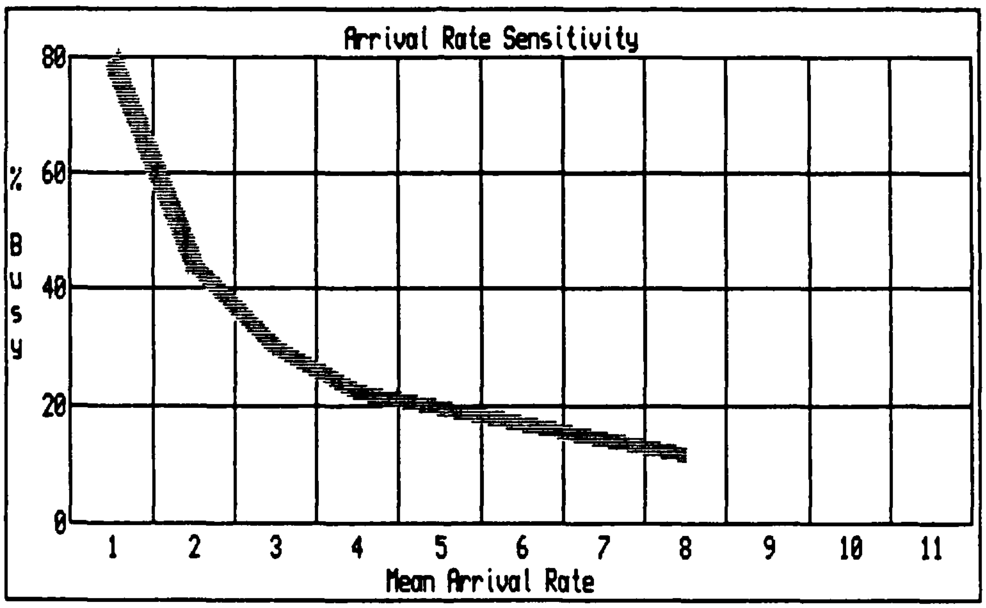

Figure 5.9 Arrival Rate Sensitivity - Staff Officer Percent Business

of this was assumed to be an increase in overall processing when the authority level was set low. The range of authority spanned from $10,000 to $90,000 and as predicted, the mean processing time over this range fell from 52 days, at the $10,000 level, and 46 days, at the $90,000 level. This information is provided in figures 5.10 through 5.14. The most obvious trend was that after the RCO authority level was set at $50,000, decreases ceased to be significant. This was also true for average queuing time. Based on this, the authority level for further experiments, was set at $50,000. It is interesting to note that this was the authority level in effect at the Baltimore District, Capitol Area Office.

5.4.5 Sensitivity of Branching Probabilities

Within the simulation program, there were a series of decision points which determine the routing of change order processing. To model these points, random probability generating functions were used. The next series of tests were performed to find out how sensitive the simulation output was to variations in the decision probabilities used. Again, the results, in terms of the effects on the five performance mesures collected, will be shown graphically. The probability of a change

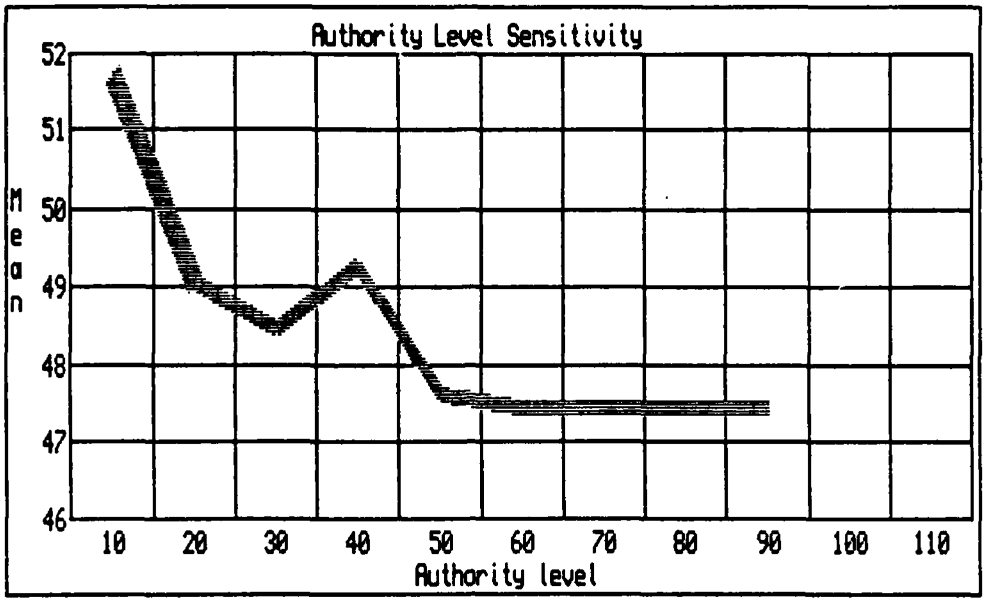

Figure 5.10 Authority Level Sensitivity - Mean Processing Time

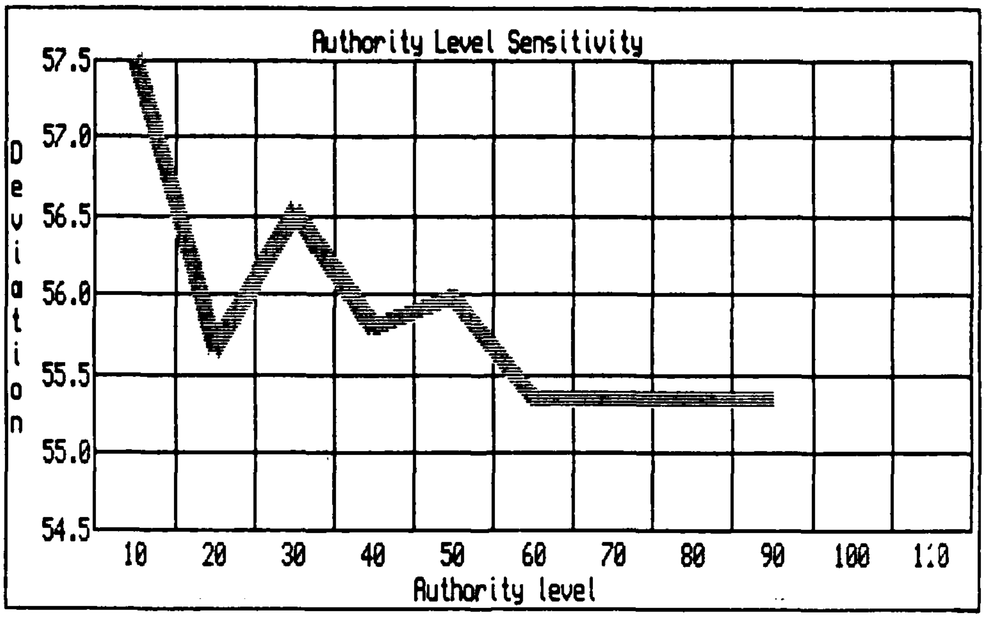

Figure 5.11 Authority Level Sensitivity - Processing Time Standard Deviation

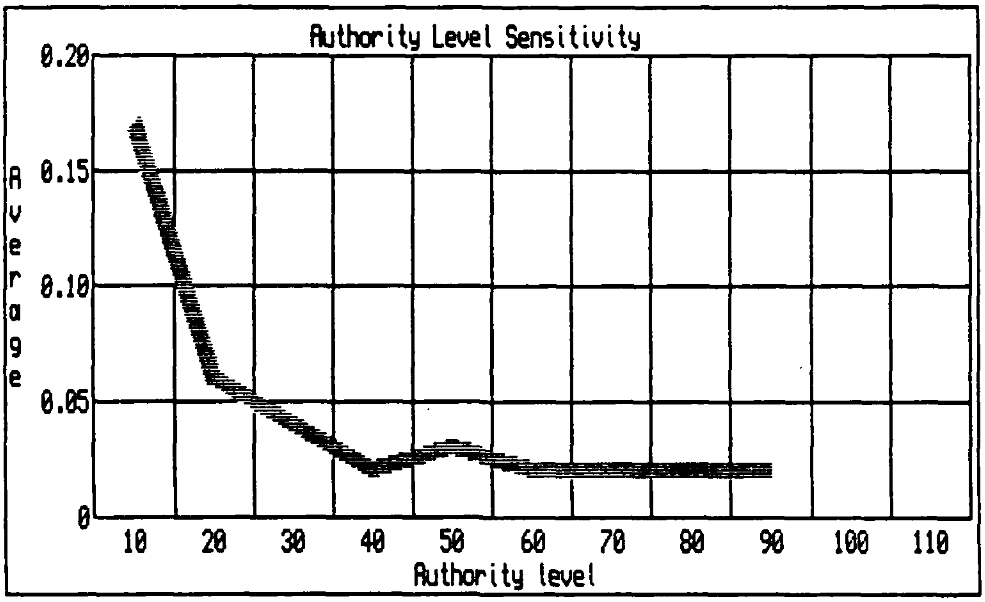

Figure 5.12 Authority Level Sensitivity - Average Queuing Time

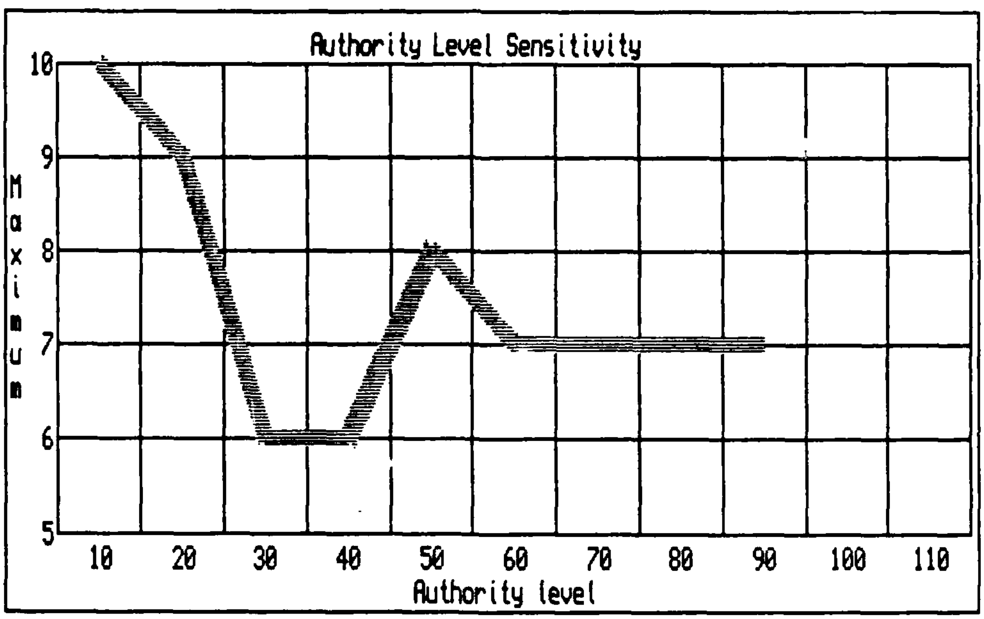

Figure 5.13 Authority Level Sensitivity - Maximum Queuing Time

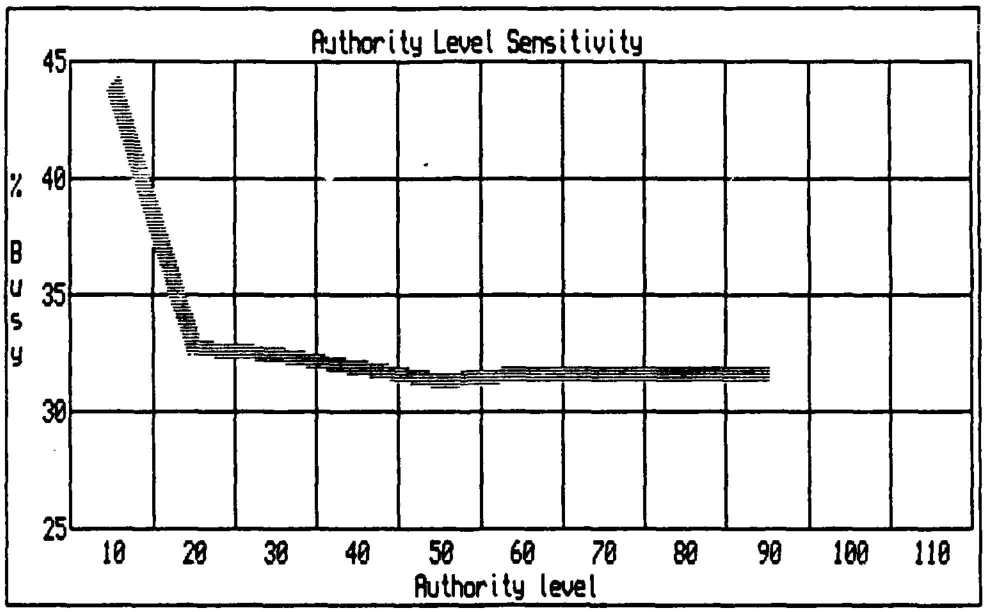

Figure 5.14 Authority Level Sensitivity - Staff Officer Percent Business

requiring negotiation was varied from .25 to .95 and an overall change in mean processing time of four days was experienced. A general increasing trend was noted and confirms the idea that the more change orders require negotiation, the longer the average processing time. The same was true for staff officer business which increased by ten percent. See figures 5.15 through 5.19.

Probability of Negotiation Success: Related to the probability of negotiation was the probability of successfully reaching an agreement once negotiations occurred. The range of the probability was varied from .6 to .9. The author felt that it was not realistic to set this success probability lower than .6 based on the examination of real data. Figures 5.20 through 5.24 show a general decrease in processing time resulted as the probability of success increased, while the impact on queuing was not very significant. The impact on mean processing time made intuitive sense, but the lack of impact on queuing times was a minor surprise.

Unilateral Change Probability: The probability of a bilateral change occurring was varied from .7 to .99 and the results are shown in figures 5.25 through 5.29. The most significant trend was a general decrease in overall processing time as the probability of such

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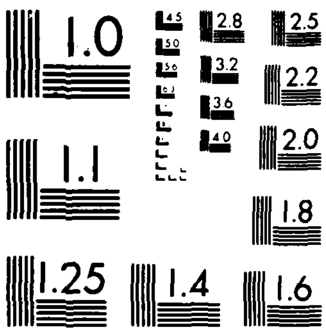

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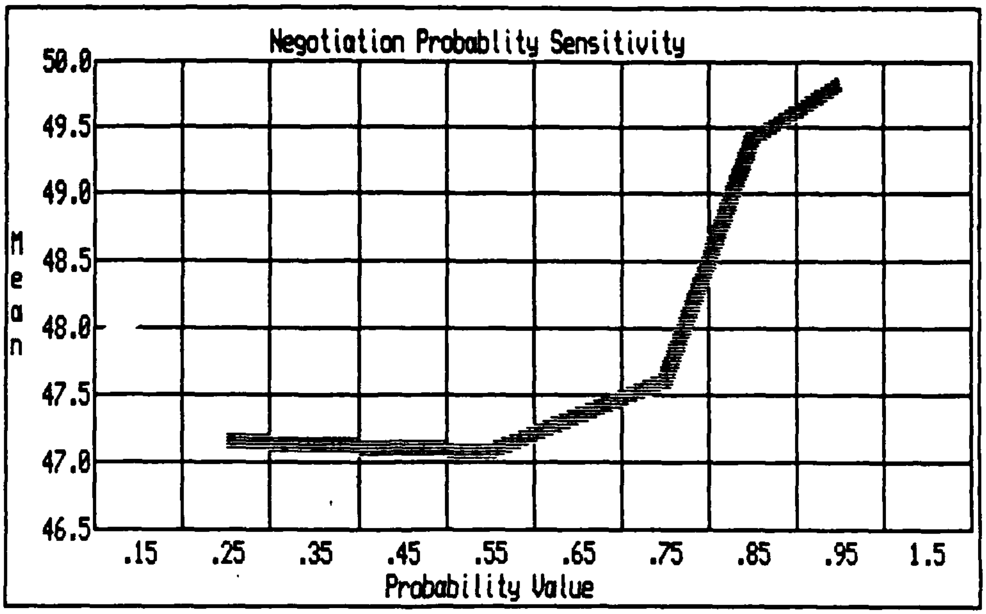


Figure 5.15 Negotiation Probability Sensitivity - Mean Processing Time

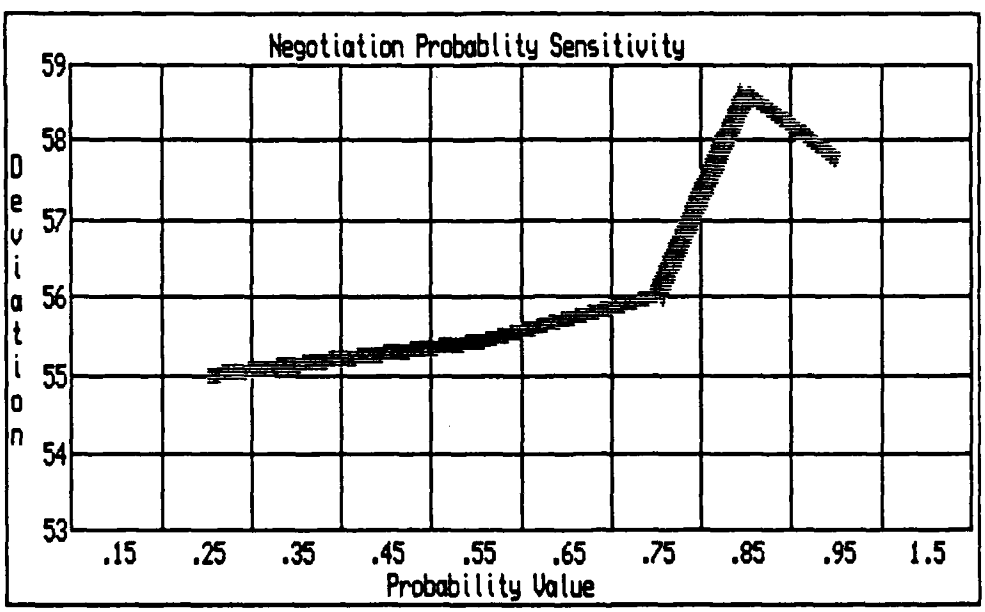


Figure 5.16 Negotiation Probability Sensitivity - Processing Time Standard Deviation

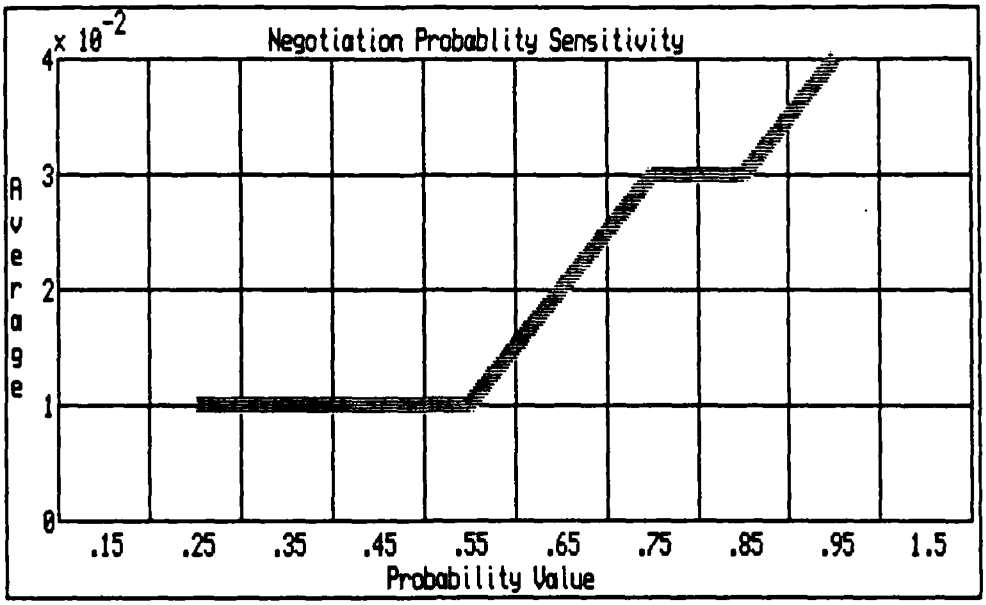


Figure 5.17 Negotiation Probability Sensitivity - Average Queuing Time

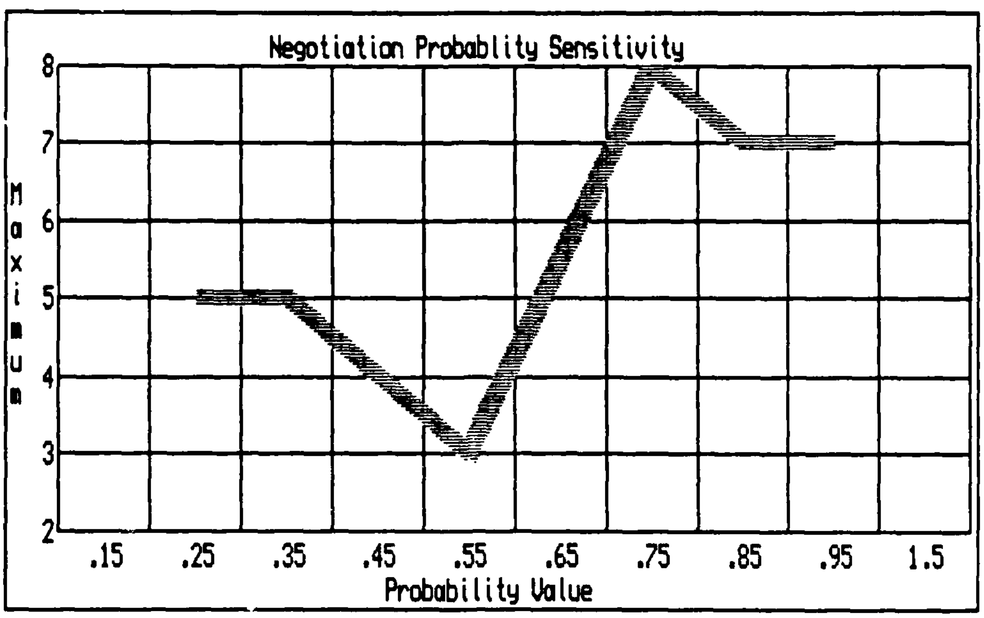


Figure 5.18 Negotiation Probability Sensitivity - Maximum Queuing Time

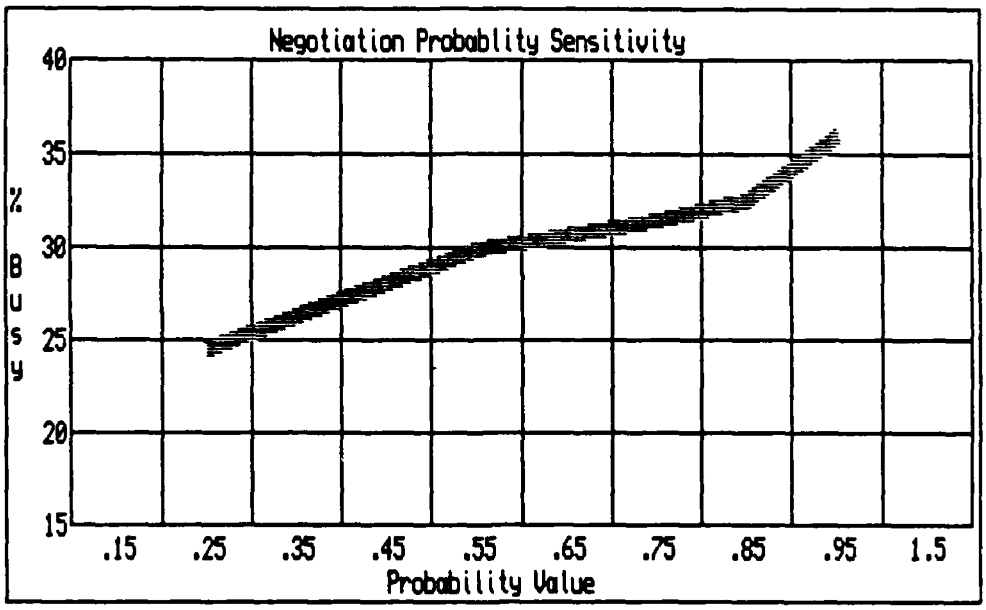


Figure 5.19 Negotiation Probability Sensitivity - Staff Officer Percent Business

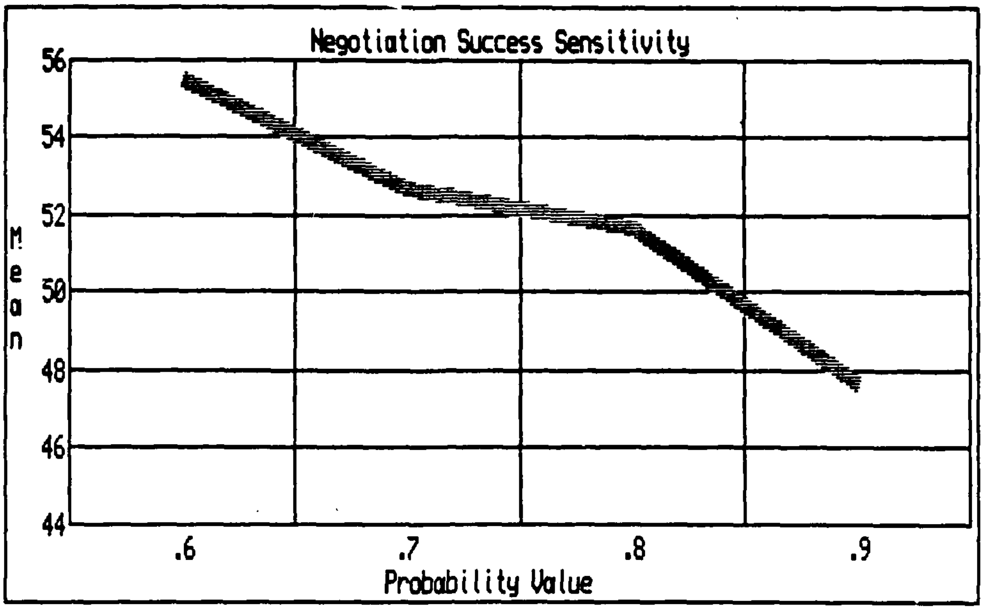


Figure 5.20 Negotiation Success Sensitivity - Mean Processing Time

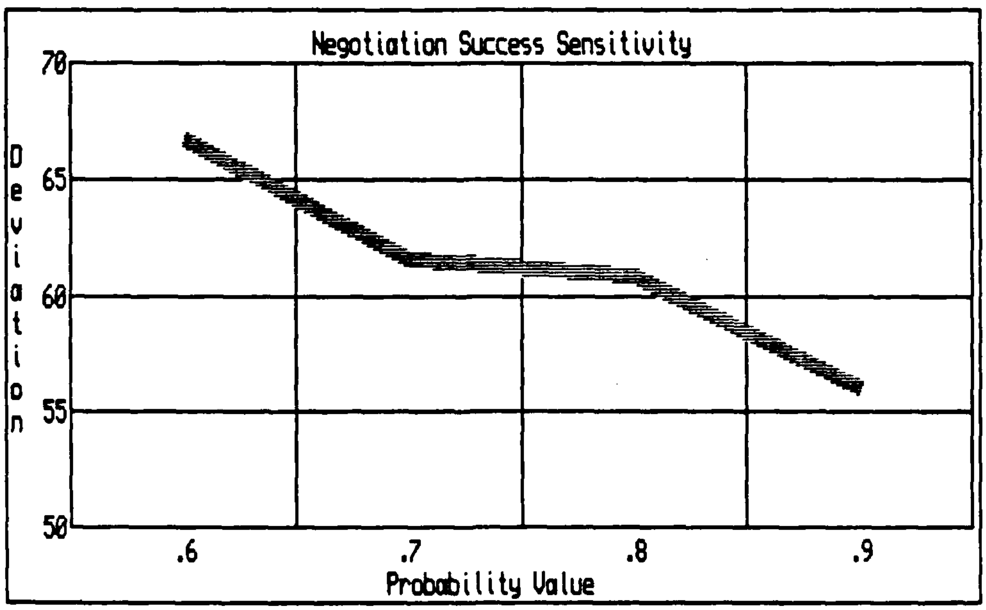


Figure 5.21 Negotiation Success Sensitivity - Processing Time Standard Deviation

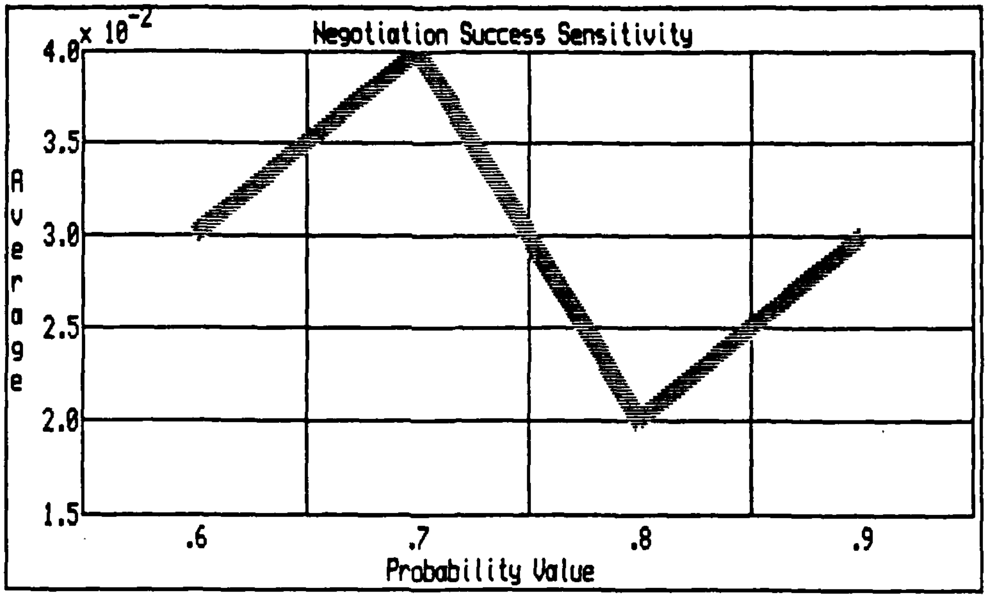


Figure 5.22 Negotiation Success Sensitivity - Average Queuing Time

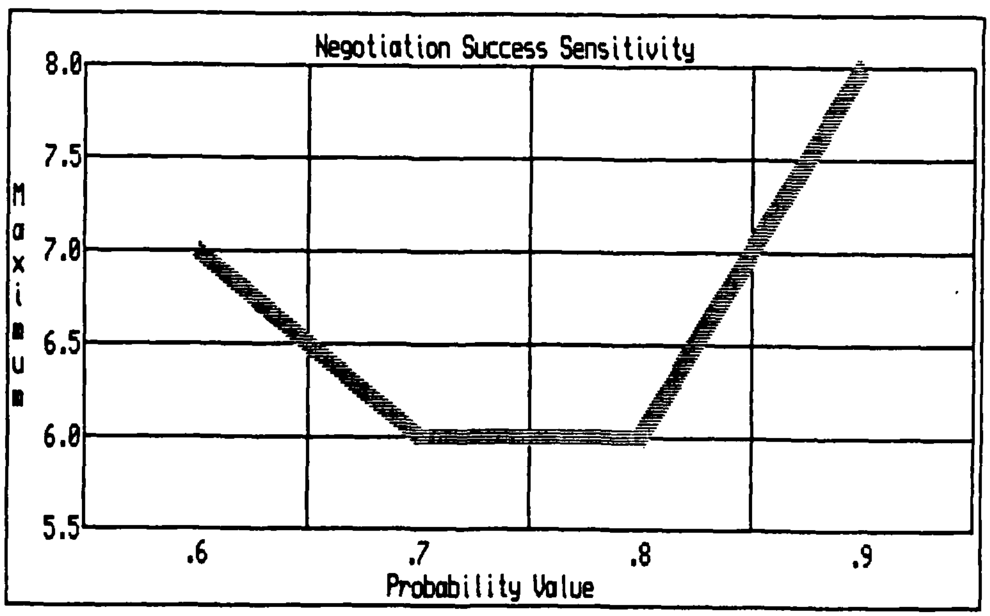


Figure 5.23 Negotiation Success Sensitivity - Maximum Queuing Time

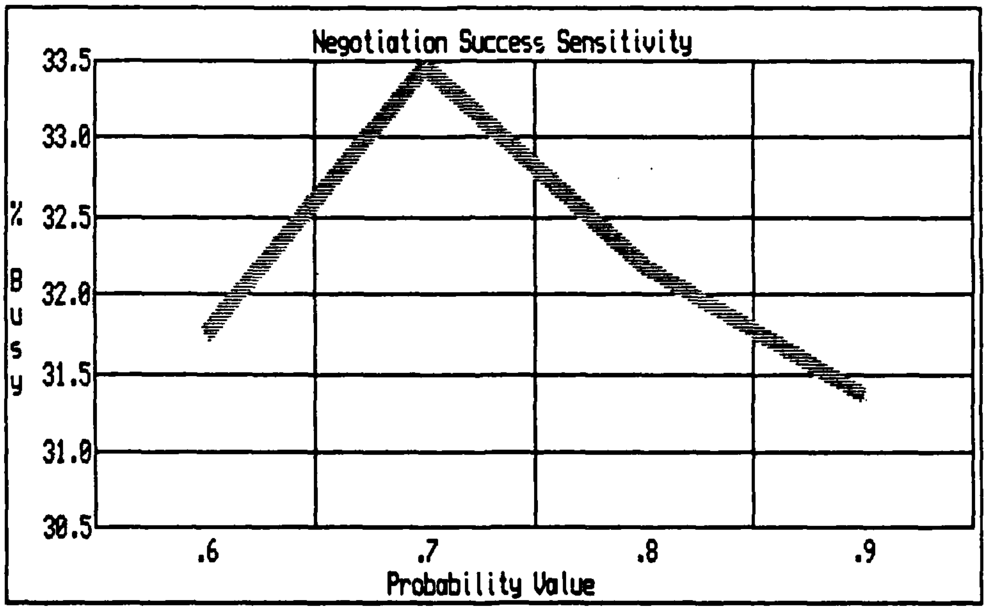


Figure 5.24 Negotiation Success Sensitivity - Staff Officer Percent Business

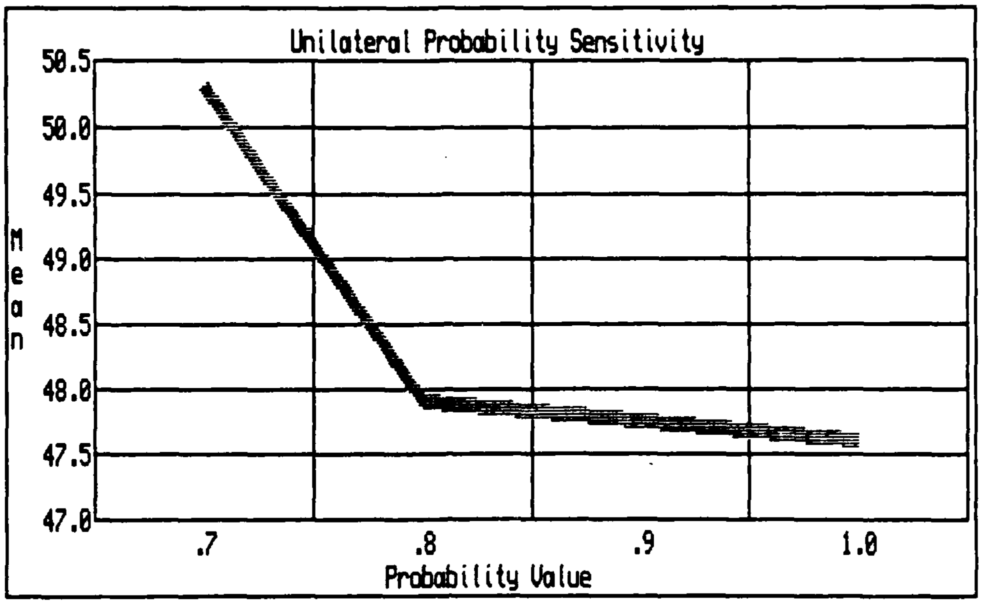


Figure 5.25 Unilateral Probability Sensitivity - Mean Processing Time

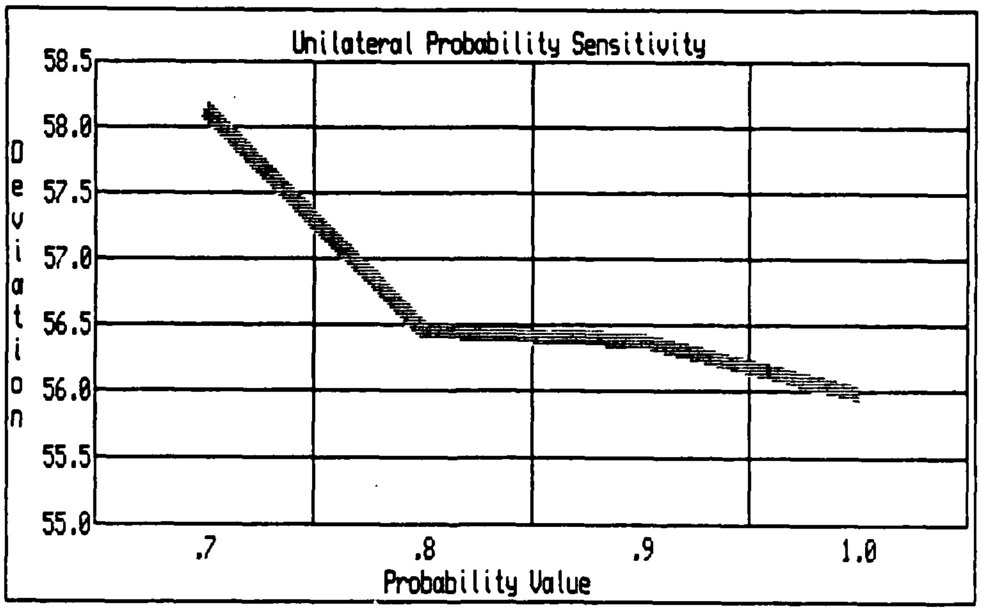


Figure 5.26 Unilateral Probability Sensitivity - Processing Time Standard Deviation

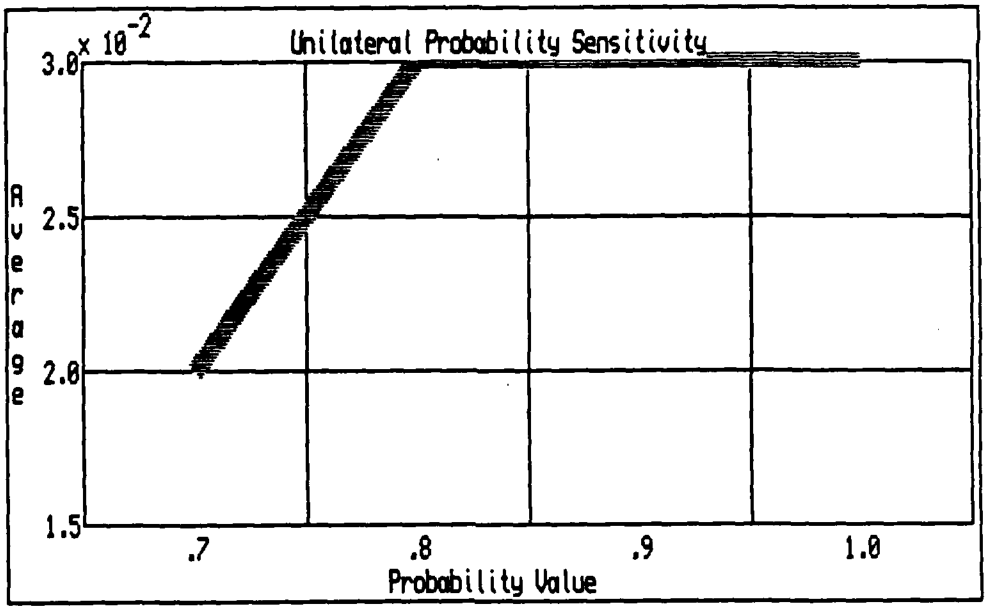


Figure 5.27 Unilateral Probability Sensitivity - Average Queuing Time

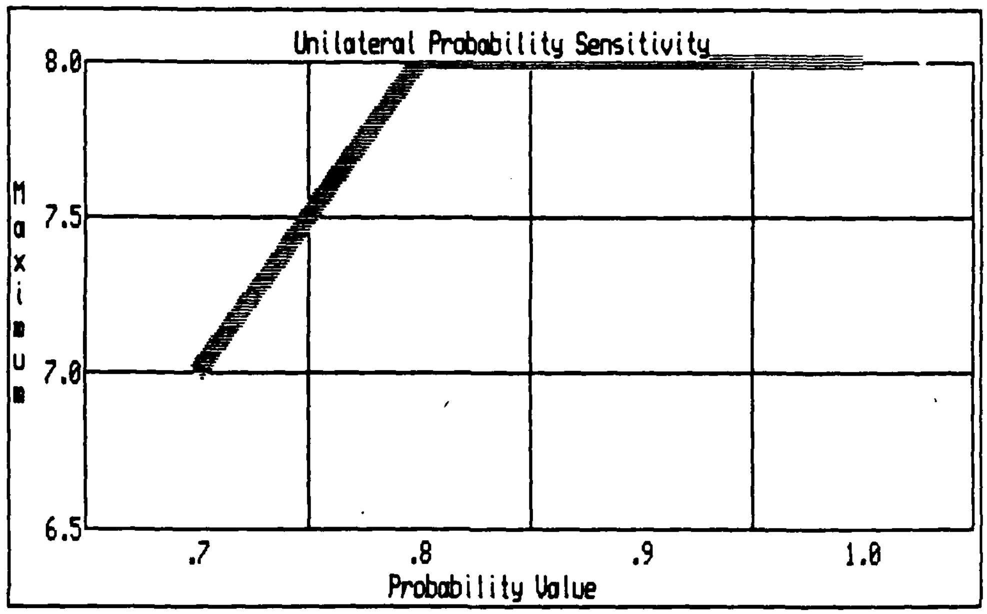


Figure 5.28 Unilateral Probability Sensitivity - Maximum Queuing Time

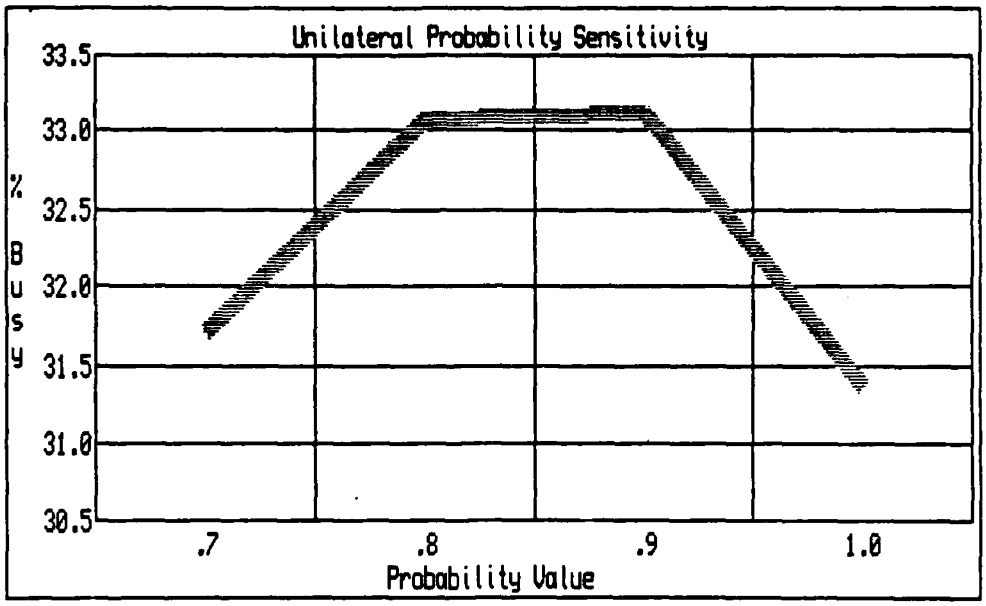


Figure 5.29 Unilateral Probability Sensitivity - Staff Officer Percent Business

changes decreased. The reader should note that the convention used was that as the probability number, .7 through .9, increased, the probabilty of a unilateral change occurring decreased. (See the program samples appendix F to see how such operations were performed.)

District/Field Probability: The probabilty of changes being generated at either district or field levels was varied from .25 to .9, with the results shown in figures 5.30 through 5.34. The processing time, time in the queue and staff business uniformly decreased as the probability of field change occurrence increased. The change in this one simulation model parameter resulted in a eleven day shift in mean processing time and this was one of the more sensitive items examined. This was attributed to the fact that this term directly determined three of the key attributes of a given change order, thereby strongly affecting its processing time.

Two Part Probability Slope: This was a special case where the probability of a two part change order was based on the function PROB.TWO.PART = M x BASE.PRICE (5-1), where M was the slope term. This model was derived from the CERL study and the slope term was varied to obtain occurrence probabilities which ranged from .003 to .013 for a $1000 change. The general trend

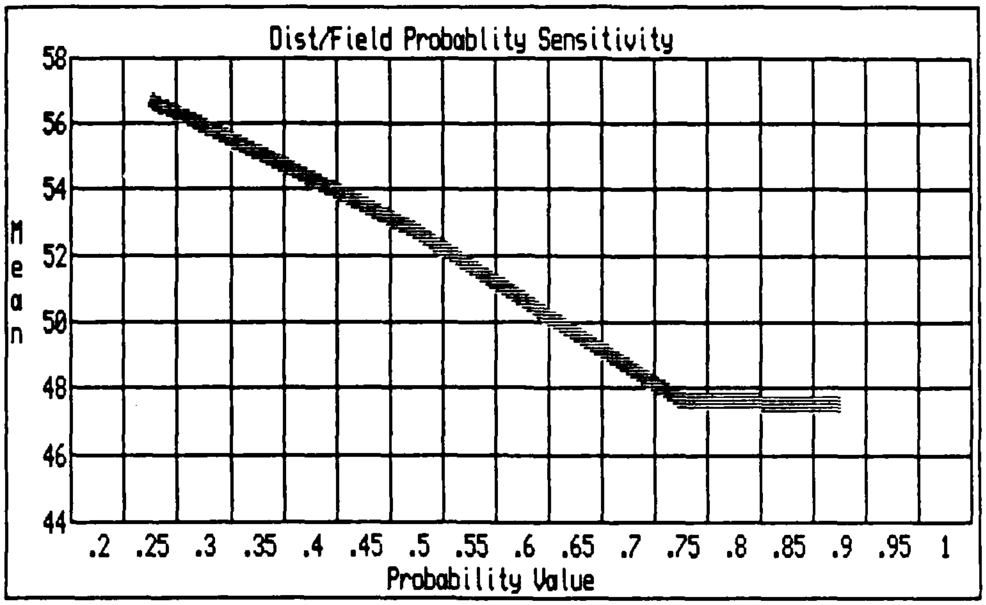


Figure 5.30 District/Field Probability Sensitivity - Mean Processing Time

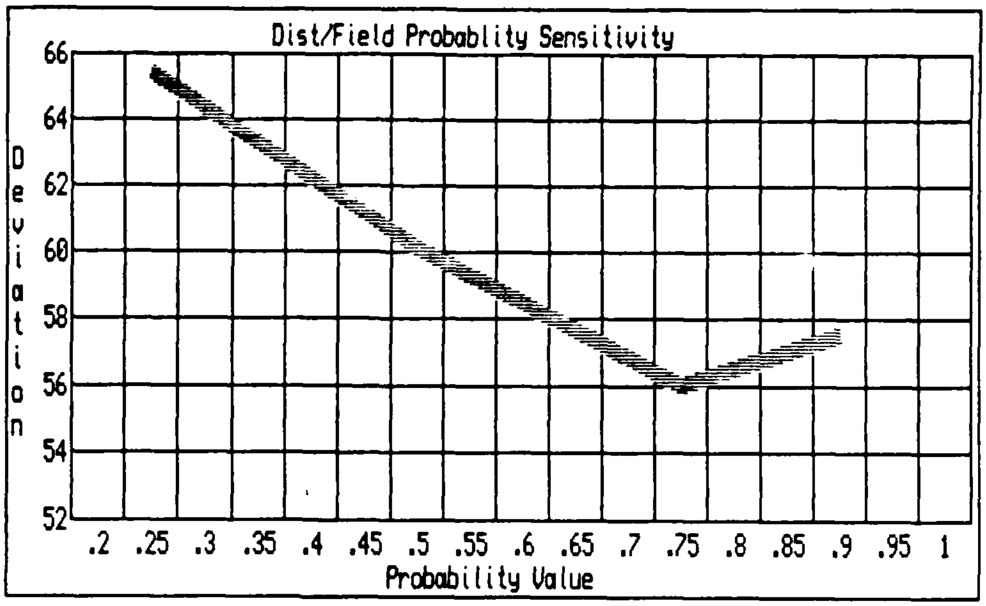


Figure 5.31 District/Field Probability Sensitivity - Processing Time Standard Deviation

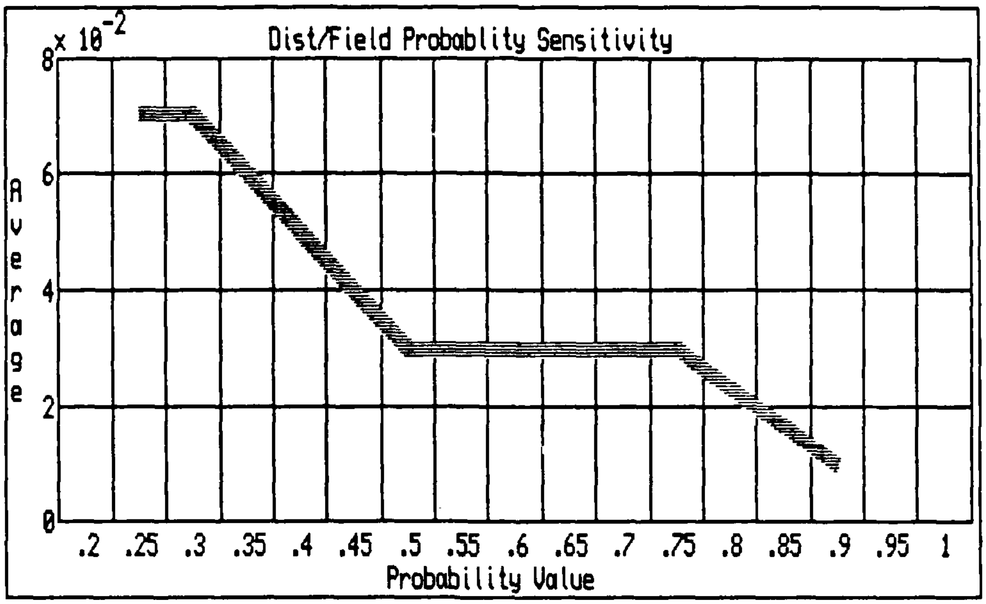


Figure 5.32 District/Field Probability Sensitivity - Average Queuing Time

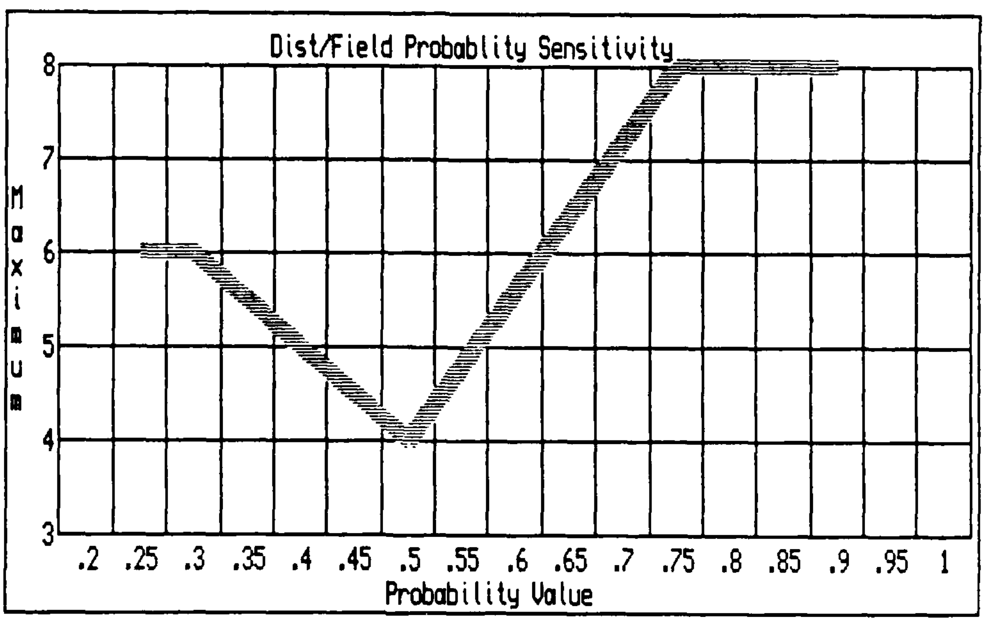


Figure 5.33 District/Field Probability Sensitivity - Maximum Queuing Time

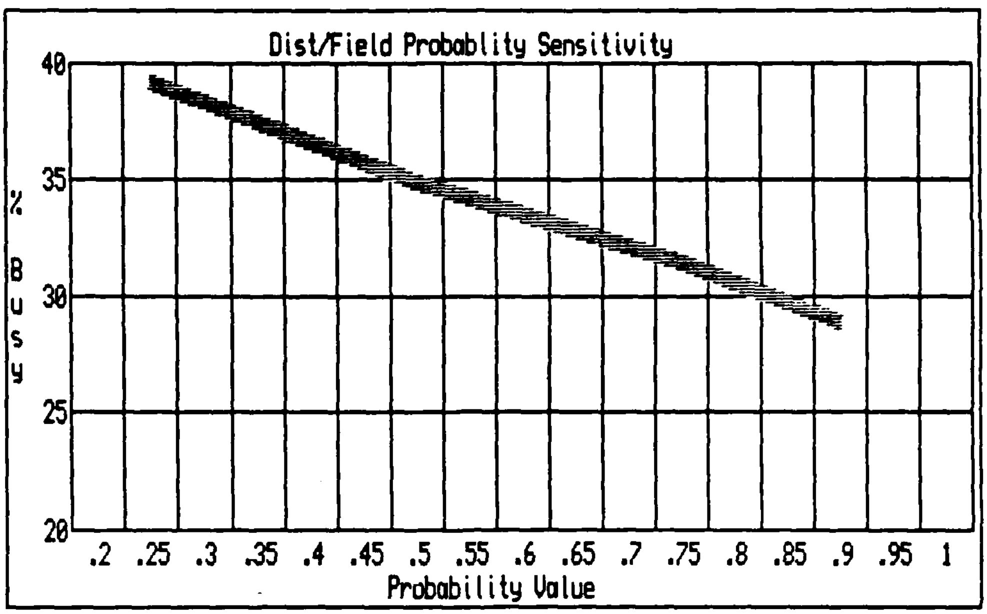


Figure 5.34 District/Field Probability Sensitivity - Staff Officer Percent Business

observed was that as the probability of a two part change varied, no appreciable change in mean processing time occurred; however, the staff business increased three percent over the entire range. See figures 5.35 through 5.39.

Probability of Acceptable Breakdown: The probabilty of the contractor's change order proposal having an breakdown was varied from .3 to .9 and this term was found to be the single most sensitive model parameter over the range studied. At a setting of .3, meaning that seventy percent of all proposals submitted had unacceptable breakdowns, the mean processing time rose to over 900 days. Fortunately, between .5 and .9, almost no change was experienced in mean processing time, so given that an estimate of this term was in the .5 - .9 range, the results obtained would be reasonable. Queuing performance showed a general upswing between .5 and .7, remaining stable elsewhere. See figures 5.40 through 5.44.

Probability of Further Negotiation Fruitfulness: In the event of a negotiation breakdown, a staff officer would have to decide whether to persue further

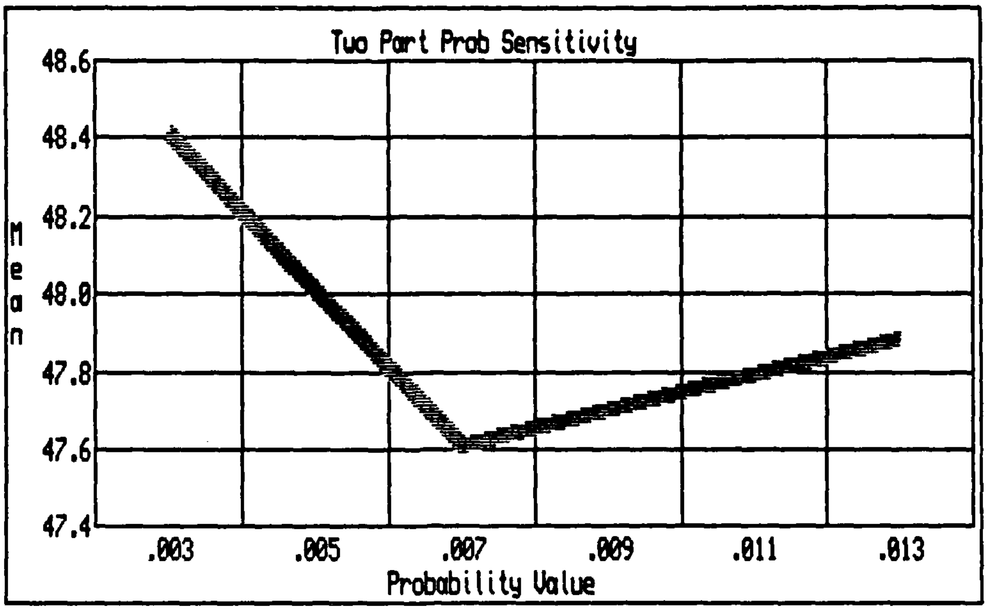


Figure 5.35 Two Part Change Probability Sensitivity - Mean Processing Time

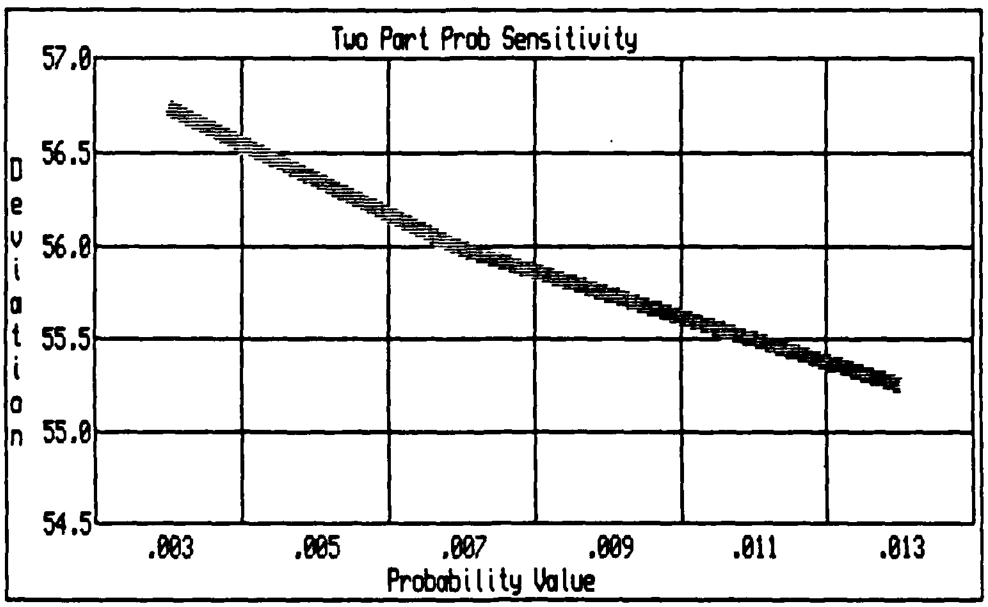


Figure 5.36 Two Part Change Probability Sensitivity - Processing Time Standard Deviation

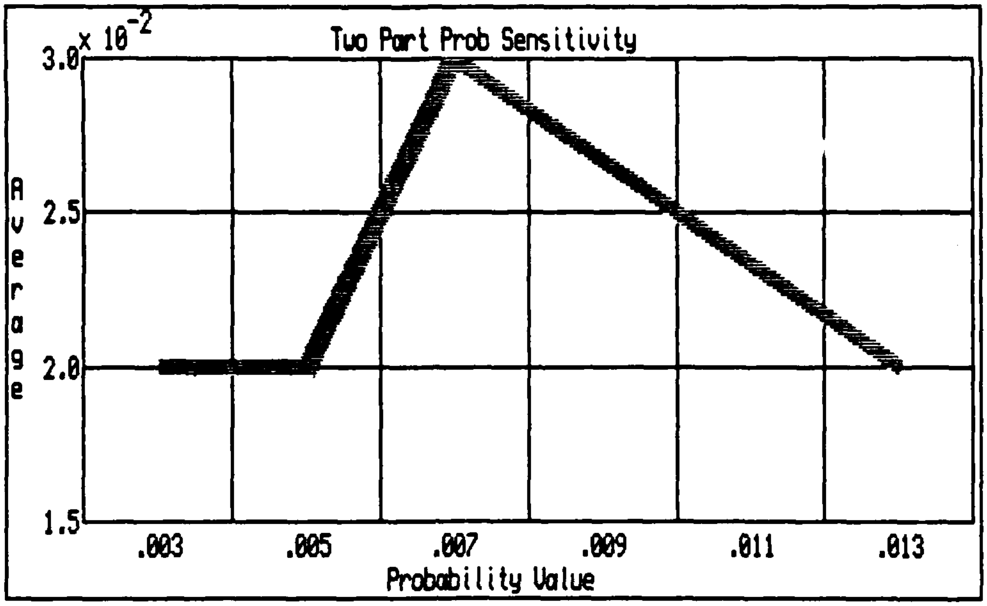


Figure 5.37 Two Part Change Probability Sensitivity - Average Queuing Time

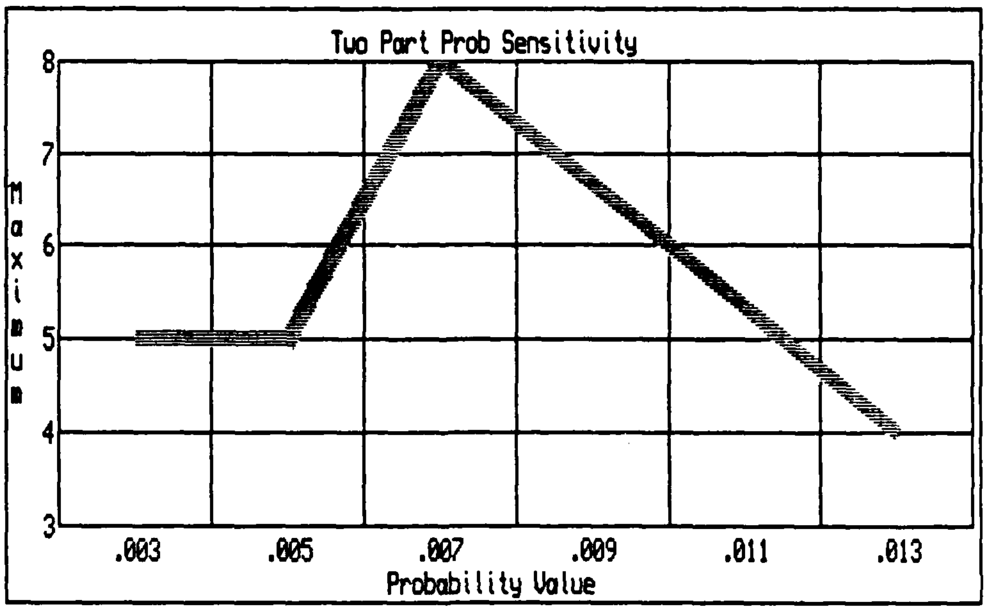


Figure 5.38 Two Part Change Probability Sensitivity - Maximum Queuing Time

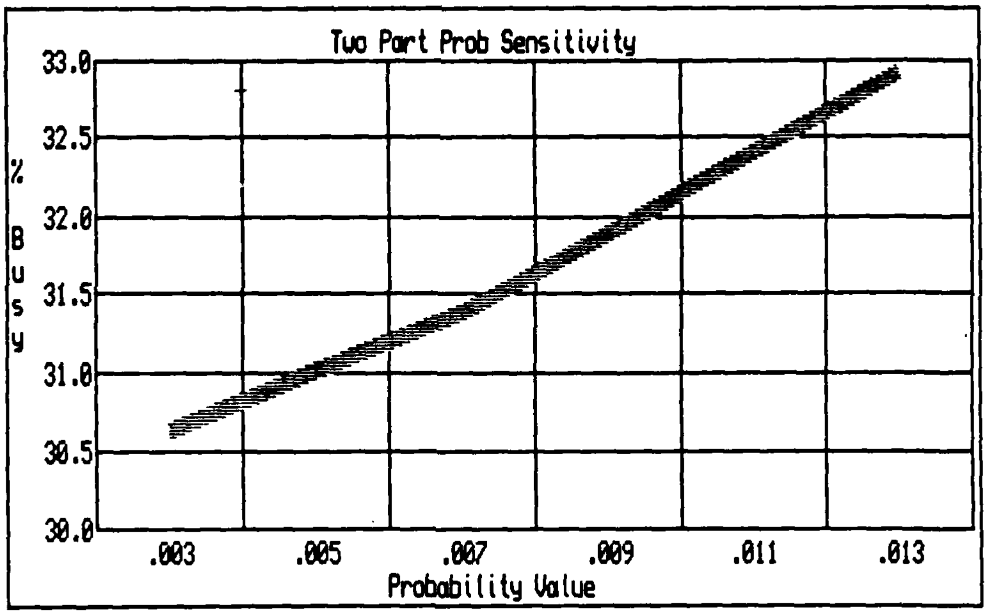


Figure 5.39 Two Part Change Probability Sensitivity - Staff Officer Percent Business

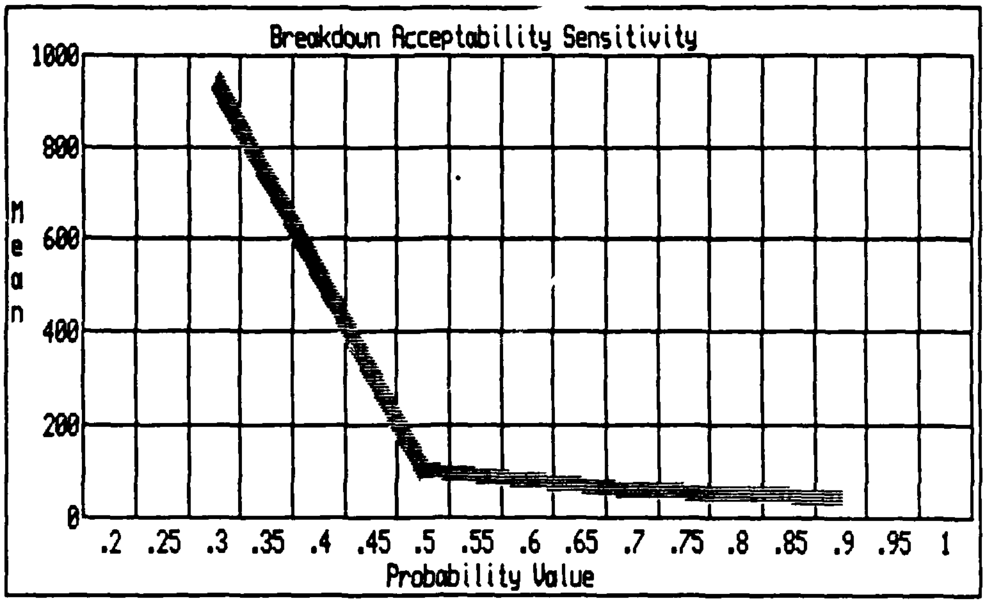


Figure 5.40 Proposal Breakdown Acceptability Sensitivity - Mean Processing Time

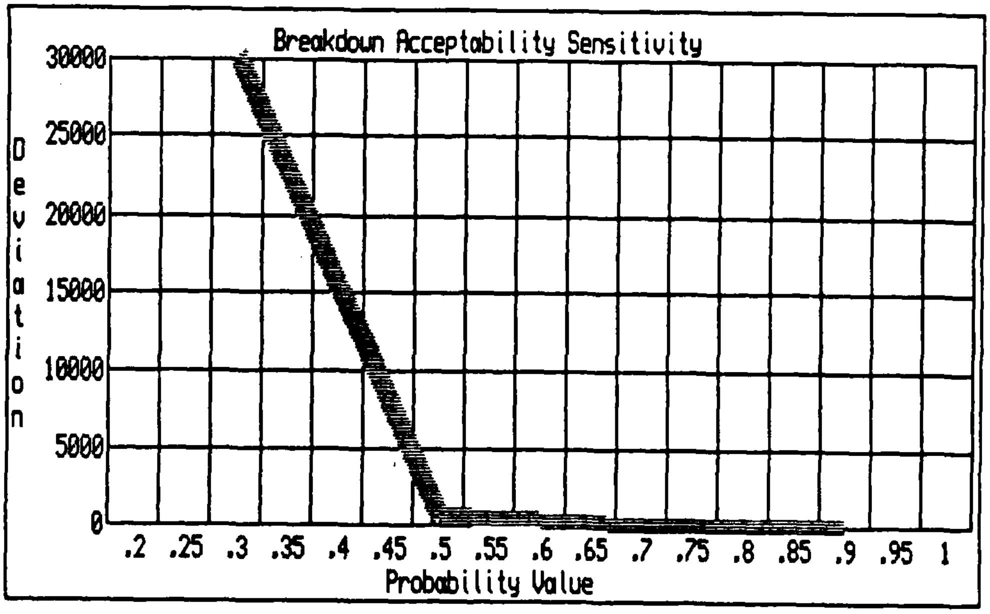


Figure 5.41 Proposal Breakdown Acceptability Sensitivity - Processing Time Standard Deviation

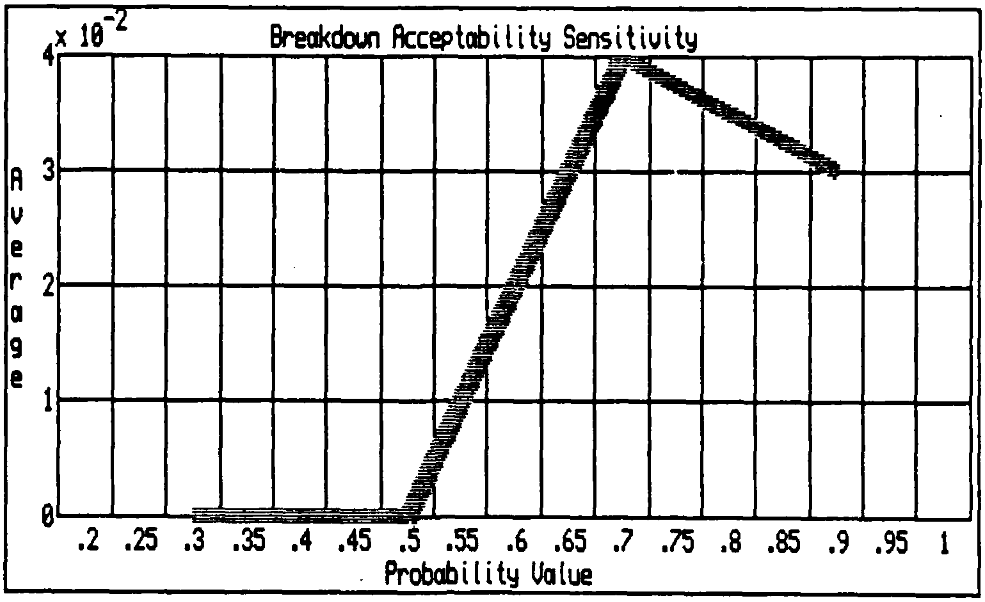


Figure 5.42 Proposal Breakdown Acceptability Sensitivity - Average Queuing Time

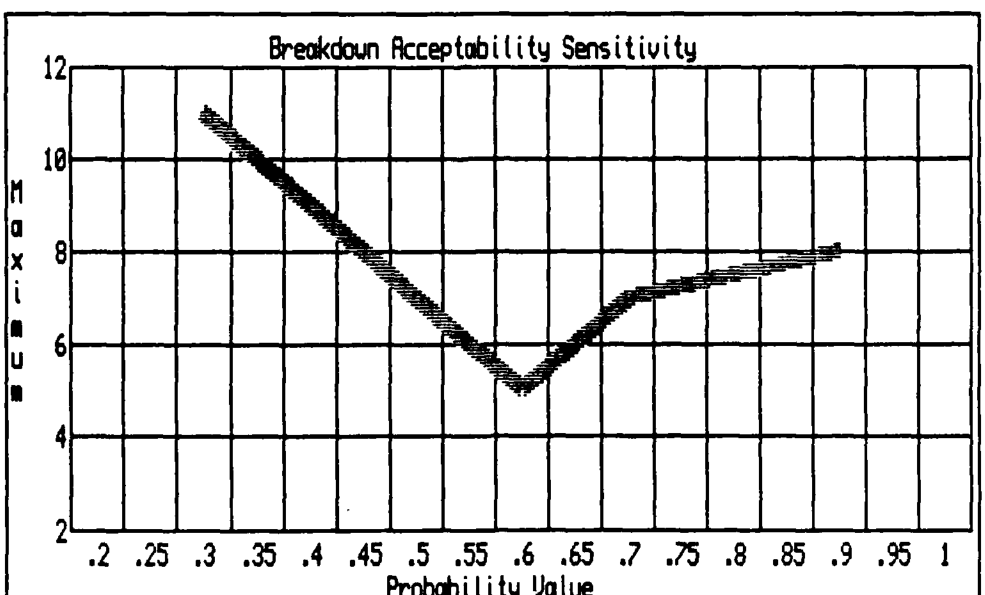


Figure 5.43 Proposal Breakdown Acceptability Sensitivity - Maximum Queuing Time

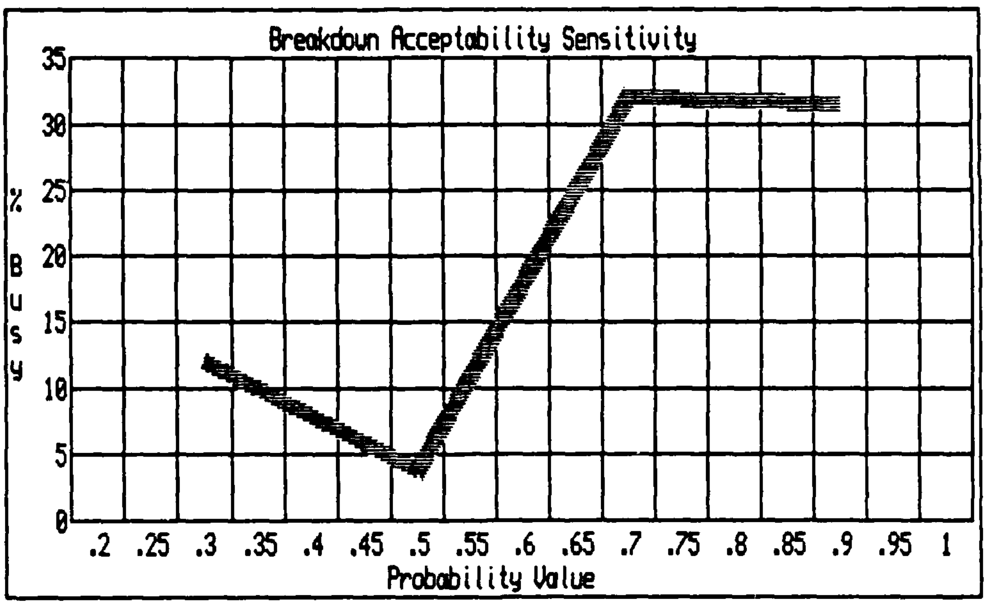


Figure 5.44 Proposal Breakdown Acceptability Sensitivity - Staff Officer Percent Business

negotiations with the contractor. To simulate such a decision, a probability of further negotiation value was assigned. This term was varied from .5 to .99 and the results are shown in figures 5.45 through 5.49. Generally the mean processing time decreased as the probability of further field negotiations increased. This was expected, as those changes not renegotiated at the field office were routed to the distrct office for negotiation, with a corresponding time lag being incurred. Staff business showed no strong trends, but the maximum queuing time generally increased.

District Processing Sensitivity: This term modeled the chance of a contractor's refusal to submit a change proposal in a timely manner requiring the District Staff to step in and take over contractor negotiations. This probability was varied from .6 to .99 and the results are shown in figures 5.5Ø through 5.54. The overall trend was that the model was not sensitive to changes in this parameter.

5.4.6 Distribution Shape Sensitivity

The last sensitivity test performed was designed to see the impact of varying the distribution shapes of the RS distributions used in the simulation model. This

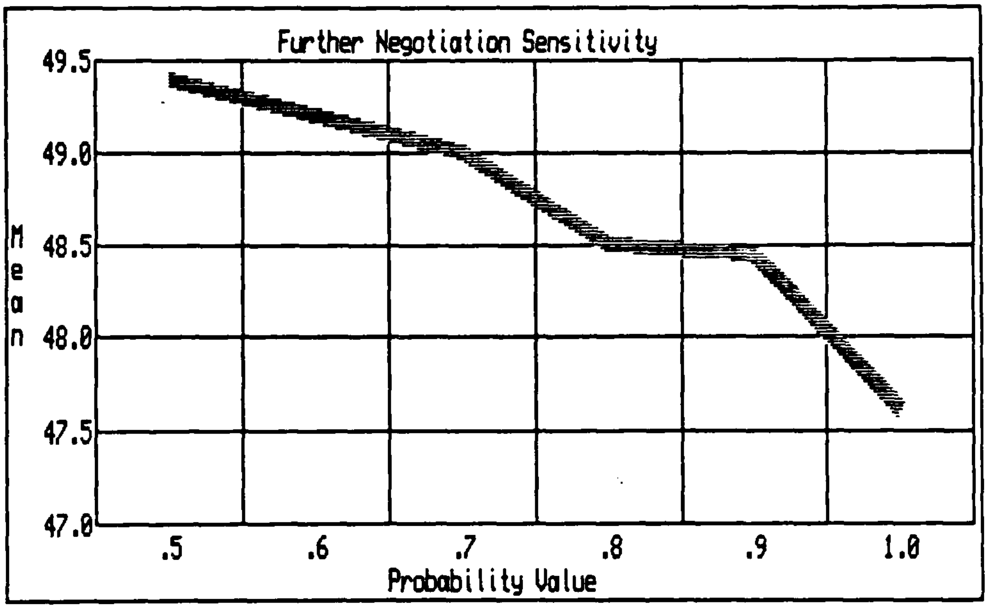


Figure 5.45 Further Negotiation Probability Sensitivity - Mean Processing Time

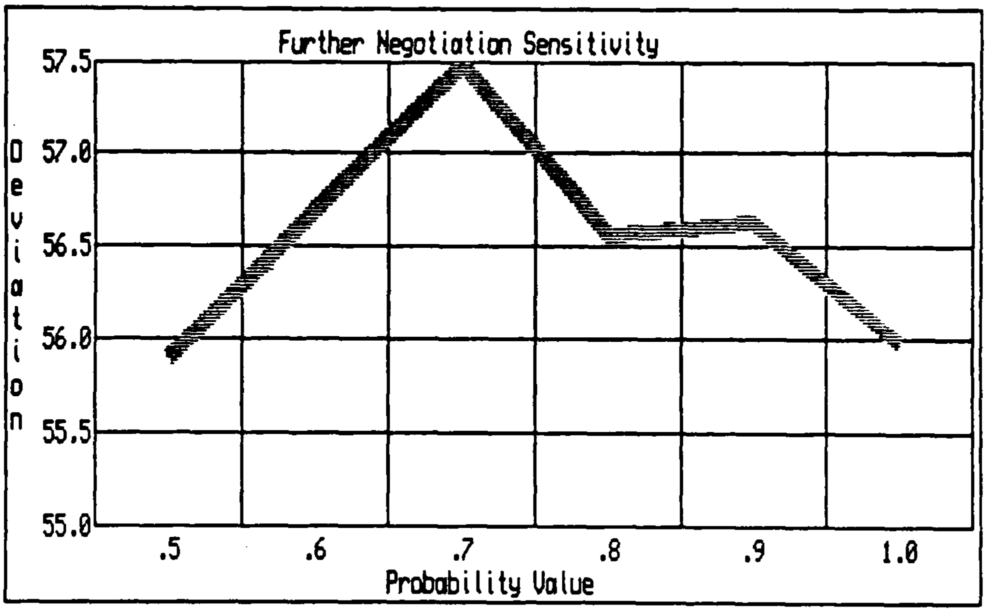


Figure 5.46 Further Negotiation Probability Sensitivity - Processing Time Standard Deviation

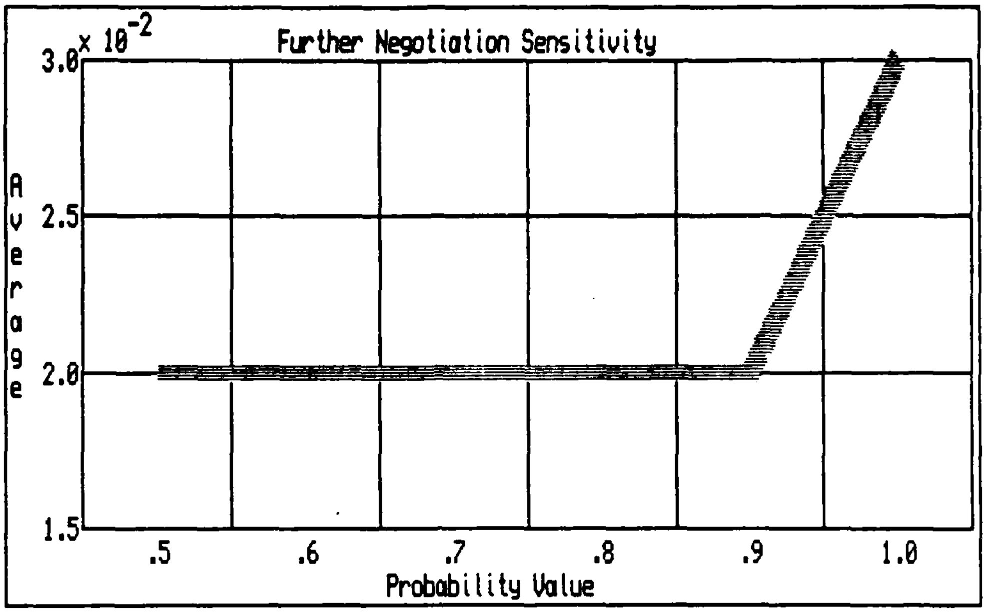


Figure 5.47 Further Negotiation Probability Sensitivity - Average Queuing Time

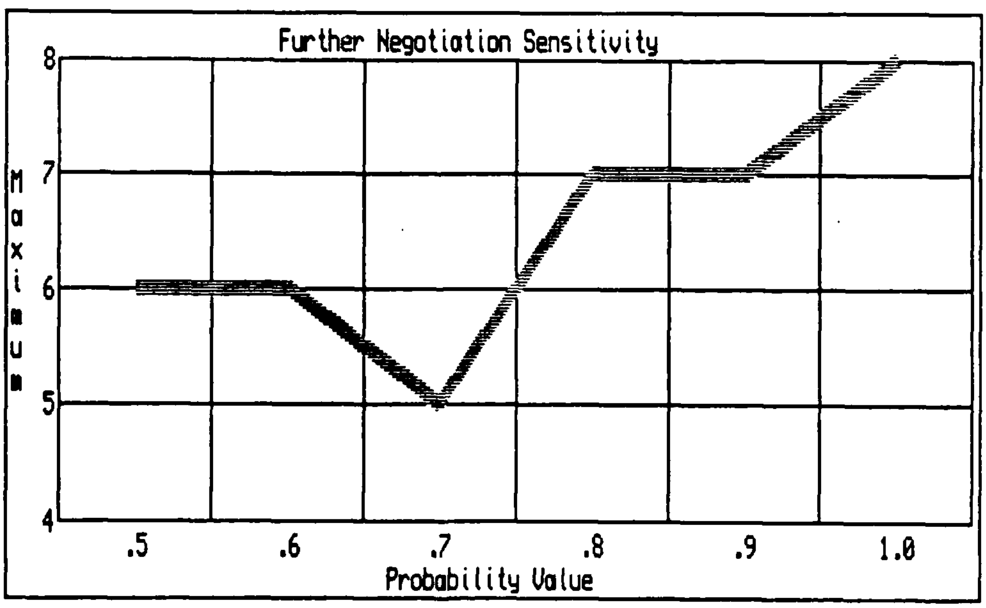


Figure 5.48 Further Negotiation Probability Sensitivity - Maximum Queuing Time

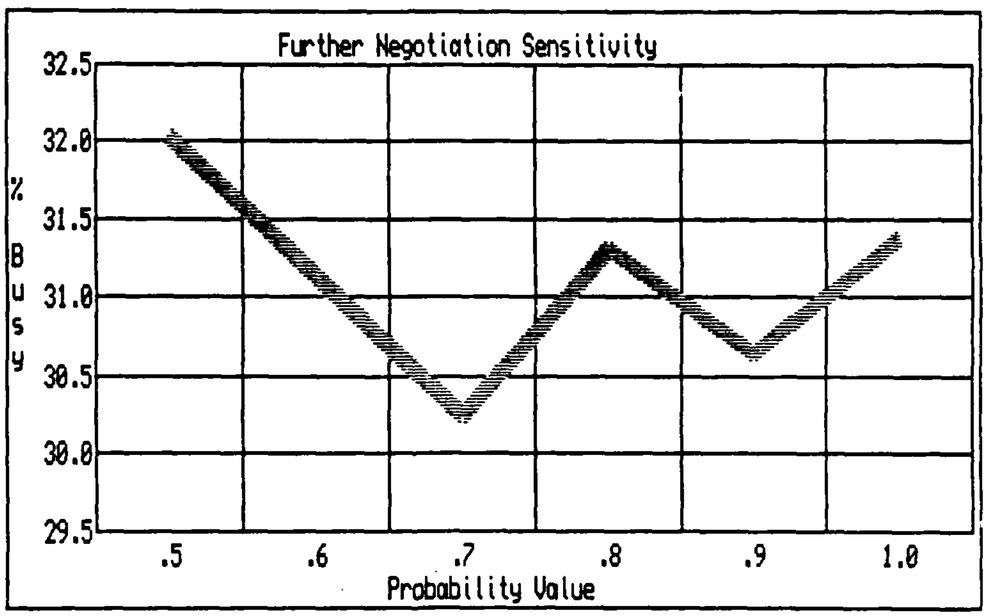


Figure 5.49 Further Negotiation Probability Sensitivity - Staff Officer Percent Business

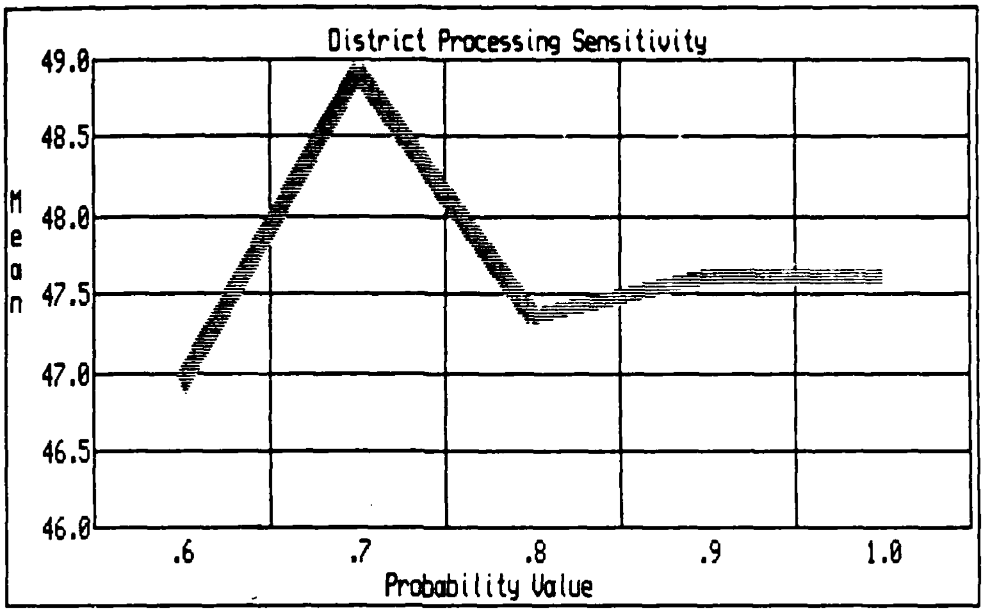


Figure 5.50 District Processing Sensitivity - Mean Processing Time

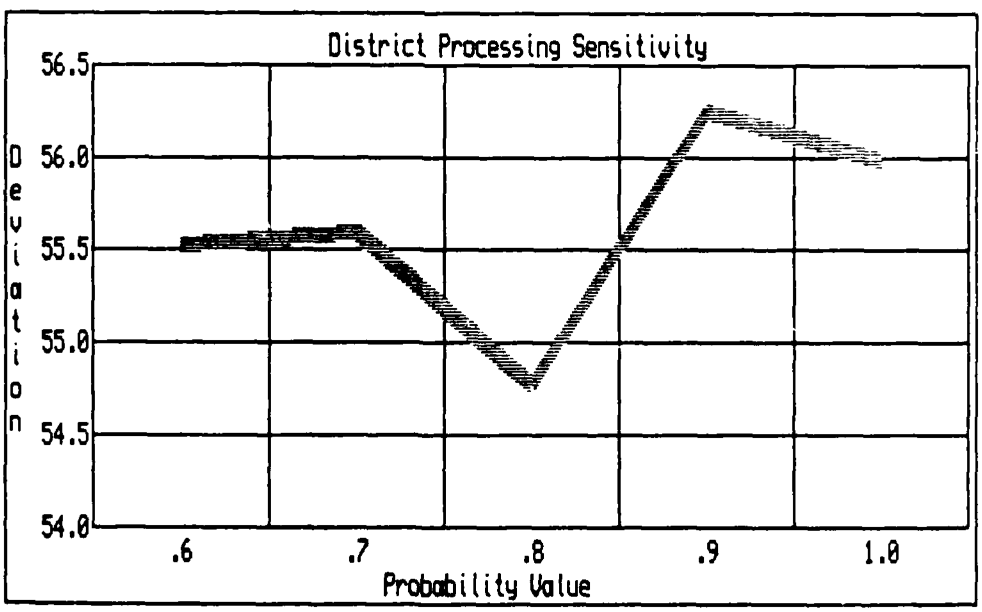


Figure 5.51 District Processing Sensitivity - Processing Time Standard Deviation

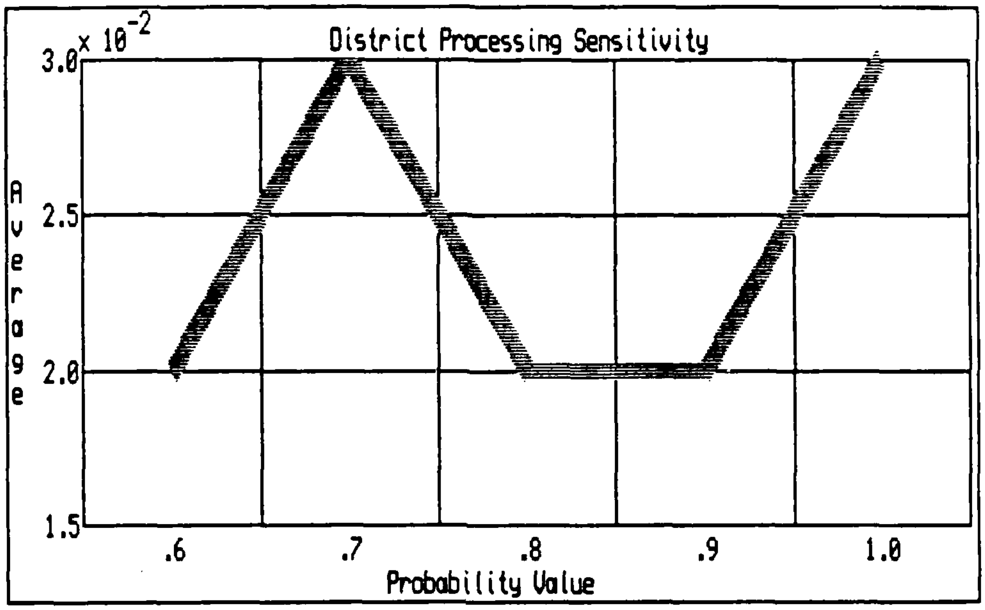


Figure 5.52 District Processing Sensitivity - Average Queuing Time

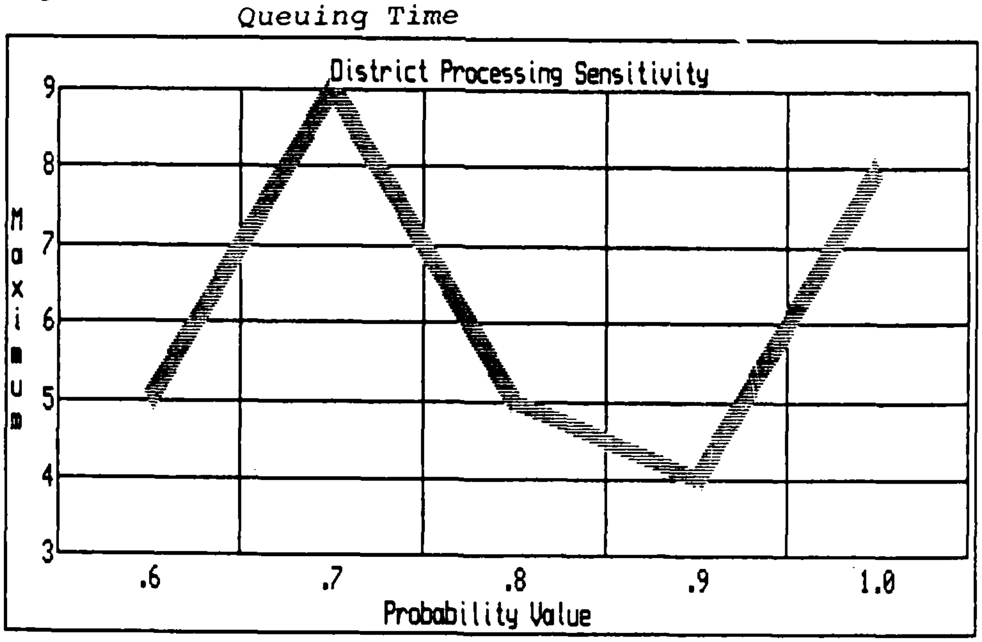


Figure 5.53 District Processing Sensitivity - Maximum Queuing Time

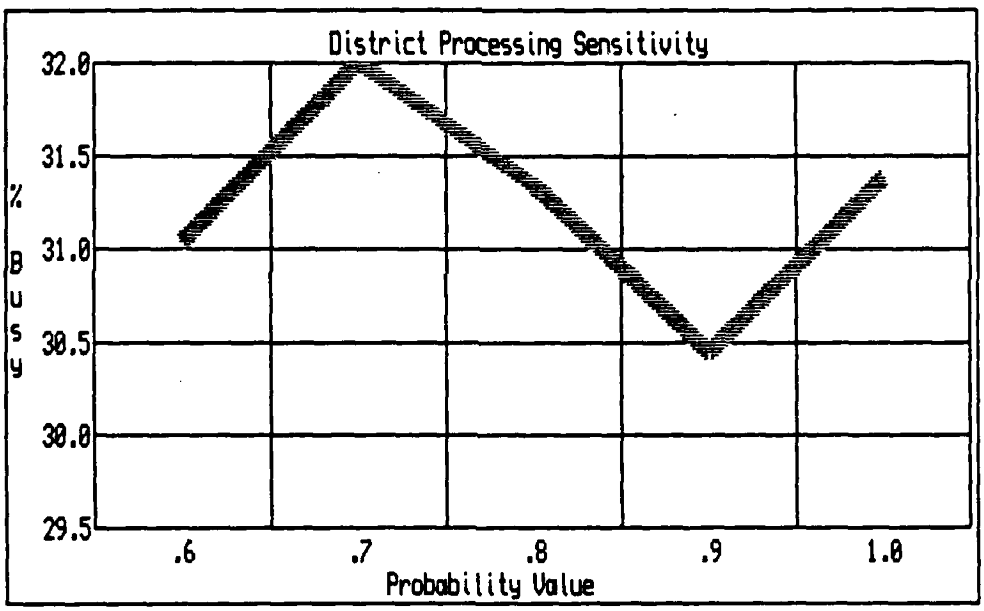


Figure 5.54 District Processing Sensitivity - Staff Officer Percent Business

was important in that, though it is sometimes possible to reasonably estimate the mean of a random variable's probability distributiion, and perhaps its standard deviation, the experimenter might not be able to obtain a clear picture of the actual distribution shape. For this reason the author allowed the various RS distributions to take on a wide range of shapes, from J-shaped, tail right, to uniform, to normal, to J-shaped, tail left, in order to measure overall model impact. The results of all experiments in terms of the effects on the five performance measurements, are given in table 4 listed on page 1Ø9.

TABLE 4
SENSITIVITY ANALYSIS OF DISTRIBUTION SHAPES

TYPE DIST	CYCLE TIME MEAN	STANDARD DEV.	QUEUING DATA AVERAGE QUEUE	MAXIMUM QUEUE	% BUSY
		FIELD BASE PRICE			
ACTUAL	47.61	55.98	.03	8	31.37
UNIFORM	48.10	57.45	.03	6	33.36
NORMAL	47.38	56.54	.04	7	33.92
REV.SKEW.	50.64	59.77	.04	5	35.61
		FIELD LEAD TIME			
ACTUAL	47.61	55.98	.03	8	31.37
UNIFORM	48.04	54.14	.02	6	31.75
NORMAL	49.65	56.62	.02	6	31.30
REV.SKEW.	49.28	55.49	.03	5	32.07
		CO WAIT TIME			
ACTUAL	47.61	55.98	.03	8	31.37
UNIFORM	49.73	57.95	.03	9	32.45
NORMAL	48.38	58.25	.03	7	33.41
REV.SKEW.	48.03	57.79	.03	9	31.76
		DIST. BASE PRICE			
ACTUAL	47.61	55.98	.03	8	31.37
UNIFORM	48.53	57.36	.03	7	31.88
NORMAL	50.12	59.30	.02	5	32.56
REV.SKEW.	48.39	58.74	.03	9	31.57
		DIST. LEAD TIME			
ACTUAL	47.61	55.98	.03	8	31.37
UNIFORM	48.90	56.75	.03	7	32.56
NORMAL	47.53	57.74	.02	4	31.08
REV.SKEW.	45.62	54.13	.03	9	30.97

TABLE 4 (continued)

TYPE DIST	MEAN	CYCLE TIME STANDARD DEV.	AVERAGE QUEUE	QUEUING DATA MAXIMUM QUEUE	% BUSY
		REVIEW TIME			
ACTUAL	47.61	55.98	.03	8	31.37
UNIFORM	61.98	50.49	.02	5	31.38
NORMAL	61.29	48.13	.02	4	32.44
REV.SKEW.	76.60	41.18	.02	4	31.38
		DIST. NEGOTIATION TIME			
ACTUAL	47.61	55.98	.03	8	31.37
UNIFORM	47.61	55.98	.03	8	31.37
NORMAL	47.61	55.98	.03	8	31.37
REV.SKEW.	47.61	55.98	.03	8	31.37

As can be seen above, the simulation model was not very sensitive to a single change in the various distribution shapes. It should be noted that most of the original RS distributions used in the model were J-shaped, tail right and are depicted above as ACTUAL. The reversed skewness test, labelled REV.SKEW., was obtained by switching the values of lambda three and lambda four in the the RS distribution formula, and by reversing the sign on lambda one. The NORMAL AND UNIFORM tests were performed by using RS distribution parameters determined by using the skewness and kurtosis of the normal and uniform distributions respectively.

5.5 Results Summary

To summarize, the entire series of sensitivity tests showed that the simulation model was not highly sensitive to any single parameter change. Also, the specific estimates used for all terms appeared to be applicable over a wide range of possible values, so if the estimate was not exact, the effects of that impreciseness, would not greatly reduce the reasonableness of model results. Finally, one important aspect of the model which was not directly tested but which was experienced by the author in the construction of the simulation model, was the extreme model sensitivity to changes in the resource/queuing model. This phase of modelling required the insertion of resource request and relinquishment calls. Care was exercised to insure that such calls occurred as they would in actual change order processing. Failure for instance, to release a resource when its use was finished, would cause queuing times to increase by weeks and falsely boost processing time. Once this problem was overcome then the model operated in a predictable fashion and seemed to be fairly robust in terms of sensitivity to change. This concludes the descriptive portion of this thesis and leads into the final chapter in which the author offers conclusions and recommendations.

CHAPTER VI

CONCLUSIONS AND RECOMMENDATIONS

6.1 Introduction

Conclusions based on the research will now be presented by first discussing, in this introduction, how well the objectives of Chapter I were met. These comments will be followed by two sections listing specific conclusions and recommendations for future research. Finally, the last section will address the original problem statement and final comments will be offered.

With respect to objective one, the CERL model was updated using AMPRS data. The results obtained were markedly different from those of the CERL study, but did closely pattern those of regression models derived from the Baltimore District data set. The processing times generated by the new model were approximately double those of the CERL study.

Sensitivity analysis was conducted per objective two, of Chapter I and it was found that the model was not very sensitive to changes in its parameters. Several parameters would have to be set at their range extremes before any appreciable change in overall results would be realized. Also, it was noticed that several parameters were insensitive over a wide range thus negating the need for precise estimation.

Comments pertaining to the Corps of Engineers' contract modifications and claims procedures will be covered in the specific recommendatios section under item four. One comment refers to setting RCO authority level at $50,000 and the other offers comments on the need to more fully utilize the AMPRS data base. This concludes the general overview. Specific conclusions and recommendations will be discussed in the next two sections.

6.2 Specific Conclusions

Five research conclusions were reached and each is described below:

1. This research was able to demonstrate the use of simulation in a construction management setting and show the potential for gaining management insight into

complex problems through simulation experiments. It should be noted however that the author is of the opinion that such models are too complex for the layman to operate without a great deal of prior coaching. By the same token, a novice would find it extremely difficult to create a new model or radically alter an existing one.

There are many small details requiring special attention and involve problems that do not contain obvious solutions. For example, a simulation may provide results which at face value, seem reasonable, but upon closer inspection, are flawed. This was covered in chapter three and in essence indicates that it is easy to be fooled by the results obtained. It took a great deal of attention to detail to prevent errors such as attribute memory destruction and resource/queuing model mistakes. This is not intended to discourage the use of simulation, in fact such use is encouraged for simulation is often the only practical solution approach to problems facing civil engineers.

2. A two pronged approach to model development, coupling simulation with such data analysis techniques as regression, provides a superior approach to solving real-world engineering problems. Without the proper

inputs, the simulation outputs will be extremely suspect. Also, prior analysis can show which simulation flow paths are actually operant and which activities or attributes are key in determing throughput times. For example, as pointed out in chapter four, change order base price was selected as the dependent variable for determining the durations of such activities as proposal preparation time and review time, yet a correlation analysis showed base price to be a poor predictor of these items.

Perhaps, this shows the value of attacking simulation modelling with a team made up with members from disciplines other than just the industrial engineering or operations research community. In this case, a knowledge of contract law terminology, as well as that of construction operations and statistics, was required. A team, with experts in each of these areas, would have less difficulty handling this problem, than a single operations research analyst.

3. Once this simulation model was set up it was very accessible and easy to use from the execution standpoint. This contrasts with the comments in conclusion one, in that this conclusion refers only to the mechanics of getting the program to run, not

performing model adjustments. The gaming potential of a simulation, such as this, is great. This of course assumes that all modelling problems mentioned above have been tackled. It took only seconds to adjust a parameter and run the simulation and the data output could be used to obtain a relative feel for what might occur, if for example, there was a policy change.

4. Per objectives one and three, it was possible to adequately duplicate the CERL model and refine the model to provide further insights into this problem. Specifically, it is recommended that the RCO authority level for processing changes should be set at the \$50,000 level. It appeared that processing time was at its lowest time at this point, while the difference in authority, say between, \$25,000 and \$50,000 in construction dollars, is not significant. Another conclusion based not so much on the simulation itself, but the data collection effort, was that the AMPRS data base should be used to its fullest potential if the data is to be analyzed, using tools like simulation. There was a problem in going from the routine report forms, to the data base. Items requiring input into the data base could not be derived easily from the forms resulting in keypunch errors. Finally, records procedures ought to

better model what is actually going on in the field. It appeared that much of the changed work was completed before the actual notice to procede was given. If this is what actually occurs, then it should be so documented. Altering figures to make it appear that administrative procedures are compatible only serves to confuse the management effort.

6.3 Specific Recommendations For Future Research:

1. It appears that there is a link between regression analysis and simulation results, especially when simulations are run in the same policy environment as that from which the regression data was derived. In particular, this thesis demonstrated that one may expect to find a path in the simulation model which includes the variables found in the corresponding regression model. This path will be the one followed by the greatest number of transactions. In such a case, the simulation model could then be used to extend beyond the existing policy environment to see what happens. This is something that the prediction model could not be used for without validity problems.

2. The relationship between change order processing time and total contract cost was beyond the scope of this research, but merits further research because then those results, combined with the simulated times could be used to make the more universally accepted, dollar based conclusions. Perhaps the relationship between the final cost of contracts and change order processing time is not significant, thereby negating the need for continued research in this area, or perhaps the relationship is greater than thought, thus increasing this problem's importance. At this point such judgements are difficult to make.

3. There must be a compromise between such user friendly simulation languages as CYCLONE, by Halpin and Woodhead, and the more complex, high level languages, such as SIMSCRIPT II.5. A flexible, user friendly language, that allows detailed engineering analysis should be developed and made available to construction managers. It would be particularly nice if the program was PC usable with a modest price tag. The author was not able to find one as of this date. Either the user control was too restrictive to allow modelling certain processes, or the languages were too difficult for the layman to operate without much prior study. A middle

level program/language would unlock the power of simulation to a whole new group of potential users.

6.4 Final Conclusion

Referring back to Chapter I, one recalls that the original problem was: "Can the U.S. Army Corps of Engineers' procedures for processing contract modifications, specifically Change Orders, be reliably modeled using computer simulation so that leaders can use the simulation to make policy decisions that reduce the overall time and cost of fixed-price construction contracts?" (Curtis, 1986)

The answer is yes, computer simulation can be used to model the contract modifications procedures, providing reliable results. It is also possible for leaders to use the model to aid policy development. Whether or not such policies will result in cost reduction remains to be seen but it appears reasonable that such policies would have a positive effect on construction time reduction.

The reader is cautioned however, that the use of simulation is not a casual endeavor. Model development requires time, patience, and preferably a combined team, consisting of experts in areas relative to the problem being studied. Originally, the author envisioned the situation where a leader, sitting at a computer work station, would work in concert with a PC-based simulation package, to develop policy decisions. The author is now of the opinion that this scenario is still a ways away in terms of both computer software technology and leader training. Given a developed program, a trained staff could effectively use a simulation program, such as the one developed in this thesis, under some expert guidance, with minimal error risk. It is doubtful however, that a layman working alone with this tool, would be very productive. In competent hands, the new technology examined in this thesis (computer simulation) can be used to effectively explore alternative ways to reduce construction time and cost at a modest investment.

LIST OF REFERENCES

Ang, Alfredo H-S and Tang, Wilson, H. Probability Concepts in Engineering Planning and Design. New York: John Wiley and Sons, 1975 [114-115].

Chang, Ki-Sung and Liu, Nien-Ping, "Identifying the Construction Delays Due to the Field Design Change Request Procedure," Class term paper, The Ohio State University, 23 May 1986.

Cook, Thomas M. and Rao, Prakash, "Airline Terminal Design Using Computer Simulation," Transactions 17 (December 1985): 314-19.

Dixon, W.J. et al., BMDP Statistical Software, 1981 Edition. Los Angeles: University of California Press, 1981 [290-303].

Halpin, Daniel W. and Woodhead, Ronald W. Design of Construction and Process Operations. New York: John Wiley and Sons, 1976 [1-76].

Kiviat, P.J.; Markowitz, Harry; and Villanueva, R. SIMSCRIPT II.5 Programming Language Los Angeles: CACI Inc.-Federal, 1983 [323-337].

Larew, Richard E. Cost Estimating and Pricing in a Construction Company Volume 2 Initial Stochastic Studies Columbus: The Ohio State University, 1976[43-51].

Larew, Richard E., The Ohio State University, Columbus, Ohio. Interview 15 August 1986.

Notz, William, The Ohio State University, Columbus, Ohio Interview 24 June 1986.

Neter, John; Wasserman, William; and Kutner, Michael H. Applied Linear Regression Models. Homewood: Richard D. Irwin Inc. 1983.

O'Connor, Michael J. Technical Report P-82, Modifications Processing Procedures: A Generalized Stochastic Network Model Champaign: U.S. Army Construction Engineering Research Laboratory, [1977].

O'Connor, Michael J. U.S. Army Construction Engineering Research Laboratory, Champaign, Illinois Interview 11 August 1985.

Perine, Robert. Office of the Chief of Engineers, U.S. Army Corps of Engineers, Washington, D.C. Interview 28 March 1986.

Russell, Edward C. Building Simualtion Models with SIMSCRIPT II.5, Los Angeles: CACI Inc.-Federal, 1983 [1-1 - 4-49].

SAS Institute Inc. SAS User's Guide: Basics, 1982 Edition. Cary, NC: SAS Institute, 1982.

Appendix A

Simulation Programs Used

Introduction

This appendix contains copies of the programs used to conduct the simulation experiments. Each program is complete with the Job Control Language (JCL) necessary to impliment it on the Ohio State University mainframe computer using the Conversational Monitor System (CMS). Programs are submitted as simple job requests and the JCL automatically sends the program to the appropriate system for execution. Once execution is complete a file is sent back to the user. This is a slightly different approach to executing SIMSCRIPT II.5 programs at OSU but is effective if executed exactly as shown.

A.1 Control Structure Program

This program was used to develop and test the control structure of the simulation to insure that the modifications processing procedure was properly modeled. Notice that for the most part, constants were used to represent the stochastic processes. This allowed the author to readily identify output flow patterns.

```
//TS      JOB 'FFZ730,            ','CESRAD',
//   REGION=1024K
/*JOBPARM       LINES=5000
//   EXEC  SIM93CG
//CMP.SYSIN DD *
PREAMBLE
  PROCESSES INCLUDE GENERATOR
  EVERY MOD HAS A BASE.PRICE
  AND A TYPE
  AND A LEAD.TIME
  AND AN INITIATION.TIME
  AND A NOTICE
  AND A GE
  AND A PART
  RESOURCES INCLUDE STAFF.OFFICER
  DEFINE BASE.PRICE AND LEAD.TIME  AS REAL VARIABLES
  DEFINE TYPE, NOTICE, GE, AND PART AS INTEGER VARIABLES
  DEFINE CYCLE.TIME AND INITIATION.TIME AS REAL VARIABLES
  ACCUMULATE AVG.QUEUE.LENGTH AS THE AVERAGE,
    MAX.QUEUE.LENGTH AS THE MAXIMUM OF N.Q.STAFF.OFFICER
  ACCUMULATE UTILIZATION AS THE AVERAGE OF N.X.STAFF.OFFICER
  TALLY MEAN.CYCLE.TIME AS THE MEAN OF CYCLE.TIME
  TALLY SD.CYCLE.TIME AS THE STD.DEV OF CYCLE.TIME
  DEFINE .YES TO MEAN 0
  DEFINE .NO TO MEAN 1
END
MAIN
  CREATE EVERY STAFF.OFFICER(1)
  LET U.STAFF.OFFICER(1)=3
  ACTIVATE A GENERATOR NOW
  START SIMULATION
  PRINT 9 LINES WITH MEAN.CYCLE.TIME, SD.CYCLE.TIME,
    AVG.QUEUE.LENGTH, MAX.QUEUE.LENGTH AND
    UTILIZATION*100/U.STAFF.OFFICER(1) THUS
  MODEL OF CORPS OF ENGINEERS CHANGE ORDER PROCESSING
  PROCESSING TIME
  THE MEAN  TIME TO PROCESS A CHANGE ORDER WAS **.** DAYS
  WITH A STANDARD DEVIATION OF **.** DAYS.
  QUEUING INFO
  THE AVERAGE WAITING TIME FOR A CHANGE AWAITING PROCESSING
  WAS **.** DAYS.
THE MAXIMUM WAIT WAS **.** DAYS.
  STAFF OFFICERS WERE BUSY **.** PERCENT OF THE TIME.
END
PROCESS GENERATOR
PRINT 1 LINE THUS
BASE.PRICE   INITIATION.TIME    TIME.V    CYCLE.TIME
  FOR I = 1 TO 100
  DO
  ACTIVATE A MOD NOW
  WAIT 2 DAYS
  LOOP
END
PROCESS MOD
DEFINE DECISION AS AN INTEGER VARIABLE
```

```
DEFINE DURATION, NEGOTIATION.TIME, AND PROB.TWO.PART AS REAL VARIABLES
DEFINE TLCS,ETRA,ISSUE.TIME,PREP.TIME AND HAGGLE AS REAL VARIABLES
  IF RANDOM.F(4)<=.75
    LET BASE.PRICE(MOD)=4
    LET TYPE(MOD)=1
    LET LEAD.TIME(MOD)=5+TIME.V
  ELSE
    LET BASE.PRICE(MOD)=10
    LET TYPE(MOD)=2
    LET LEAD.TIME(MOD)=45+TIME.V
  ALWAYS
    LET INITIATION.TIME(MOD)=TIME.V
  LET NOTICE(MOD)=0
  LET GE(MOD)=0
  LET PART(MOD)=0
  REQUEST 1 STAFF.OFFICER(1)
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
    WORK DURATION DAYS
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
ELSE
 LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME = BASE.PRICE(MOD)
LET HAGGLE = 2
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
    IF DECISION=.YES
GO TO 'RECYCLE'
ALWAYS
      WORK .125 DAYS
       IF BASE.PRICE(MOD) <= 10
GO TO 'LATE'
ALWAYS
         LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
      WORK DURATION DAYS
     GO TO 'LATE'
  'RECYCLE' LET NOTICE(MOD)=1
      WORK .125 DAYS
       IF BASE.PRICE(MOD) <= 10
GO TO 'SKIP'
```

```
ALWAYS
        WORK 5 DAYS
       LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
        WORK DURATION DAYS
'SKIP'  LET PROB.TWO.PART=1/150*BASE.PRICE(MOD)
    IF RANDOM.F(3) <= PROB.TWO.PART
'SPLIT' LET PART(MOD)=1
      LET DURATION = .25* BASE.PRICE(MOD)
      WORK DURATION DAYS
    ALWAYS
  'LATE' IF NOTICE(MOD) = .NO
      GO TO 'CHECK'
        ALWAYS
      IF RANDOM.F(4)>=.75
       GO TO 'EST'
      ALWAYS
'BREAK' IF RANDOM.F(5)>=.9
    WAIT .125 DAYS
     LET DELAY=1/2*(TIME.V-INITIATION.TIME(MOD))
     WAIT DELAY DAYS
     GO TO 'LATE'
  ALWAYS
   LET DURATION = .25 * BASE.PRICE(MOD)
  WAIT DURATION DAYS
  IF RANDOM.F(5)>=.75
      RELINQUISH 1 STAFF.OFFICER(1)
     GO TO 'ACCEPT'
     ALWAYS
 'RENEG'    LET NEGOTIATION.TIME = .125*BASE.PRICE(MOD)
    WAIT NEGOTIATION.TIME DAYS
  IF RANDOM.F(5)<=.8
    RELINQUISH 1 STAFF.OFFICER(1)
   GO TO 'ACCEPT'
   ALWAYS
  IF NOTICE(MOD)=.YES
GO TO 'LOOP'
ALWAYS
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
ELSE
LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME=BASE.PRICE(MOD)
LET HAGGLE=2
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
```

```
ALWAYS
    IF DECISION=.YES
    RELINQUISH 1 STAFF.OFFICER(1)
    GO TO 'RECYCLE'
     ALWAYS
'LOOP' IF PART(MOD)=0
    LET PROB.TWO.PART = 1/150*BASE.PRICE(MOD)
     IF RANDOM.F(4) <= PROB.TWO.PART
      RELINQUISH 1 STAFF.OFFICER(1)
    GO TO 'SPLIT'
  ALWAYS
ALWAYS
  IF RANDOM.F(5)<=.8
  GO TO 'RENEG'
  ALWAYS
  GO TO 'DIST'
  'CHECK' IF RANDOM.F(4)<=.95
    GO TO 'BREAK'
   ALWAYS
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
ELSE
LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME=BASE.PRICE(MOD)
LET HAGGLE=2
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
   IF DECISION=.YES
  GO TO 'RECYCLE'
ALWAYS
  'EST' LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
   WORK DURATION DAYS
  'DIST' WORK .125 DAYS
   WORK 5 DAYS
  'ACCEPT' IF RANDOM.F(4)>=.9
      LET DURATION = .25 * BASE.PRICE(MOD)
      WORK DURATION DAYS
   ALWAYS
     WORK .125 DAYS
    RELINQUISH 1 STAFF.OFFICER(1)
    LET CYCLE.TIME = TIME.V - INITIATION.TIME(MOD)
PRINT 1 LINE WITH BASE.PRICE(MOD), INITIATION.TIME(MOD),
TIME.V AND CYCLE.TIME THUS
  ***.**       ***.**          ***.**       ***.**
END
/*
//GO.SYSIN  DD *
/*
//
```

BASE.PRICE	INITIATION.TIME	TIME.V	CYCLE.TIME
4.00	0.	3.00	3.00
4.00	4.00	6.25	2.25
10.00	2.00	7.25	5.25
10.00	6.00	10.00	4.00
4.00	8.00	10.75	2.75
4.00	118.00	121.19	3.19
4.00	122.00	124.75	2.75
4.00	124.00	126.75	2.75
10.00	120.00	127.87	7.88
4.00	126.00	128.75	2.75
4.00	128.00	130.25	2.25
4.00	130.00	132.25	2.25
4.00	132.00	134.75	2.75
4.00	136.00	138.25	2.25
4.00	138.00	140.75	2.75
10.00	134.00	141.87	7.88
4.00	140.00	142.75	2.75
4.00	142.00	144.75	2.75
4.00	144.00	146.75	2.75
4.00	146.00	149.00	3.00
4.00	150.00	152.75	2.75
4.00	152.00	154.25	2.25
4.00	154.00	156.25	2.25
4.00	156.00	158.25	2.25
10.00	148.00	158.37	10.37
10.00	158.00	163.25	5.25
10.00	160.00	164.00	4.00
4.00	162.00	164.75	2.75
4.00	164.00	166.75	2.75
4.00	166.00	169.75	3.75
4.00	168.00	170.75	2.75
4.00	174.00	176.75	2.75
10.00	172.00	177.25	5.25
10.00	170.00	177.87	7.88
4.00	178.00	180.25	2.25
4.00	180.00	184.37	4.37
4.00	176.00	185.97	9.97
10.00	182.00	189.87	7.88
10.00	184.00	191.87	7.88
4.00	188.00	192.62	4.62
10.00	186.00	193.75	7.75
10.00	190.00	195.12	5.13
4.00	194.00	196.75	2.75
10.00	192.00	199.87	7.88
4.00	198.00	200.75	2.75
10.00	196.00	203.87	7.88

MODEL OF CORPS OF ENGINEERS CHANGE ORDER PROCESSING
PROCESSING TIME
THE MEAN TIME TO PROCESS A CHANGE ORDER WAS 4.12 DAYS
WITH A STANDARD DEVIATION OF 2.16 DAYS.
QUEUING INFO
THE AVERAGE WAITING TIME FOR A CHANGE AWAITING PROCESSING
WAS .03 DAYS.

THE MAXIMUM WAIT WAS 1.00 DAYS.
STAFF OFFICERS WERE BUSY 59.85 PERCENT OF THE TIME.

Section A.2

CERL Duplication Program

Introduction

This program was used to duplicate the experiment performed by USA CERL in 1977. This was done to establish a common base for future program enhancement.

```
//TS      JOB 'FFZ730,             ','CEGRAD',
//    REGION=1024K
/*JOBPARM      LINES=5000
//    EXEC  SIM93CG
//CMP.SYSIN DD *
PREAMBLE
  PROCESSES INCLUDE GENERATOR
  EVERY MOD HAS A BASE.PRICE
  AND A TYPE
  AND A LEAD.TIME
  AND AN INITIATION.TIME
  AND A NOTICE
  AND A GE
  AND A PART
  RESOURCES INCLUDE STAFF.OFFICER
  DEFINE BASE.PRICE AND LEAD.TIME  AS REAL VARIABLES
  DEFINE TYPE, NOTICE, GE, AND PART AS INTEGER VARIABLES
  DEFINE CYCLE.TIME AND INITIATION.TIME AS REAL VARIABLES
  ACCUMULATE AVG.QUEUE.LENGTH AS THE AVERAGE,
    MAX.QUEUE.LENGTH AS THE MAXIMUM OF N.Q.STAFF.OFFICER
  ACCUMULATE UTILIZATION AS THE AVERAGE OF N.X.STAFF.OFFICER
  TALLY MEAN.CYCLE.TIME AS THE MEAN OF CYCLE.TIME
  TALLY SD.CYCLE.TIME AS THE STD.DEV OF CYCLE.TIME
TALLY DIST(0 TO 500 BY 10) AS THE HISTOGRAM OF CYCLE.TIME
  DEFINE .YES TO MEAN 0
  DEFINE .NO TO MEAN 1
END
MAIN
DEFINE I AS AN INTEGER VARIABLE
  CREATE EVERY STAFF.OFFICER(1)
  LET U.STAFF.OFFICER(1)=5
  ACTIVATE A GENERATOR NOW
  START SIMULATION
  PRINT 9 LINES WITH MEAN.CYCLE.TIME, SD.CYCLE.TIME,
    AVG.QUEUE.LENGTH, MAX.QUEUE.LENGTH AND
    UTILIZATION*100/U.STAFF.OFFICER(1) THUS
  MODEL OF CORPS OF ENGINEERS CHANGE ORDER PROCESSING
  PROCESSING TIME
  THE MEAN  TIME TO PROCESS A CHANGE ORDER WAS **.** DAYS
  WITH A STANDARD DEVIATION OF **.** DAYS.
  QUEUING INFO
  THE AVERAGE WAITING TIME FOR A CHANGE AWAITING PROCESSING
  WAS **.** DAYS.
THE MAXIMUM WAIT WAS **.** DAYS.
  STAFF OFFICERS WERE BUSY **.** PERCENT OF THE TIME.
PRINT 2 LINE WITH DIST(1) THUS
CYCLE TIME RANGE         NUMBER
T<10                       *
FOR I=2 TO 50
PRINT 1 LINE WITH 10*(I-1), 10*I AND DIST(I) THUS
 *** <=T<   *          *
PRINT 1 LINE WITH DIST(51) THUS
<=T                        *
END
PROCESS GENERATOR
```

```
PRINT 1 LINE THUS
BASE.PRICE   INITIATION.TIME    TIME.V    CYCLE.TIME
  FOR I = 1 TO 20
  DO
  ACTIVATE A MOD NOW
  WAIT 2 DAYS
IF I=100
RESET TOTALS OF H.Q.STAFF.OFFICER, N.X.STAFF.OFFICER AND CYCLE.TIME
ALWAYS
  LOOP
END
PROCESS MOD
DEFINE DECISION AS AN INTEGER VARIABLE
DEFINE DURATION, NEGOTIATION.TIME, AND PROB.TWO.PART AS REAL VARIABLES
DEFINE TLCS,ETRA,ISSUE.TIME,PREP.TIME AND HAGGLE AS REAL VARIABLES
  IF RANDOM.F(4)<=.75
LET M=6.547
LET N=4.36
LET A=.778
LET B=.4661
LET C=8.2171
LET D=1.122
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
    LET BASE.PRICE(MOD)=DURATION
    LET TYPE(MOD)=1
LET M=6.8473
LET N=4
LET A=-.754
LET B=.1492
LET C=.0333
LET D=.1691
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
    LET LEAD.TIME(MOD)=DURATION+TIME.V
  ELSE
LET M=17.14
LET N=12.51
LET A=.778
LET B=.4661
LET C=8.2171
LET D=1.122
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
    LET BASE.PRICE(MOD)=DURATION
    LET TYPE(MOD)=2
LET M=45
LET N=12.24
LET A=0
LET B=.243
LET C=.1766
LET D=.1766
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
    LET LEAD.TIME(MOD)=DURATION+TIME.V
  ALWAYS
    LET INITIATION.TIME(MOD)=TIME.V
  LET NOTICE(MOD)=0
  LET GE(MOD)=0
```

```
  LET PART(MOD)=0
  REQUEST 1 STAFF.OFFICER(1)
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
    WORK DURATION DAYS
RELINQUISH 1 STAFF.OFFICER(1)
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
ELSE
 LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME = BASE.PRICE(MOD)
LET HAGGLE = 1
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
    IF DECISION=.YES
GO TO 'RECYCLE'
ALWAYS
REQUEST 1 STAFF.OFFICER(1)
      WORK .125 DAYS
RELINQUISH 1 STAFF.OFFICER(1)
       IF BASE.PRICE(MOD) <= 10
GO TO 'LATE'
ALWAYS
        LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
      WORK DURATION DAYS
     GO TO 'LATE'
  'RECYCLE' LET NOTICE(MOD)=1
REQUEST 1 STAFF.OFFICER(1)
      WORK .125 DAYS
RELINQUISH 1 STAFF.OFFICER(1)
       IF BASE.PRICE(MOD) <= 10
GO TO 'SKIP'
ALWAYS
LET M=5
LET N=2
LET A=-.725
LET B=.2527
LET C=.0775
LET D=.3422
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
        WORK DURATION DAYS
```

```
      LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
REQUEST 1 STAFF.OFFICER(1)
        WORK DURATION DAYS
RELINQUISH 1 STAFF.OFFICER(1)
'SKIP'  LET PROB.TWO.PART=1/150*BASE.PRICE(MOD)
    IF RANDOM.F(3) <= PROB.TWO.PART
'SPLIT' LET PART(MOD)=1
      LET DURATION = .25* BASE.PRICE(MOD)
      WORK DURATION DAYS
    ALWAYS
  'LATE' IF NOTICE(MOD) = .NO
      GO TO 'CHECK'
        ALWAYS
      IF RANDOM.F(4)>=.75
WAIT 10 DAYS
       GO TO 'EST'
      ALWAYS
'BREAK' WAIT BASE.PRICE(MOD) DAYS
 IF RANDOM.F(5)>=.9
REQUEST 1 STAFF.OFFICER(1)
    WAIT .125 DAYS
RELINQUISH 1 STAFF.OFFICER(1)
     LET DELAY=1/2*(TIME.V-INITIATION.TIME(MOD))
     WAIT DELAY DAYS
     GO TO 'LATE'
  ALWAYS
   LET DURATION = .25 * BASE.PRICE(MOD)
REQUEST 1 STAFF.OFFICER(1)
  WAIT DURATION DAYS
RELINQUISH 1 STAFF.OFFICER(1)
  IF RANDOM.F(5)>=.75
     GO TO 'ACCEPT'
     ALWAYS
 'RENEG'    LET NEGOTIATION.TIME = .125*BASE.PRICE(MOD)
REQUEST 1 STAFF.OFFICER(1)
    WAIT NEGOTIATION.TIME DAYS
RELINQUISH 1 STAFF.OFFICER(1)
  IF RANDOM.F(5)<=.8
   GO TO 'ACCEPT'
   ALWAYS
  IF NOTICE(MOD)=.YES
GO TO 'LOOP'
ALWAYS
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
ELSE
LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME=BASE.PRICE(MOD)
LET HAGGLE=1
```

```
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
    IF DECISION=.YES
    GO TO 'RECYCLE'
     ALWAYS
'LOOP' IF PART(MOD)=0
    LET PROB.TWO.PART = 1/150*BASE.PRICE(MOD)
     IF RANDOM.F(4) <= PROB.TWO.PART
    GO TO 'SPLIT'
  ALWAYS
ALWAYS
  IF RANDOM.F(5)<=.8
  GO TO 'RENEG'
  ALWAYS
  GO TO 'DIST'
  'CHECK' IF RANDOM.F(4)<=.95
    GO TO 'BREAK'
   ALWAYS
WAIT 10 DAYS
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
ELSE
LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME=BASE.PRICE(MOD)
LET HAGGLE=1
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
   IF DECISION=.YES
  GO TO 'RECYCLE'
ALWAYS
  'EST' LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
   WORK DURATION DAYS
  'DIST' WORK .125 DAYS
LET M=13
LET N=5
LET A=-.725
LET B=.2527
LET C=.0775
LET D=.3422
```

```
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
   WORK DURATION DAYS
  'ACCEPT' IF RANDOM.F(4)>=.9
      LET DURATION = .25 * BASE.PRICE(MOD)
      WORK DURATION DAYS
   ALWAYS
REQUEST 1 STAFF.OFFICER(1)
     WORK .125 DAYS
RELINQUISH 1 STAFF.OFFICER(1)
    LET CYCLE.TIME = TIME.V - INITIATION.TIME(MOD)
PRINT 1 LINE WITH BASE.PRICE(MOD), INITIATION.TIME(MOD),
TIME.V AND CYCLE.TIME THUS
  ***.**       ***.**          ***.**       ***.**
END
ROUTINE RS GIVEN M,N,A,B,C AND D YIELDING DURATION
DEFINE M,N,A,B,C AND D AS REAL VARIABLES
LET P=RANDOM.F(1)
LET DURATION=M+N*(A+(P**C-(1-P)**D)/B)
IF DURATION<0
  LET DURATION=0
ALWAYS
RETURN WITH DURATION
END
/*
//GO.SYSIN  DD *
/*
//
```

```
BASE.PRICE   INITIATION.TIME     TIME.V     CYCLE.TIME
    3.09          2.00           12.16        10.16
    1.72         18.00           21.04         3.04
     .86         22.00           23.86         1.86
   10.78          6.00           29.93        23.93
    8.61         16.00           30.24        14.24
    3.01          8.00           30.28        22.28
   14.33          0.             30.59        30.59
    5.02         14.00           31.90        17.90
    6.06         26.00           35.34         9.34
    2.98         28.00           38.18        10.18
    2.29         38.00           41.96         3.96
   11.98         12.00           42.91        30.91
   30.89          4.00           50.58        46.58
   17.58         24.00           52.81        28.81
    5.54         34.00           54.77        20.77
   15.65         20.00           55.62        35.62
   28.55         10.00           56.65        46.65
    4.51         30.00           59.59        29.59
   13.39         32.00           61.57        29.57
    3.42         36.00           66.38        30.38
  MODEL OF CORPS OF ENGINEERS CHANGE ORDER PROCESSING
  PROCESSING TIME
  THE MEAN  TIME TO PROCESS A CHANGE ORDER WAS 22.32 DAYS
  WITH A STANDARD DEVIATION OF 13.02 DAYS.
  QUEUING INFO
  THE AVERAGE WAITING TIME FOR A CHANGE AWAITING PROCESSING
  WAS  0.   DAYS.
THE MAXIMUM WAIT WAS  0.   DAYS.
  STAFF OFFICERS WERE BUSY 36.11 PERCENT OF THE TIME.
CYCLE TIME RANGE         NUMBER
T<10                       4
  10 <=T<  20              4
  20 <=T<  30              6
  30 <=T<  40              4
  40 <=T<  50              2
  50 <=T<  60              0
  60 <=T<  70              0
```

Section A.3

The New Model Program

Introduction

This program was the final product of the research and incorporated all enhancements such as data based probability distributions and flow path decision probabilities.

```
//TS      JOB 'FFZ730,          ','CEGRAD',
//   REGION=1024K
/*JOBPARM      LINES=5000
//   EXEC  SIM93CC
//CMP.SYSIN DD *
PREAMBLE
  PROCESSES INCLUDE GENERATOR
  EVERY MOD HAS A BASE.PRICE
  AND A TYPE
  AND A PROP.TIME
  AND A LEAD.TIME
  AND AN INITIATION.TIME
  AND A NOTICE
  AND A GE
  AND A PART
  RESOURCES INCLUDE STAFF.OFFICER
  DEFINE BASE.PRICE AND LEAD.TIME  AS REAL VARIABLES
  DEFINE TYPE, NOTICE, GE, AND PART AS INTEGER VARIABLES
  DEFINE CYCLE.TIME AND INITIATION.TIME AS REAL VARIABLES
  ACCUMULATE AVG.QUEUE.LENGTH AS THE AVERAGE,
    MAX.QUEUE.LENGTH AS THE MAXIMUM OF N.Q.STAFF.OFFICER
  ACCUMULATE UTILIZATION AS THE AVERAGE OF N.X.STAFF.OFFICER
  TALLY MEAN.CYCLE.TIME AS THE MEAN OF CYCLE.TIME
  TALLY SD.CYCLE.TIME AS THE STD.DEV OF CYCLE.TIME
TALLY DIST(0 TO 500 BY 10) AS THE HISTOGRAM OF CYCLE.TIME
  DEFINE .YES TO MEAN 0
  DEFINE .NO TO MEAN 1
END
MAIN
DEFINE I AS AN INTEGER VARIABLE
  CREATE EVERY STAFF.OFFICER(1)
  LET U.STAFF.OFFICER(1)=5
  ACTIVATE A GENERATOR NOW
  START SIMULATION
  PRINT 9 LINES WITH MEAN.CYCLE.TIME, SD.CYCLE.TIME,
    AVG.QUEUE.LENGTH, MAX.QUEUE.LENGTH AND
    UTILIZATION*100/U.STAFF.OFFICER(1) THUS
  MODEL OF CORPS OF ENGINEERS CHANGE ORDER PROCESSING
  PROCESSING TIME
  THE MEAN  TIME TO PROCESS A CHANGE ORDER WAS **.** DAYS
  WITH A STANDARD DEVIATION OF **.** DAYS.
  QUEUING INFO
  THE AVERAGE WAITING TIME FOR A CHANGE AWAITING PROCESSING
  WAS **.** DAYS.
THE MAXIMUM WAIT WAS **.** DAYS.
  STAFF OFFICERS WERE BUSY **.** PERCENT OF THE TIME.
PRINT 2 LINES WITH DIST(1) THUS
CYCLE TIME RANGE           NUMBER
       <=T                   *
FOR I=2 TO 50
PRINT 1 LINE WITH 10*(I-1), 10*I AND DIST(I) THUS
  *** <=T< ***                 *
PRINT 1 LINE WITH DIST(51) THUS
      <=T                    *
END
```

```
PROCESS GENERATOR
  FOR I = 1 TO 5000
  DO
  ACTIVATE A MOD NOW
  WAIT POISSON.F(2.0,1) DAYS
IF I=100
RESET TOTALS OF N.Q.STAFF.OFFICER, N.X.STAFF.OFFICER AND CYCLE.TIME
ALWAYS
  LOOP
END
PROCESS MOD
DEFINE DECISION AS AN INTEGER VARIABLE
DEFINE DURATION, NEGOTIATION.TIME, AND PROP.TWO.PART AS REAL VARIABLES
DEFINE TLCS,ETRA,ISSUE.TIME,PREP.TIME AND HAGGLE AS REAL VARIABLES
  IF RANDOM.F(4)<=.75
LET M=5.92
LET N=6.33
LET A=1.311
LET B=.4415
LET C=4.3993
LET D=.309
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
    LET BASE.PRICE(MOD)=DURATION
    LET TYPE(MOD)=1
LET M=9.644
LET N=10.85
LET A=1.577
LET B=.3644
LET C=19.983
LET D=.60731
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
    LET LEAD.TIME(MOD)=DURATION+TIME.V
  LET PROP.TIME(MOD)=DURATION
  ELSE
LET M=14.6
LET N=14.29
LET A=.773
LET B=.5008
LET C=5.5245
LET D=.85032
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
    LET BASE.PRICE(MOD)=DURATION
    LET TYPE(MOD)=2
LET M=10.083
LET N=35.72
LET A=-.381
LET B=.5732
LET C=.8965
LET D=2.2392
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
    LET LEAD.TIME(MOD)=DURATION+TIME.V
  LET PROP.TIME(MOD)=DURATION
  ALWAYS
    LET INITIATION.TIME(MOD)=TIME.V
  LET NOTICE(MOD)=0
```

```
  LET GE(MOD)=0
  LET PANT(MOD)=0
  REQUEST 1 STAFF.OFFICER(1)
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
    WORK DURATION DAYS
RELINQUISH 1 STAFF.OFFICER(1)
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
ELSE
 LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME = BASE.PRICE(MOD)
LET HAGGLE = 1
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
    IF DECISION=.YES
GO TO 'RECYCLE'
ALWAYS
REQUEST 1 STAFF.OFFICER(1)
      WORK .125 DAYS
RELINQUISH 1 STAFF.OFFICER(1)
       IF BASE.PRICE(MOD) <= 10
GO TO 'LATE'
ALWAYS
        LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
      WORK DURATION DAYS
     GO TO 'LATE'
  'RECYCLE' LET NOTICE(MOD)=1
REQUEST 1 STAFF.OFFICER(1)
      WORK .125 DAYS
RELINQUISH 1 STAFF.OFFICER(1)
       IF BASE.PRICE(MOD) <= 10
GO TO 'SKIP'
ALWAYS
LET M=5
LET N=2
LET A=-.725
LET B=.2527
LET C=.0775
LET D=.3422
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
```

```
          WORK DURATION DAYS
        LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
REQUEST 1 STAFF.OFFICER(1)
          WORK DURATION DAYS
RELINQUISH 1 STAFF.OFFICER(1)
'SKIP'  LET PROB.TWO.PART=1/150*BASE.PRICE(MOD)
    IF RANDOM.F(3) <= PROB.TWO.PART
'SPLIT' LET PART(MOD)=1
      LET DURATION = .25* BASE.PRICE(MOD)
      WORK DURATION DAYS
    ALWAYS
  'LATE' IF NOTICE(MOD) = .NO
      GO TO 'CHECK'
        ALWAYS
      IF RANDOM.F(4)>=.99
WAIT 10 DAYS
       GO TO 'EST'
      ALWAYS
'BREAK' WAIT PROP.TIME(MOD) DAYS
 IF RANDOM.F(5)>=.9
REQUEST 1 STAFF.OFFICER(1)
    WAIT .125 DAYS
RELINQUISH 1 STAFF.OFFICER(1)
     LET DELAY=1/2*(TIME.V-INITIATION.TIME(MOD))
     WAIT DELAY DAYS
     GO TO 'LATE'
  ALWAYS
LET M=34.1
LET N=50.78
LET A=1.863
LET B=.3195
LET C=12.398
LET D=.34295
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
  WAIT DURATION DAYS
  IF RANDOM.F(5)>=.75
     GO TO 'ACCEPT'
     ALWAYS
 'RENEG'    LET NEGOTIATION.TIME = .125*BASE.PRICE(MOD)
REQUEST 1 STAFF.OFFICER(1)
    WAIT NEGOTIATION.TIME DAYS
RELINQUISH 1 STAFF.OFFICER(1)
  IF RANDOM.F(5)<=.9
   GO TO 'ACCEPT'
   ALWAYS
  IF NOTICE(MOD)=.YES
GO TO 'LOOP'
ALWAYS
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
```

```
ELSE
LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME=BASE.PRICE(MOD)
LET HAGGLE=1
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
     IF DECISION=.YES
     GO TO 'RECYCLE'
      ALWAYS
'LOOP' IF PART(MOD)=0
     LET PROB.TWO.PART = 1/150*BASE.PRICE(MOD)
      IF RANDOM.F(4) <= PROB.TWO.PART
     GO TO 'SPLIT'
   ALWAYS
ALWAYS
   IF RANDOM.F(5)<=.99
   GO TO 'RENEG'
   ALWAYS
   GO TO 'DIST'
   'CHECK' IF RANDOM.F(4)<=.99
     GO TO 'BREAK'
    ALWAYS
WAIT 10 DAYS
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
ELSE
LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME=BASE.PRICE(MOD)
LET HAGGLE=1
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
    IF DECISION=.YES
  GO TO 'RECYCLE'
ALWAYS
  'EST' LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
    WORK DURATION DAYS
  'DIST' WORK .125 DAYS
LET M=13
```

```
LET N=5
LET A=-.725
LET B=.2527
LET C=.0775
LET D=.3422
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
   WORK DURATION DAYS
  'ACCEPT' IF RANDOM.F(4)>=.99
      LET DURATION = .25 * BASE.PRICE(MOD)
      WORK DURATION DAYS
   ALWAYS
REQUEST 1 STAFF.OFFICER(1)
     WORK .125 DAYS
RELINQUISH 1 STAFF.OFFICER(1)
    LET CYCLE.TIME = TIME.V - INITIATION.TIME(MOD)
END
ROUTINE RS GIVEN M,N,A,B,C AND D YIELDING DURATION
DEFINE M,N,A,B,C AND D AS REAL VARIABLES
LET P=RANDOM.F(1)
LET DURATION=M+N*(A+(P**C-(1-P)**D)/B)
IF DURATION<0
  LET DURATION=0
ALWAYS
RETURN WITH DURATION
END
/*
//GO.SYSIN  DD *
/*
//
```

MODEL OF CORPS OF ENGINEERS CHANGE ORDER PROCESSING
PROCESSING TIME
THE MEAN TIME TO PROCESS A CHANGE ORDER WAS 51.99 DAYS
WITH A STANDARD DEVIATION OF 58.72 DAYS.
QUEUING INFO
THE AVERAGE WAITING TIME FOR A CHANGE AWAITING PROCESSING
WAS .04 DAYS.
THE MAXIMUM WAIT WAS 10.00 DAYS.
STAFF OFFICERS WERE BUSY 36.19 PERCENT OF THE TIME.

CYCLE TIME RANGE	NUMBER
<=T	949
10 <=T< 20	838
20 <=T< 30	646
30 <=T< 40	436
40 <=T< 50	351
50 <=T< 60	321
60 <=T< 70	228
70 <=T< 80	174
80 <=T< 90	112
90 <=T< 100	123
100 <=T< 110	89
110 <=T< 120	64
120 <=T< 130	67
130 <=T< 140	70
140 <=T< 150	49
150 <=T< 160	60
160 <=T< 170	39
170 <=T< 180	43
180 <=T< 190	38
190 <=T< 200	30
200 <=T< 210	29
210 <=T< 220	31
220 <=T< 230	17
230 <=T< 240	28
240 <=T< 250	20
250 <=T< 260	13
260 <=T< 270	13
270 <=T< 280	16
280 <=T< 290	8
290 <=T< 300	6
300 <=T< 310	1
310 <=T< 320	5
320 <=T< 330	3
330 <=T< 340	1
340 <=T< 350	1
350 <=T< 360	1
360 <=T< 370	0
370 <=T< 380	0
380 <=T< 390	0
390 <=T< 400	2
400 <=T< 410	0
410 <=T< 420	0
420 <=T< 430	0
430 <=T< 440	0
440 <=T< 450	0
450 <=T< 460	1
460 <=T< 470	0
470 <=T< 480	0
480 <=T< 490	0
490 <=T< 500	0

Appendix B

AMPRS Data Listing

Table 5

AMPRS Data Listing

OBS	TOT	TREX	TYPE	PREP	REV	GE	CE	DTC	PERC	CON	EASE	TPERC
1	14	18898	0	6	7	0	6.00	92	12.000	1	18.898	0
2	12	8000	1	10	2	0	1.00	419	4.000	2	8.000	0
3	137	3799	0	15	137	1	15.00	0	1.000	3	3.799	1
4	13	1700	0	12	1	0	12.00	0	0.500	3	1.700	2
5	186	2239	0	186	0	0	18.40	193	0.800	3	2.239	1
6	287	1262	0	272	0	0	18.40	309	0.400	3	1.262	2
7	20	4445	0	9	11	0	18.40	166	1.600	3	4.445	1
8	1	1243	0	0	0	0	42.00	214	0.400	3	1.243	2
9	63	29206	1	17	47	1	17.00	317	10.300	3	29.206	0
10	95	8086	0	0	95	0	18.40	312	2.800	3	8.086	0
11	33	8511	0	6	27	0	6.00	336	3.000	3	8.511	0
12	4	1293	0	4	0	1	4.00	349	0.300	4	1.293	3
13	52	7455	0	23	29	1	23.00	338	1.800	4	7.455	1
14	74	4080	0	0	25	0	10.00	299	1.000	4	4.080	1
15	208	2194	0	15	0	0	15.00	334	0.500	4	2.194	2
16	225	874	0	49	176	0	16.00	211	0.200	4	0.874	5
17	100	19810	0	0	10	0	13.60	63	4.700	4	19.810	0
18	27	23260	1	15	12	0	8.60	266	3.500	5	23.260	0
19	48	-5750	1	6	32	0	6.00	239	-0.900	5	5.750	-1
20	44	2130	0	14	30	0	13.00	191	0.300	5	2.130	3
21	30	44130	1	10	20	1	10.00	187	6.600	5	44.130	0
22	69	10058	0	6	63	0	6.00	124	1.500	5	10.058	1
23	9	1500	0	9	0	0	8.00	30	0.200	5	1.500	5
24	27	12066	0	0	0	0	8.60	0	1.800	5	12.068	1
25	237	18000	0	0	237	0	8.60	232	2.700	5	18.000	0
26	26	0	1	0	26	0	10.80	347	0.000	6	0.000	0
27	31	7037	0	15	16	11	15.00	221	6.500	6	7.037	0
28	15	4498	0	11	4	3	11.00	109	4.100	6	4.498	0
29	30	457	0	20	0	0	19.00	184	0.400	6	0.457	2
30	11	595	0	1	1	1	1.00	92	0.500	6	0.595	2
31	23	1966	0	13	10	1	12.00	61	1.800	6	1.966	1
32	135	3985	1	86	49	1	19.00	184	3.700	6	3.985	0
33	4	771	0	4	0	1	1.00	34	0.700	6	0.771	1
34	14	1650	0	7	7	1	7.00	43	1.500	6	1.650	1
35	51	2026	0	36	15	0	13.00	31	1.900	6	2.026	1
36	28	5998	0	8	20	1	11.00	60	15.000	7	5.998	0
37	4	1872	0	0	0	0	1.00	0	4.600	7	1.872	0
38	25	641	0	7	0	0	7.00	306	0.020	8	0.641	50
39	31	9242	0	21	3	1	1.00	134	0.400	8	9.242	2
40	344	148	0	184	79	0	1.00	369	0.006	8	0.148	167
41	344	601	0	8	0	0	40.00	369	0.020	8	0.601	50
42	344	1321	0	71	8	0	12.25	369	0.060	8	1.321	17
43	16	27335	1	5	11	1	4.00	176	15.000	9	27.335	0
44	34	17835	0	0	34	0	34.00	170	9.900	9	17.835	0
45	1	6648	0	0	0	0	16.00	136	3.700	9	6.648	0
46	4	962	0	4	0	1	4.00	66	0.500	9	0.962	2
47	75	9638	0	0	54	0	3.00	205	1.300	10	9.638	1
48	146	22849	0	90	56	0	90.00	142	3.000	10	22.849	0
49	182	9447	1	18	143	0	39.00	162	1.200	10	9.447	1
50	244	212874	1	229	16	8	64.50	120	28.000	10	212.874	0
51	135	4136	1	1	134	0	34.00	0	0.500	10	4.136	2
52	133	14227	0	17	116	0	34.00	0	1.900	10	14.227	1
53	14	7794	0	0	0	1	25.50	283	0.800	12	7.794	1
54	138	-7465	0	95	43	1	95.00	403	-0.700	12	7.465	-1
55	128	10529	1	12	116	0	14.00	411	1.000	12	10.529	1
56	25	962	0	0	25	0	25.50	294	0.090	12	0.962	11

Table 5 (continued)

OBS	TOT	TREX	TYPE	PREP	REV	GE	CE	DTC	PERC	CON	BASE	TPERC
57	14	1370	0	4	12	1	4.0	283	0.1	12	1.370	9.9999
58	1	20538	0	0	1	1	1.0	364	2.0	12	20.538	0.5000
59	49	15750	0	26	23	1	25.5	171	1.6	12	15.750	0.6250
60	41	4122	0	22	19	4	22.0	180	0.4	12	4.122	2.5000
61	30	165012	1	15	15	0	15.0	161	16.0	12	165.012	0.0625
62	142	668	0	0	142	0	5.0	176	0.9	13	0.668	1.1111
63	21	700	0	14	1	1	15.0	29	2.0	14	0.700	0.5000
64	18	575	1	12	0	1	12.0	0	1.8	14	0.575	0.5556
65	48	2095	0	28	20	0	28.0	262	0.2	12	2.095	5.0000

Appendix C

Correlation Matrix

Table 6

Correlation Matrix

VARIABLE	N	MEAN	STD DEV	SUM	MINIMUM	MAXIMUM
TOT	65	78.7	91	5114	1	344
TYPE	65	0.2	0	14	0	1
PREP	65	27.2	54	1768	0	272
REV	65	33.5	50	2180	0	237
GE	65	0.7	2	47	0	11
CE	65	17.2	18	1115	1	95
DTC	65	190.0	124	12348	0	419
TPERC	65	15390.3	124034	1000367	-1	1000000
CON	65	7.2	3	465	1	14

CORRELATION COEFFICIENTS / PROB > |R| UNDER H0:RHO=0
/ N = 65

	TOT	TYPE	PREP	REV
TOT	1.00000	-0.00309	0.61948	0.44619
TOTAL TIME	0.0000	0.9805	0.0001	0.0002
TYPE	-0.00309	1.00000	0.03848	0.11555
	0.9805	0.0000	0.7609	0.3594
PREP	0.61948	0.03848	1.00000	-0.02377
PROPOSAL PREPARATION TIME	0.0001	0.7609	0.0000	0.8509
REV	0.44619	0.11555	-0.02377	1.00000
REVIEW	0.0002	0.3594	0.8509	0.0000
GE	-0.03800	0.06184	0.19895	-0.13695
GENERAL ESTIMATE	0.7638	0.6246	0.1121	0.2767
CE	0.30971	0.03086	0.34678	0.12953
CONTRACTORS ESTIMATE	0.0121	0.8072	0.0047	0.3038
DTC	0.30089	0.09991	0.16158	0.01582
DAYS TO COMPLETE	0.0149	0.4284	0.1985	0.9005
TPERC	-0.07274	0.23856	-0.06328	-0.01895
	0.5647	0.0557	0.6165	0.8809
CON	-0.00367	0.09692	-0.03742	0.06077
CONTRACT NUMBER	0.9768	0.4425	0.7673	0.6306

Table 6 (continued)

	GE	CE	DTC	TPERC
TOT TOTAL TIME	-0.03800 0.7638	0.30971 0.0121	0.30089 0.0149	-0.07274 0.5647
TYPE	0.06184 0.6246	0.03086 0.8072	0.09991 0.4284	0.23856 0.0557
PREP PROPOSAL PREPARATION TIME	0.19895 0.1121	0.34678 0.0047	0.16158 0.1985	-0.06328 0.6165
REV REVIEW	-0.13695 0.2767	0.12953 0.3038	0.01582 0.9005	-0.01895 0.8809
GE GENERAL ESTIMATE	1.00000 0.0000	0.14972 0.2339	-0.06564 0.6034	-0.05193 0.6812
CE CONTRACTORS ESTIMATE	0.14972 0.2339	1.00000 0.0000	0.08239 0.5141	-0.04447 0.7250
DTC DAYS TO COMPLETE	-0.06564 0.6034	0.08239 0.5141	1.00000 0.0000	0.15912 0.2055
TPERC	-0.05193 0.6812	-0.04447 0.7250	0.15912 0.2055	1.00000 0.0000
CON CONTRACT NUMBER	0.11840 0.3475	0.27754 0.0252	-0.02890 0.8193	-0.04221 0.7385

	CON
TOT TOTAL TIME	-0.00367 0.9768
TYPE	0.09692 0.4425
PREP PROPOSAL PREPARATION TIME	-0.03742 0.7673
REV REVIEW	0.06077 0.6306
GE GENERAL ESTIMATE	0.11840 0.3475
CE CONTRACTORS ESTIMATE	0.27754 0.0252
DTC DAYS TO COMPLETE	-0.02890 0.8193
TPERC	-0.04221 0.7385
CON CONTRACT NUMBER	1.00000 0.0000

Appendix D

RS Subroutine Verification Program

Introduction

This program was used to insure that the RS probability distribution was performing as expected. The key to this program's utility lies in the format of its output.

```
//TS      JOB 'FFZ730,          ','CEGRAD',
//   REGION=1024K
/*JOBPARM      LINES=5000
//   EXEC  SIM93CG
//CMP.SYSIN DD *
PREAMBLE
  PROCESSES INCLUDE GENERATOR
  EVERY MOD HAS A BASE.PRICE
  AND A TYPE
  AND A LEAD.TIME
  AND AN INITIATION.TIME
  AND A NOTICE
  AND A GE
  AND A PART
  RESOURCES INCLUDE STAFF.OFFICER
  DEFINE BASE.PRICE AND LEAD.TIME  AS REAL VARIABLES
  DEFINE TYPE, NOTICE, GE, AND PART AS INTEGER VARIABLES
  DEFINE CYCLE.TIME AND INITIATION.TIME AS REAL VARIABLES
  ACCUMULATE AVG.QUEUE.LENGTH AS THE AVERAGE,
    MAX.QUEUE.LENGTH AS THE MAXIMUM OF N.Q.STAFF.OFFICER
  ACCUMULATE UTILIZATION AS THE AVERAGE OF N.X.STAFF.OFFICER
  TALLY MEAN.CYCLE.TIME AS THE MEAN OF CYCLE.TIME
  TALLY SD.CYCLE.TIME AS THE STD.DEV OF CYCLE.TIME
  DEFINE .YES TO MEAN 0
  DEFINE .NO TO MEAN 1
END
MAIN
  CREATE EVERY STAFF.OFFICER(1)
  LET U.STAFF.OFFICER(1)=5000
  ACTIVATE A GENERATOR NOW
  START SIMULATION
  PRINT 9 LINES WITH MEAN.CYCLE.TIME, SD.CYCLE.TIME,
    AVG.QUEUE.LENGTH, MAX.QUEUE.LENGTH AND
    UTILIZATION*100/U.STAFF.OFFICER(1) THUS
  MODEL OF CORPS OF ENGINEERS CHANGE ORDER PROCESSING
  PROCESSING TIME
  THE MEAN  TIME TO PROCESS A CHANGE ORDER WAS **.** DAYS
   ITH A STANDARD DEVIATION OF **.** DAYS.
   UEUING INFO
  THE AVERAGE WAITING TIME FOR A CHANGE AWAITING PROCESSING
  WAS **.** DAYS.
THE MAXIMUM WAIT WAS **.** DAYS.
  STAFF OFFICERS WERE BUSY **.** PERCENT OF THE TIME.
END
PROCESS GENERATOR
PRINT 1 LINE THUS
BASE.PRICE   INITIATION.TIME    TIME.V    CYCLE.TIME
  FOR I = 1 TO 10
  DO
  ACTIVATE A MOD NOW
  WAIT 2 DAYS
  LOOP
END
PROCESS MOD
DEFINE DECISION AS AN INTEGER VARIABLE
```

```
DEFINE DURATION, NEGOTIATION.TIME, AND PROB.TWO.PART AS REAL VARIABLES
DEFINE TLCS,ETRA,ISSUE.TIME,PREP.TIME AND HAGGLE AS REAL VARIABLES
  IF RANDOM.F(4)<=.75
LET M=6.547
LET N=4.36
LET A=.778
LET B=.4661
LET C=8.2171
LET D=1.122
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
PRINT 1 LINE WITH DURATION THUS
RS1= ***.**
     LET BASE.PRICE(MOD)=DURATION
     LET TYPE(MOD)=1
LET M=6.8473
LET N=4
LET A=-.754
LET B=.1492
LET C=.0333
LET D=.1691
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
PRINT 1 LINE WITH DURATION THUS
RS2= ***.**
     LET LEAD.TIME(MOD)=DURATION+TIME.V
   ELSE
LET M=17.14
LET N=12.51
LET A=.778
LET B=.4661
LET C=8.2171
LET D=1.122
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
PRINT 1 LINE WITH DURATION THUS
RS3= ***.**
     LET BASE.PRICE(MOD)=DURATION
     LET TYPE(MOD)=2
LET M=45
LET N=12.24
LET A=0
LET B=.243
LET C=.1766
LET D=.1766
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
PRINT 1 LINE WITH DURATION THUS
RS4= ***.**
     LET LEAD.TIME(MOD)=DURATION+TIME.V
  ALWAYS
     LET INITIATION.TIME(MOD)=TIME.V
  LET NOTICE(MOD)=0
  LET GE(MOD)=0
  LET PART(MOD)=0
  REQUEST 1 STAFF.OFFICER(1)
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
```

```
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
    WORK DURATION DAYS
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
ELSE
 LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME = BASE.PRICE(MOD)
LET HAGGLE = 1
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
    IF DECISION=.YES
GO TO 'RECYCLE'
ALWAYS
      WORK .125 DAYS
       IF BASE.PRICE(MOD) <= 10
GO TO 'LATE'
ALWAYS
        LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
      WORK DURATION DAYS
     GO TO 'LATE'
  'RECYCLE' LET NOTICE(MOD)=1
      WORK .125 DAYS
       IF BASE.PRICE(MOD) <= 10
GO TO 'SKIP'
ALWAYS
LET M=5
LET N=2
LET A=-.725
LET B=.2527
LET C=.0775
LET D=.3422
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
PRINT 1 LINE WITH DURATION THUS
RS5= ***.**
        WORK DURATION DAYS
       LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
        WORK DURATION DAYS
'SKIP'  LET PROB.TWO.PART=1/150*BASE.PRICE(MOD)
```

```
     IF RANDOM.F(3) <= PROB.TWO.PART
'SPLIT' LET PART(MOD)=1
       LET DURATION = .25* BASE.PRICE(MOD)
       WORK DURATION DAYS
     ALWAYS
   'LATE' IF NOTICE(MOD) = .NO
       GO TO 'CHECK'
         ALWAYS
       IF RANDOM.F(4)>=.75
        GO TO 'EST'
       ALWAYS
'BREAK' IF RANDOM.F(5)>=.9
     WAIT .125 DAYS
      LET DELAY=1/2*(TIME.V-INITIATION.TIME(MOD))
      WAIT DELAY DAYS
      GO TO 'LATE'
   ALWAYS
    LET DURATION = .25 * BASE.PRICE(MOD)
   WAIT DURATION DAYS
   IF RANDOM.F(5)>=.75
       RELINQUISH 1 STAFF.OFFICER(1)
      GO TO 'ACCEPT'
      ALWAYS
 'RENEG'     LET NEGOTIATION.TIME = .125*BASE.PRICE(MOD)
     WAIT NEGOTIATION.TIME DAYS
   IF RANDOM.F(5)<=.8
     RELINQUISH 1 STAFF.OFFICER(1)
    GO TO 'ACCEPT'
    ALWAYS
   IF NOTICE(MOD)=.YES
GO TO 'LOOP'
ALWAYS
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
ELSE
LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME=BASE.PRICE(MOD)
LET HAGGLE=1
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
    IF DECISION=.YES
    RELINQUISH 1 STAFF.OFFICER(1)
    GO TO 'RECYCLE'
     ALWAYS
'LOOP' IF PART(MOD)=0
    LET PROB.TWO.PART = 1/150*BASE.PRICE(MOD)
     IF RANDOM.F(4) <= PROB.TWO.PART
      RELINQUISH 1 STAFF.OFFICER(1)
    GO TO 'SPLIT'
```

```
  ALWAYS
ALWAYS
  IF RANDOM.F(5)<=.8
  GO TO 'RENEG'
  ALWAYS
  GO TO 'DIST'
  'CHECK' IF RANDOM.F(4)<=.95
    GO TO 'BREAK'
   ALWAYS
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
ELSE
LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME=BASE.PRICE(MOD)
LET HAGGLE=1
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
   IF DECISION=.YES
  GO TO 'RECYCLE'
ALWAYS
  'EST' LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
   WORK DURATION DAYS
  'DIST' WORK .125 DAYS
LET M=13
LET N=5
LET A=-.725
LET B=.2527
LET C=.0775
LET D=.3422
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
PRINT 1 LINE WITH DURATION THUS
RS6= ***.**
   WORK DURATION DAYS
  'ACCEPT' IF RANDOM.F(4)>=.9
      LET DURATION = .25 * BASE.PRICE(MOD)
      WORK DURATION DAYS
   ALWAYS
     WORK .125 DAYS
    RELINQUISH 1 STAFF.OFFICER(1)
    LET CYCLE.TIME = TIME.V - INITIATION.TIME(MOD)
PRINT 1 LINE WITH BASE.PRICE(MOD), INITIATION.TIME(MOD),
TIME.V AND CYCLE.TIME THUS
  ***.**      ***.**         ***.**       ***.**
END
```

```
ROUTINE RS GIVEN M,N,A,B,C AND D YIELDING DURATION
DEFINE M,N,A,B,C AND D AS REAL VARIABLES
LET P=RANDOM.F(1)
LET DURATION=M+N*(A+(P**C-(1-P)**D)/B)
IF DURATION<0
  LET DURATION=0
ALWAYS
RETURN WITH DURATION
END
/*
//GO.SYSIN  DD *
/*
//
```

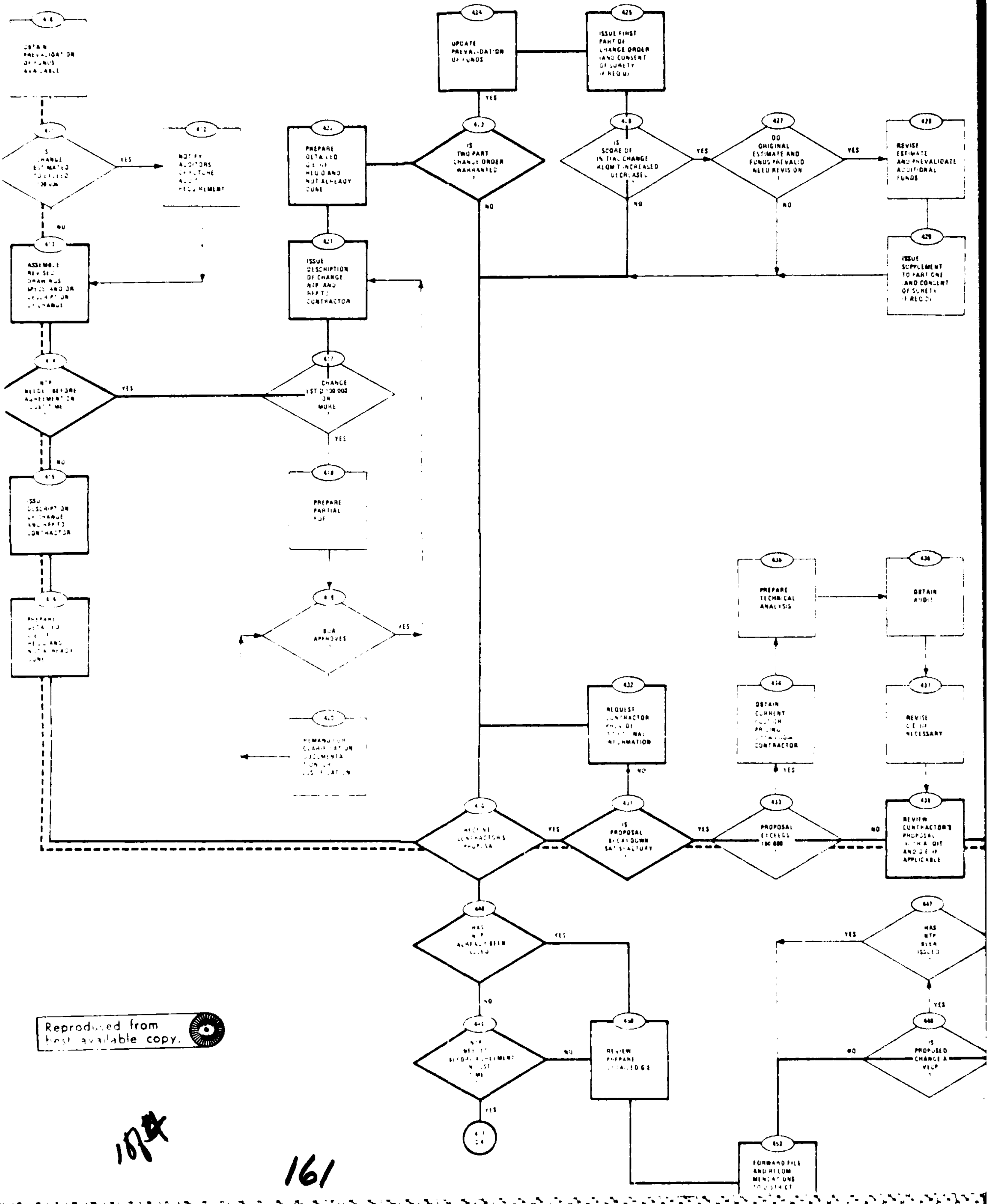
```
BASE.PRICE   INITIATION.TIME    TIME.V    CYCLE.TIME
RS1=  14.33
RS2=   3.21
RS1=   3.09
RS2=  16.39
RS5=   3.47
RS1=  11.34
RS2=   7.91
RS6=  18.17
RS1=   4.69
RS2=   3.75
RS5=   4.53
RS3=   7.40
RS4=  56.64
     4.69          6.00             8.60          2.60
RS1=  10.20
RS2=  11.54
     7.40          8.00            11.95          3.95
RS1=  12.53
RS2=   5.57
RS5=   4.81
RS1=   6.39
RS2=   8.96
RS5=   4.60
RS5=   2.60
RS1=   4.01
RS2=   4.70
    14.33          0.              16.26         16.26
RS1=  15.65
RS2=   7.71
     6.39         14.00            18.25          4.25
     4.01         16.00            19.51          3.51
RS5=   1.68
     3.09          2.00            22.72         20.72
RS5=   5.10
RS5=   5.36
    10.20         10.00            26.53         16.53
    15.65         18.00            31.67         13.67
    11.34          4.00            37.41         33.41
    12.53         12.00            38.88         26.88
  MODEL OF CORPS OF ENGINEERS CHANGE ORDER PROCESSING
  PROCESSING TIME
  THE MEAN  TIME TO PROCESS A CHANGE ORDER WAS 14.18 DAYS
  WITH A STANDARD DEVIATION OF 10.17 DAYS.
  QUEUING INFO
  THE AVERAGE WAITING TIME FOR A CHANGE AWAITING PROCESSING
  WAS  0.   DAYS.
THE MAXIMUM WAIT WAS  0.   DAYS.
  STAFF OFFICERS WERE BUSY   .06 PERCENT OF THE TIME.
```

Appendix E

Modifications Procedure Flow Chart

Introduction

This flow chart diagrams the actual procedures used by the Army Corps of Engineers to process change orders. It is annotated to show those areas where simplifications have been made (O'Connor 1977).


UPDATE PREVALIDATION OF FUNDS
ISSUE FIRST PART OF CHANGE ORDER (AND CONSENT OF SURETY IF REQ'D)
YES
IS TWO PART CHANGE ORDER WARRANTED ?
NO
IS SCORE OF INITIAL CHANGE REQMT INCREASED DECREASED ?
DO ORIGINAL ESTIMATE AND FUNDS PREVALID NEED REVISION ?
REVISE ESTIMATE AND PREVALIDATE ADDITIONAL FUNDS
ISSUE SUPPLEMENT TO PART ONE (AND CONSENT OF SURETY IF REQ'D)
NOTIFY AUDITORS OF FUTURE AUDIT REQUIREMENT
PREPARE DETAILED GE IF REQ'D AND NOT ALREADY DONE
ISSUE DESCRIPTION OF CHANGE, NTP AND RFP TO CONTRACTOR
CHANGE EST'D 100 000 OR MORE ?
PREPARE PARTIAL PDF
BOA APPROVES ?
NTP NEEDED BEFORE AGREEMENT ON COST TIME ?
PREPARE TECHNICAL ANALYSIS
OBTAIN AUDIT
REQUEST CONTRACTOR PROVIDE ADDITIONAL INFORMATION
OBTAIN CURRENT FACTOR PRICING FROM CONTRACTOR
REVISE GE IF NECESSARY
IS PROPOSAL BREAKDOWN SATISFACTORY ?
PROPOSAL EXCEEDS 100 000
REVIEW CONTRACTOR'S PROPOSAL WITH AUDIT AND GE IF APPLICABLE
RECEIVE CONTRACTOR'S PROPOSAL
HAS NTP ALREADY BEEN ISSUED ?
HAS NTP BEEN ISSUED ?
IS PROPOSED CHANGE A VECP ?
REVIEW PREPARE DETAILED GE
FORWARD FILE AND RECOMMENDATIONS TO DISTRICT
YES
NO

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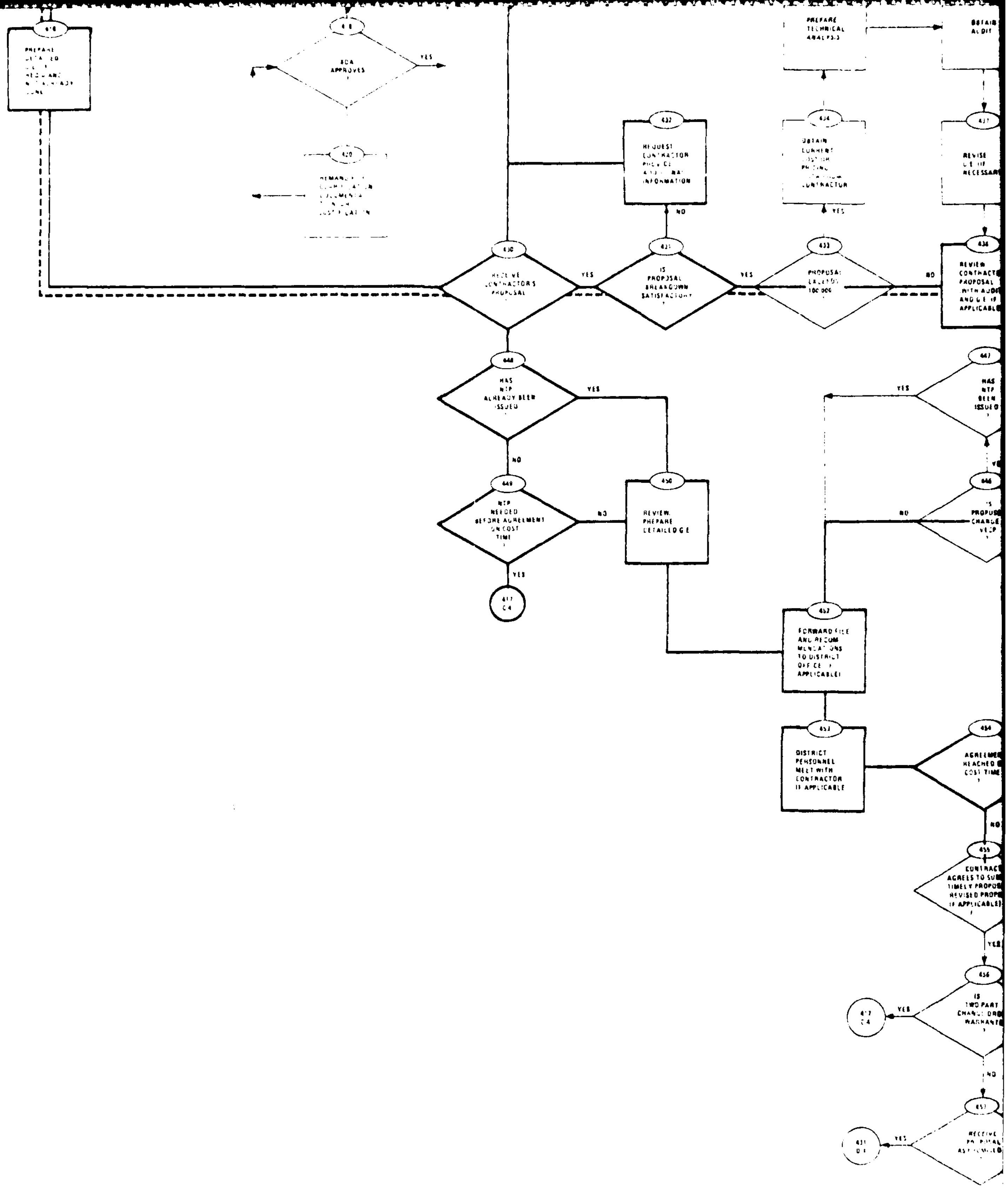

PREPARE TECHNICAL ANALYSIS
REQUEST CONTRACTOR
INFORMATION
OBTAIN
CONTRACTOR
REVISE
NECESSARY
RECEIVE CONTRACTOR'S PROPOSAL
YES
IS PROPOSAL BREAKDOWN SATISFACTORY
NO
YES
PROPOSAL
NO
REVIEW
PROPOSAL
APPLICABLE
HAS NTP ALREADY BEEN ISSUED
YES
NO
NTP NEEDED BEFORE AGREEMENT ON COST TIME
NO
YES
REVIEW, PREPARE DETAILED G.E.
FORWARD FILE
TO DISTRICT
APPLICABLE
DISTRICT PERSONNEL MEET WITH CONTRACTOR IF APPLICABLE
YES
NO
YES
YES
NO
YES

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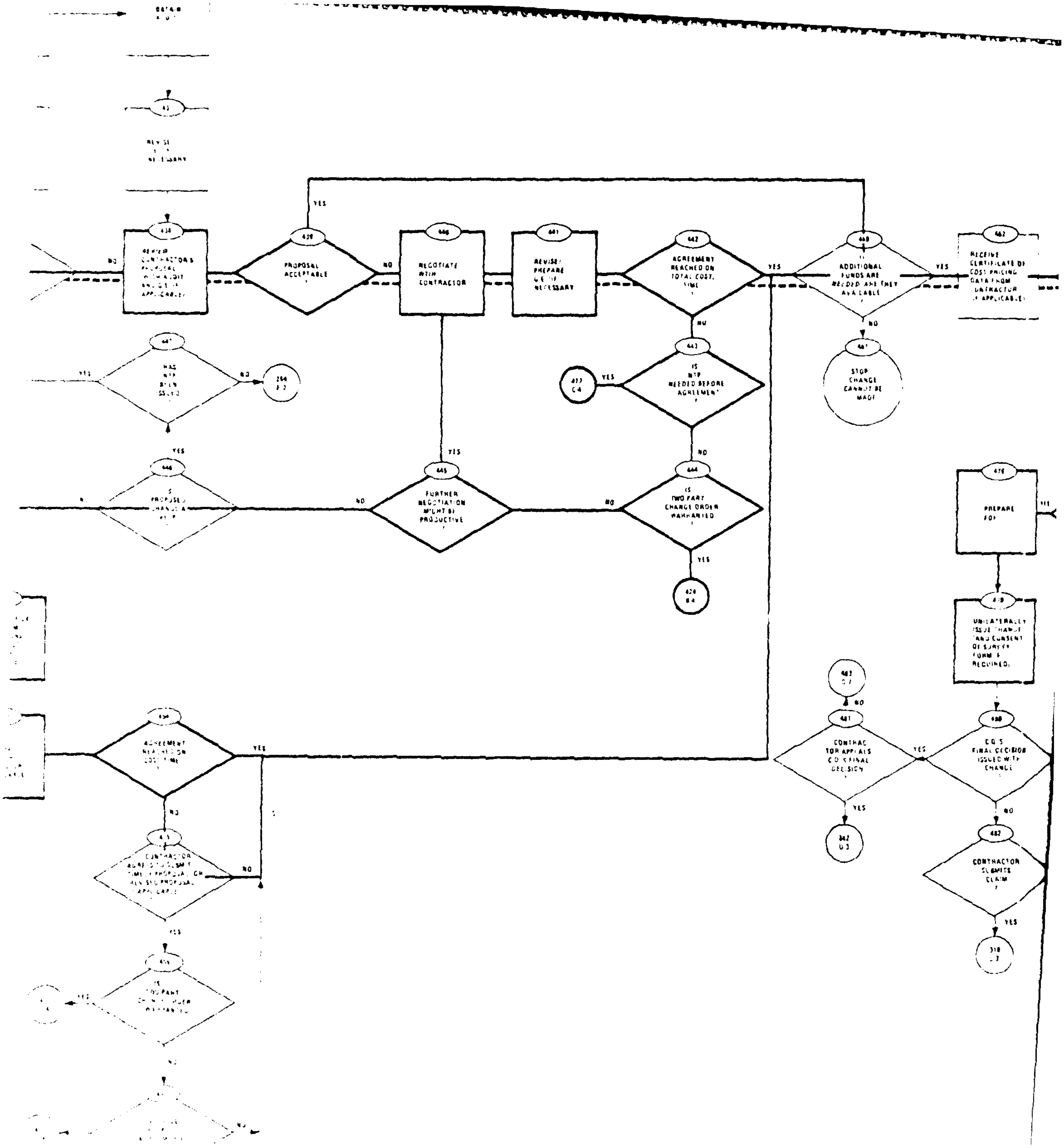
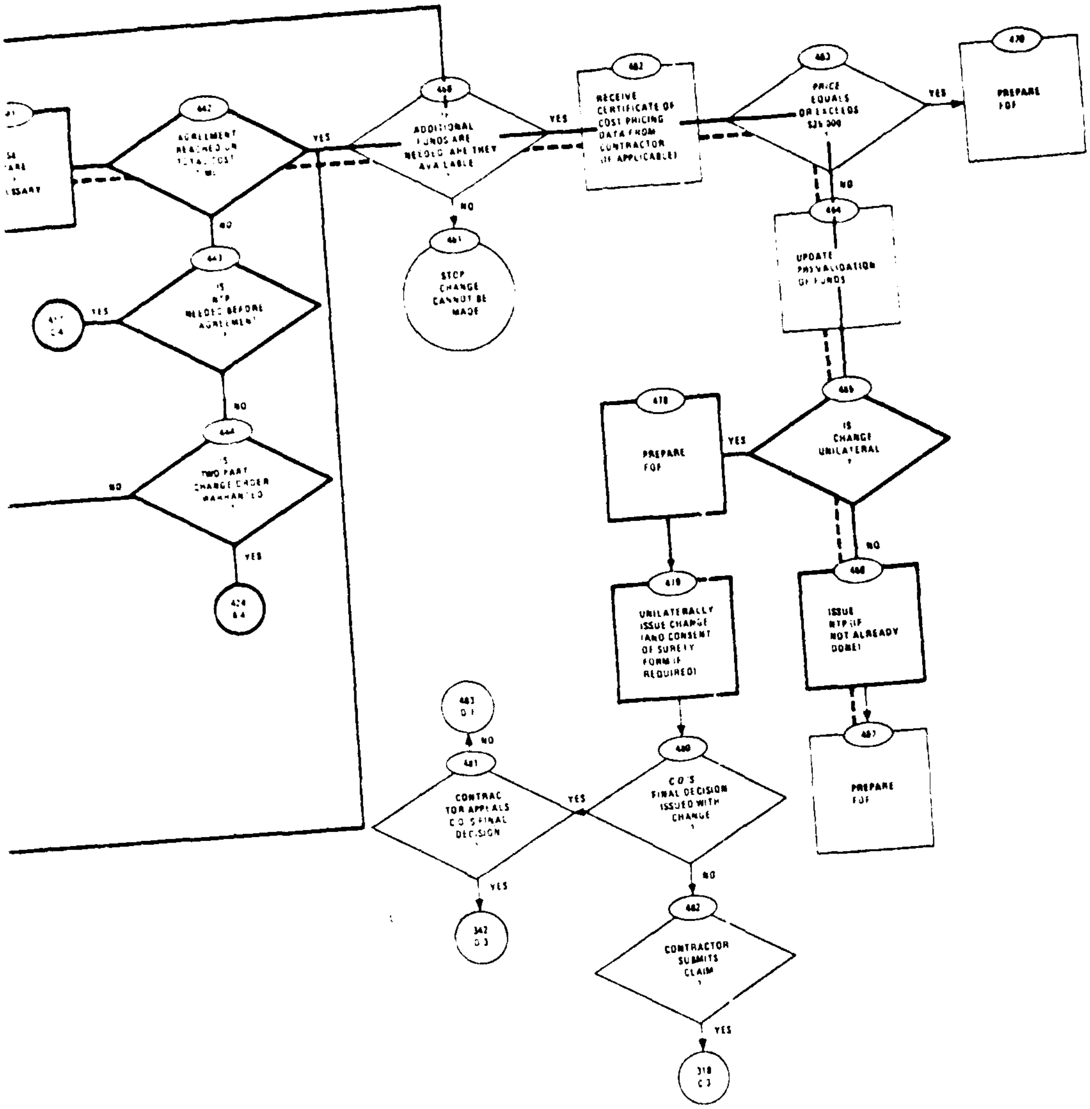

REVISE IF NECESSARY
REVIEW CONTRACTOR'S PROPOSAL
PROPOSAL ACCEPTABLE ?
NEGOTIATE WITH CONTRACTOR
REVISE/PREPARE IF NECESSARY
AGREEMENT REACHED ON TOTAL COST, TIME ?
ADDITIONAL FUNDS ARE NEEDED ARE THEY AVAILABLE ?
RECEIVE CERTIFICATE OF COST PRICING DATA FROM CONTRACTOR (IF APPLICABLE)
HAS NTP BEEN ISSUED ?
IS NTP NEEDED BEFORE AGREEMENT ?
STOP CHANGE CANNOT BE MADE
FURTHER NEGOTIATION MIGHT BE PRODUCTIVE ?
IS TWO PART CHANGE ORDER WARRANTED ?
PREPARE
UNILATERALLY ISSUE CHANGE (AND CONSENT OF SURETY FORM IF REQUIRED)
AGREEMENT REACHED ON COST/TIME ?
CONTRACTOR APPEALS CO'S FINAL DECISION ?
CO'S FINAL DECISION ISSUED WITH CHANGE ?
CONTRACTOR SUBMITS CLAIM ?
YES
NO

3 of 4


AGREEMENT REACHED ON TOTAL COST
YES
NO
IS NTP NEEDED BEFORE AGREEMENT
NO
IS TWO PART CHANGE ORDER WARRANTED
NO
YES
ADDITIONAL FUNDS ARE NEEDED ARE THEY AVAILABLE
YES
NO
STOP CHANGE CANNOT BE MADE
RECEIVE CERTIFICATE OF COST PRICING DATA FROM CONTRACTOR (IF APPLICABLE)
PRICE EQUALS OR EXCEEDS
YES
PREPARE FDF
NO
UPDATE PREVALIDATION OF FUNDS
IS CHANGE UNILATERAL
YES
PREPARE FDF
NO
UNILATERALLY ISSUE CHANGE (AND CONSENT OF SURETY FORM IF REQUIRED)
ISSUE NTP (IF NOT ALREADY DONE)
PREPARE FDF
CO'S FINAL DECISION ISSUED WITH CHANGE
YES
NO
CONTRACTOR APPEALS CO'S FINAL DECISION
NO
YES
CONTRACTOR SUBMITS CLAIM
YES

Appendix F

Annotated Simulation Program

Introduction

This program is annotated to allow the reader to compare the flow chart shown in Appendix E with the actual simulation program code. The numbers shown to the right indicate the activities being modeled.

```
//TS      JOB 'FF2730,          ','CEGRAD',
//   REGION=1024K
/*JOBPARM     LINES=5000
//   EXEC  SIM93CG
//CMP.SYSIN DD *
PREAMBLE
  PROCESSES INCLUDE GENERATOR
  EVERY MOD HAS A BASE.PRICE
  AND A TYPE
  AND A PROF.TIME
  AND A LEAD.TIME
  AND AN INITIATION.TIME
  AND A NOTICE
  AND A GE
  AND A PART
  RESOURCES INCLUDE STAFF.OFFICER
  DEFINE BASE.PRICE AND LEAD.TIME  AS REAL VARIABLES
  DEFINE TYPE, NOTICE, GE, AND PART AS INTEGER VARIABLES
  DEFINE CYCLE.TIME AND INITIATION.TIME AS REAL VARIABLES
  ACCUMULATE AVG.QUEUE.LENGTH AS THE AVERAGE,
    MAX.QUEUE.LENGTH AS THE MAXIMUM OF N.Q.STAFF.OFFICER
  ACCUMULATE UTILIZATION AS THE AVERAGE OF N.X.STAFF.OFFICER
  TALLY MEAN.CYCLE.TIME AS THE MEAN OF CYCLE.TIME
  TALLY SD.CYCLE.TIME AS THE STD.DEV OF CYCLE.TIME
TALLY DIST(0 TO 500 BY 10) AS THE HISTOGRAM OF CYCLE.TIME
  DEFINE .YES TO MEAN 0
  DEFINE .NO TO MEAN 1
END
MAIN
DEFINE I AS AN INTEGER VARIABLE
  CREATE EVERY STAFF.OFFICER(1)
  LET U.STAFF.OFFICER(1)=5
  ACTIVATE A GENERATOR NOW
  START SIMULATION
  PRINT 9 LINES WITH MEAN.CYCLE.TIME, SD.CYCLE.TIME,
    AVG.QUEUE.LENGTH, MAX.QUEUE.LENGTH AND
    UTILIZATION*100/U.STAFF.OFFICER(1) THUS
  MODEL OF CORPS OF ENGINEERS CHANGE ORDER PROCESSING
  PROCESSING TIME
  THE MEAN  TIME TO PROCESS A CHANGE ORDER WAS **.** DAYS
  WITH A STANDARD DEVIATION OF **.** DAYS.
  QUEUING INFO
  THE AVERAGE WAITING TIME FOR A CHANGE AWAITING PROCESSING
  WAS **.** DAYS.
THE MAXIMUM WAIT WAS **.** DAYS.
  STAFF OFFICERS WERE BUSY **.** PERCENT OF THE TIME.
PRINT 2 LINES WITH DIST(1) THUS
CYCLE TIME RANGE            NUMBER
       <=T                    *
FOR I=2 TO 50
PRINT 1 LINE WITH 10*(I-1), 10*I AND DIST(I) THUS
  *** <=T< ***                *
PRINT 1 LINE WITH DIST(51) THUS
      <=T                     *
END
```

```
PROCESS GENERATOR
  FOR I = 1 TO 5000
  DO
  ACTIVATE A MOD NOW
  WAIT POISSON.F(2.0,1) DAYS
IF I=100
RESET TOTALS OF N.Q.STAFF.OFFICER, N.X.STAFF.OFFICER AND CYCLE.TIME
ALWAYS
  LOOP
END
PROCESS MOD
DEFINE DECISION AS AN INTEGER VARIABLE
DEFINE DURATION, NEGOTIATION.TIME, AND PROB.TWO.PART AS REAL VARIABLES
DEFINE TLCS,ETRA,ISSUE.TIME,PREP.TIME AND HAGGLE AS REAL VARIABLES
  IF RANDOM.F(4)<=.75
LET M=5.92
LET N=6.33
LET A=1.311
LET B=.4415
LET C=4.3993
LET D=.309
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
    LET BASE.PRICE(MOD)=DURATION
    LET TYPE(MOD)=1
LET M=9.644
LET N=10.85
LET A=1.577
LET B=.3644
LET C=19.983
LET D=.60731
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
    LET LEAD.TIME(MOD)=DURATION+TIME.V
  LET PROP.TIME(MOD)=DURATION
  ELSE
LET M=14.6
LET N=14.29
LET A=.773
LET B=.5008
LET C=5.5245
LET D=.85032
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
    LET BASE.PRICE(MOD)=DURATION
    LET TYPE(MOD)=2
LET M=10.083
LET N=35.72
LET A=-.381
LET B=.5732
LET C=.8965
LET D=2.2392
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
    LET LEAD.TIME(MOD)=DURATION+TIME.V
   LET PROP.TIME(MOD)=DURATION
  ALWAYS
    LET INITIATION.TIME(MOD)=TIME.V
  LET NOTICE(MOD)=0
```

```
  LET GE(MOD)=0
  LET PART(MOD)=0
  REQUEST 1 STAFF.OFFICER(1)
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE                                         413
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
    WORK DURATION DAYS
RELINQUISH 1 STAFF.OFFICER(1)
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
ELSE
 LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME = BASE.PRICE(MOD)
LET HAGGLE = 1
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE          414
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
    IF DECISION=.YES
GO TO 'RECYCLE'
ALWAYS
REQUEST 1 STAFF.OFFICER(1)
      WORK .125 DAYS                      415
RELINQUISH 1 STAFF.OFFICER(1)
       IF BASE.PRICE(MOD) <= 10
GO TO 'LATE'
ALWAYS
        LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE                                         416
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
      WORK DURATION DAYS
     GO TO 'LATE'
  'RECYCLE' LET NOTICE(MOD)=1
REQUEST 1 STAFF.OFFICER(1)
      WORK .125 DAYS
RELINQUISH 1 STAFF.OFFICER(1)
       IF BASE.PRICE(MOD) <= 10
GO TO 'SKIP'
ALWAYS
LET M=5
LET N=2
LET A=-.725
LET B=.2527
LET C=.0775
LET D=.3422
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATIO
                                                      421
```

```
                                            421
        WORK DURATION DAYS
       LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE
LET DURATION=.125*BASE.PRICE(MOD)           422
ALWAYS
REQUEST 1 STAFF.OFFICER(1)
        WORK DURATION DAYS
RELINQUISH 1 STAFF.OFFICER(1)
'SKIP'  LET PROB.TWO.PART=1/150*BASE.PRICE(MOD)   423
    IF RANDOM.F(3) <= PROB.TWO.PART
'SPLIT' LET PART(MOD)=1
      LET DURATION = .25* BASE.PRICE(MOD)   424/425
      WORK DURATION DAYS
    ALWAYS
  'LATE' IF NOTICE(MOD) = .NO
      GO TO 'CHECK'
        ALWAYS
      IF RANDOM.F(4)>=.99                   430
WAIT 10 DAYS
       GO TO 'EST'
      ALWAYS
'BREAK' WAIT PROP.TIME(MOD) DAYS
 IF RANDOM.F(5)>=.9                         431
REQUEST 1 STAFF.OFFICER(1)
    WAIT .125 DAYS
RELINQUISH 1 STAFF.OFFICER(1)
     LET DELAY=1/2*(TIME.V-INITIATION.TIME(MOD))   432
     WAIT DELAY DAYS
     GO TO 'LATE'
  ALWAYS
LET M=34.1
LET N=50.78
LET A=1.863
LET B=.3195                                 438
LET C=12.398
LET D=.34295
CALL BS GIVING M,N,A,B,C AND D YIELDING DURATION
  WAIT DURATION DAYS
  IF RANDOM.F(5)>=.75                       439
    GO TO 'ACCEPT'
     ALWAYS
 'RENEG'    LET NEGOTIATION.TIME = .125*BASE.PRICE(MOD)
REQUEST 1 STAFF.OFFICER(1)                  440/441
    WAIT NEGOTIATION.TIME DAYS
RELINQUISH 1 STAFF.OFFICER(1)
  IF RANDOM.F(5)<=.9
   GO TO 'ACCEPT'
   ALWAYS                                   442
  IF NOTICE(MOD)=.YES
GO TO 'LOOP'
ALWAYS
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125                         443
```

```
ELSE
LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME=BASE.PRICE(MOD)
LET HAGGLE=1
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA                                    443
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
    IF DECISION=.YES
    GO TO 'RECYCLE'
     ALWAYS
'LOOP' IF PART(MOD)=0
    LET PROB.TWO.PART = 1/150*BASE.PRICE(MOD)
     IF RANDOM.F(4) <= PROB.TWO.PART            444
    GO TO 'SPLIT'
  ALWAYS
ALWAYS
  IF RANDOM.F(5)<=.99
  GO TO 'RENEG'                445
  ALWAYS
  GO TO 'DIST'
  'CHECK' IF RANDOM.F(4)<=.99
    GO TO 'BREAK'              448
   ALWAYS
WAIT 10 DAYS
IF BASE.PRICE(MOD)<=10
LET ISSUE.TIME=.125
ELSE
LET ISSUE.TIME=5
ALWAYS
LET PREP.TIME=BASE.PRICE(MOD)                   449
LET HAGGLE=1
LET ETRA=ISSUE.TIME+PREP.TIME+HAGGLE
LET TLCS=LEAD.TIME(MOD)-TIME.V
IF TLCS<ETRA
LET DECISION=.YES
ELSE
LET DECISION=.NO
ALWAYS
   IF DECISION=.YES
  GO TO 'RECYCLE'
ALWAYS
  'EST' LET GE(MOD)=1
IF TYPE(MOD)=1
LET DURATION=.25*BASE.PRICE(MOD)
ELSE                                         450
LET DURATION=.125*BASE.PRICE(MOD)
ALWAYS
   WORK DURATION DAYS
  'DIST' WORK .125 DAYS
LET N=13                                     452
                                             453
```

```
LET N=5
LET A=-.725
LET B=.2527
LET C=.0775                                                    453
LET D=.3422
CALL RS GIVING M,N,A,B,C AND D YIELDING DURATION
   WORK DURATION DAYS
  'ACCEPT' IF RANDOM.F(4)>=.99                  465
      LET DURATION = .25 * BASE.PRICE(MOD)
      WORK DURATION DAYS                                  478
   ALWAYS
REQUEST 1 STAFF.OFFICER(1)
     WORK .125 DAYS                              479/466
RELINQUISH 1 STAFF.OFFICER(1)
    LET CYCLE.TIME = TIME.V - INITIATION.TIME(MOD)
END
ROUTINE RS GIVEN M,N,A,B,C AND D YIELDING DURATION
DEFINE M,N,A,B,C AND D AS REAL VARIABLES
LET P=RANDOM.F(1)
LET DURATION=M+N*(A+(P**C-(1-P)**D)/B)
IF DURATION<0
  LET DURATION=0
ALWAYS
RETURN WITH DURATION
END
/*
//GO.SYSIN  DD *
/*
//
```

END

1-87

DTIC