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A Q-GERT MODEL FOR DETERMINING
THE MAINTENANCE CREW SIZE FOR
THE SAC COMMAND POST UPGRADE

THESIS

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THESIS

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Harold R. Agnew

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Abstract

To meet new requirements and correct existing deficiencies SAC is upgrading its Headquarters Command Post by adding five state-of-the-art electronic systems. After installing the systems, SAC must determine whether the equipment will be maintained by contractors, Air Force technicians, or a combination of contractor and Air Force technicians. If Air Force technicians maintain the equipment three Air Force Specialties will be required.

The purpose of this thesis is to develop a model which can be used to determine the number of Air Force technicians required to maintain the equipment planned for the SAC Command Post upgrade. The model was developed, tested and validated using the system science paradigm as a conceptual framework and the Q-GERT simulation language as the implementing tool.

The results of the simulation model were analyzed using multiple analysis of variance. THe results indicated that two technicians of each Air Force Specialty, one 5-level and one 3-level, were sufficient to provide an equipment availability of greater than 99 percent. Furthermore, the results indicate that the utilization of the technicians would be so low that the same technicians would be able to maintain another system of similar size,in addition to the upgraded Command Post systems, and still maintain an availability greater than 99 percent.

A Q-GERT MODEL FOR DETERMINING THE MAINTENANCE CREW SIZE FOR THE SAC COMMAND POST UPGRADE

I INTRODUCTION

Background

To meet new requirements and correct existing deficiencies SAC decided to upgrade its Headquarters Command Post by adding five state-of-the-art electronic systems. These electronic systems, like their predecessors, will require maintenence and SAC must decide upon a concept for maintaining them. Three concepts commonly used on the type of equipment planned for the SAC Command Post upgrade are contractor maintenance, U.S. Air Force "blue suit" maintenance, and combined contractor and Air Force maintenance.

When comparing these maintenance concepts,SAC must perform both qualitative and quantitative analysis on the options. Qualitative issues include such concepts as control over maintenance personnel, quality of maintenance, and responsiveness to equipment outages. Qualitative issues, then, are subjectively judged and, depending on circumstances may be the overriding issues when choosing a maintenance concept. However, when qualitative issues are not overriding, or if qualitative judgements are not decisive, quantitative issues become important.

The quantitative issues normally associated with maintenance include cost of logistics support, cost of technical documentation, and cost of maintenance personnel. When contractors provide maintenance, they usually provide the logistics support and technical documentation associated with that maintenance. Bids for maintenance contracts then, usually contain all costs associated with maintenance.

Conversely,when the Air Force provides the maintenance, it must also provide the logistics support and technical documentation. Air Force Logistics Command (AFLC) computes the life cycle cost of providing logistics support using standard formulas, and contractors submit costs for technical documentation along with bids for integration and installation contracts. However, to compute maintenance personnel costs Air Force Communications Command (AFCC) needs to know the number and skill level mix of the maintenance personnel required for a system.

Currently, though, SAC does not know the number or skill level mix of maintenance personnel required to maintain the equipment planned for the upgraded SAC Command Post. Furthermore, SAC does not have a method of determining the required number or skill levels of maintenance personnel for new systems. In fact, the current method of determining how many maintenance personnel are required for a new system involves former maintenance personnel making educated guesses. While this method is sometimes successful, often the guesses are wrong, especially when the system contains a new technology.

These wrong guesses can cause severe short term problems with system maintenance, especially if the initial maintenance crew is too small. Too few people on the maintenance crew can result in lower than required system availability and low morale among the maintenance personnel. On the other hand, overestimating maintenance crew size can waste money by spending too much for Air Force maintenance personnel or hiring contractors when Air Force maintenance would be more cost effective. Accurate estimates of the maintenance crew size, then are critical for making valid cost estimates to compare contractor versus Air Force maintenance.

Problem Statement

The current method of determining the number of people required to maintain an electronic system at SAC involves experienced maintenance personnel making educated guesses. No method exists, manual or automated, which determines the appropriate number of maintenance personnel required to maintain the electronic equipment planned for the SAC Command Post upgrade. Before SAC can determine whether to use contractor or Air Force maintenance, or a combination of the two, SAC needs an accurate determination of the number and skill level mix of the Air Force maintenance personnel required to maintain the upgraded SAC Command Post (Ref 1).

Objective

The primary objective of this thesis is to develop test, and validate a model which can be used to determine the number and skill level mix of Air Force maintenance personnel required to maintain the electronic systems proposed for the SAC Command Post upgrade.

Subobjectives include:

1. Determination of the sensitivity of the maintenance crew size to variance in equipment reliability (expressed in terms of mean time between failures (MTBF)) and maintainability (expressed in terms of mean time to repair (MTTR)),system size and complexity, spares level, and system availability and maintenance response requirements.
2. Determination of the sensitivity of system availability to variance in equipment reliability and maintainability, system size and complexity, spares level, and maintenance crew size.

Methodology

Modeling the availability, reliability, and maintainability of the systems planned for the new SAC Command Post to determine the appropriate number of maintenance personnel quickly becomes too complex to calculate analytically. With five separate, yet integrated electronic systems in the upgraded Command Post, each system containing a variety of subsystems, complete mathematical formulation of the system availability, reliability, and maintainability becomes extremely difficult, if not impossible.

Because of the complexity of the SAC Command Post systems and subsystems, computer simulation was chosen for the model. Of the six conditions Shannon lists for application of computer simulation, the following three apply in this case: (Ref 19:11)

1. A complete mathematical formulation of the problem does not exist or analytical methods of solving the mathematical model have not been developed. Many waiting line (queueing) models are in this category.

2. Analytical methods are available, but the mathematical procedures are so complex and arduous that simulation provides a simpler method of solution.

3. It is desired to observe a simulated history of the process over a period of time in addition to estimating certain parameters.

When developing complex simulation models, the need for a conceptual framework is paramount. The system science paradigm suggested by Schoderbek, Schoderbek, and Kefalas was chosen as the conceptual framework for the model developed in this thesis. The system science paradigm consists of three phases: (1) conceptualization, (2) analysis and measurement, and (3) computerization (Ref 18:295-303).

In the conceptualization phase the scientist looks at the system as open and organic, having constant interactions with its environment. The scientist therefore focuses on both the system and its environment, and models the interactions between the system and its environment. Finally, the scientist tries to understand as much of this interaction as possible (Ref 18:297).

The analysis and measurement phase of the system science paradigm consists of converting the conceptual model developed in Phase I into a parametric model. When developing a parametric model the scientist must decide: (Ref 18:301)

1. In what language he will express his results (language).
2. To what objects and in what environment his results will apply (specification).
3. How his results can be used (standardization).
4. How one can assess the "truth" of the results and evaluate their use (accuracy and control).

Computerization involves translating the parametric model developed in the analysis and measurement phase into a "computer-consumable project" (Ref 18:302). The results of this computer program will dictate the necessity to repeat the first two phases. The system science paradigm, then, is an iterative process (Ref 18:302,303).

Overview

Chapter I contains the development of the problem addressed in this thesis and explains the approach taken in this thesis to solve it. It explains why the problem exists and what benefits can be expected from deriving a solution to the problem.

Explaination of the development of the conceptualization phase occurs in Chapter II. Conceptualization begins with the cones of resolution technique described by Schoderbek, Schoderbek, and Kefalas and uses causal diagrams to explain important interactions in the third level of resolution. In addition, Chapter II shows the development of the equipment configuration modeled in this thesis.

Chapter III contains a discussion of the analysis and measurement phase of the system science paradigm. The conceptual model developed in Chapter II will be analyzed to determine what components and subsystems contribute to system availability. Additionally, this chapter defines system availability for the system being modeled. Finally, Chapter III describes the parametric model developed from the conceptual model and contains a description of the Q-GERT model.

Chapter IV discusses how the parametric model developed in Chapter III is computerized. That is, this chapter discusses how the Q-GERT model is converted into Q-GERT and FORTRAN code and run on the computer. This chapter describes how the computer code works.

Chapter V contains the validation and verification of the model. Justification for the reliability and maintainability times and probability distributions is provided. In addition, this chapter describes the verification process for determining that the results obtained from this simulation are in fact good and can be used as intended.

Conclusions and recommendations are contained in Chapter VI. The applicability of the results of this thesis will be discussed along with recommended extensions.

II CONCEPTUALIZATION

As stated in Chapter I, the first phase of the system science paradigm involves conceptualization. In this phase the researcher focuses on both the system and its environment, models the interactions between the system and its envoronment, and tries to understand as much of the interactions as possible. As suggested by Schoderbek, Schoderbek, and Kefalas, the cones of resolution technique proves especially helpful during the conceptualization phase (Ref 18: 297-299).

With the cones of resolution technique the researcher advances from the abstract to the detailed by proceeding through the levels of the cone. Level one is the most abstract level. In level one the researcher takes a broad look at the system and its environment, and chooses one of the distinguishable features at that level. To advance to the second level the researcher expands upon the feature, breaking it into further distinguishing features. The process of selecting and expanding features, then, provides a path to each subsequent level. The researcher, then, proceeds through the levels of resolution until the level with the desired detail is reached.

As an example of the cones of resolution technique consider a person planning a vacation. Based on the persons interests and finances he must decide where to go for vacation. In this case, the first level of resolution is the entire world. Picking one country, say the United States, as a distinguishable feature, the vacationer can advance to the second level of resolution. The vacationer can further break the Unites States into distinguishable features, the various states, and choose one, possibly California, thereby advancing to the third level of resolution. California, being a large state, would be too difficult to fit into one vacation, therefore the vacationer must also break it into distinguishable features, possibly cities, and choose one, say San Francisco and advance to the fourth level of resolution. Once at the fourth level, the vacationer will choose those distinguishable features that he wishes to visit, such as the Golden Gate Bridge, Fishermans Warf, and the cable cars. This vacationer's cones of resolution for his vacation would contain four levels.

Figure 1 contains a model of the Command Post - Environment Interactions System using cones of resolution. In this model, level one shows the simple relationship between the Command Post and its environment. The first level provides little useful information by itself, but provides a logical step to the second level.

Level two focuses on the Command Post environment. This level elaborates the interactions of the Battle Staff, Controllers, Emergency Actions (EA) Team, Support Centers, and electronic equipment. The interactions of greatest concern involve the equipment. In every case the equipment

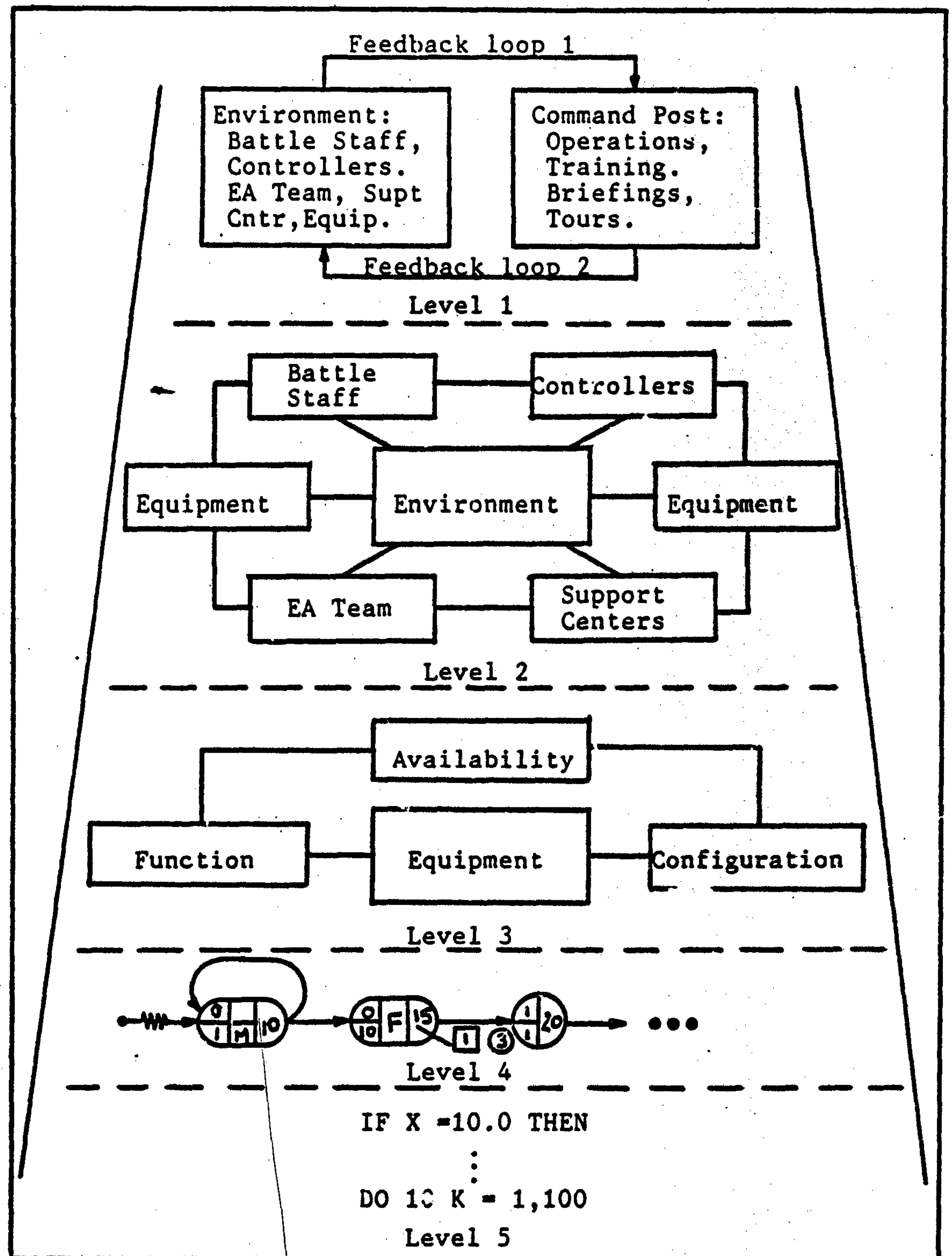

Figure 1. Command Post - Environment Interaction System

provides the users with the information needed to make decisions. The third level, therefore, models the equipment sector of the Command Post environment.

Level three breaks the equipment sector into three smaller sectors - availability, function, and configuration. To provide the Command Post users with critical information when needed, the equipment must operate satisfactorily for long periods of time (availability). In addition, the equipment must provide the information in the form most useful to the Command Post users (function). Finally, the various systems must be put together in such a way that the users can easily obtain the information (configuration). To better explain the interactions of the equipment within the Command Post the next three sections provide detailed descriptions of the equipment availability. function, and configuration.

Availability

Availability is a function of reliability and maintainability; therefore, before availability can be defined it is necessary to define reliability and maintainability. Kapur and Lamberson provide the following definition of reliability: (Ref 9:1)

> The reliability of a system is the probability that, when operating under stated environmental conditions, the system will perform its intended function adequately for a specified interval of time.

However, Kapur and Lamberson point out three problems with this definition: (Ref 9:1)

(1) the acceptance of the probabilistic notion of reliability which admits the possibility of failure,
(2) the concept of adequate performance for system parameters that deteroirate solely with time, and
(3) the judgement necessary to determine the proper statement of environmental conditions.

Chapter V addresses these problems in explaination of the analysis and measurement phase of the system science paradigm.

Similarly, Kapur and Lamberson define maintainability as "the probability that a failed system can be made operable in a specified interval of downtime" (Ref 9:225). Factors contributing to downtime include failure detection time, repair time, administrative time, and logistics time. The maintainability function, then, describes the probabilistic time a system will remain in a failed state (Ref 9:225).

Using the above definitions of reliability and maintainability, Kapur and Lamberson provide the following definition of availability: (Ref 9:225)

> Availability is defined as the probability that a system is operating satisfactorily at any point in time and considers only operating time and downtime, thus excluding idle time. Availability is a measure of the ratio of the operating time of the system to the operating time plus the downtime. Thus it includes both reliability and maintainability.

Furthermore, Kapur and Lamberson define the availability function to be

$$\text{Availability (A)} = \frac{\text{Operating time}}{\text{Operating time + downtime}} \tag{1}$$

or equivalently

$$A = \frac{\text{Mean time to failure (MTTF)}}{\text{Mean time to failure (MTTF) + Mean time to repair (MTTR)}} \tag{2}$$

When using the exponential distribution to describe the reliability function, equation (2) can be rewritten as

$$A = \frac{\text{Mean time between failures (MTBF)}}{\text{Mean time between failures (MTBF)} + \text{MTTR}} \qquad (3)$$

Justification for using the exponential distribution to model equipment failures in this thesis is provided in Chapter V.

To further explain the interactions associated with availability, Figure 2 contains a causal-loop diagram of the factors contributing to availability. Richardson and Pugh describe causal links (the arrows used in causal-loop diagrams) as follows: (Ref 17:26)

> $$A \xrightarrow{\quad +} B$$
>
> A causal link from A to B is positive (1) if A adds to B, or (2) if a change in A produces a change in B in the same direction.
>
> $$A \xrightarrow{\quad -} B$$
>
> A causal link from A to B is negative (1) if A subtracts from B, or (2) if a change in A produces a change in B in the opposite direction.

Thus, in Figure 2, a low system availability causes pressure to increase reliability, maintainability, or maintehance crew (size and skill), and to decrease logistics time. Reliability can be increased by a number of engineering changes including using more reliable components and designing redundancy into the system. Reliability engineering should be performed during the system design phase but can be accomplished any time during the system life. Increasing the system reliability will decrease the failure

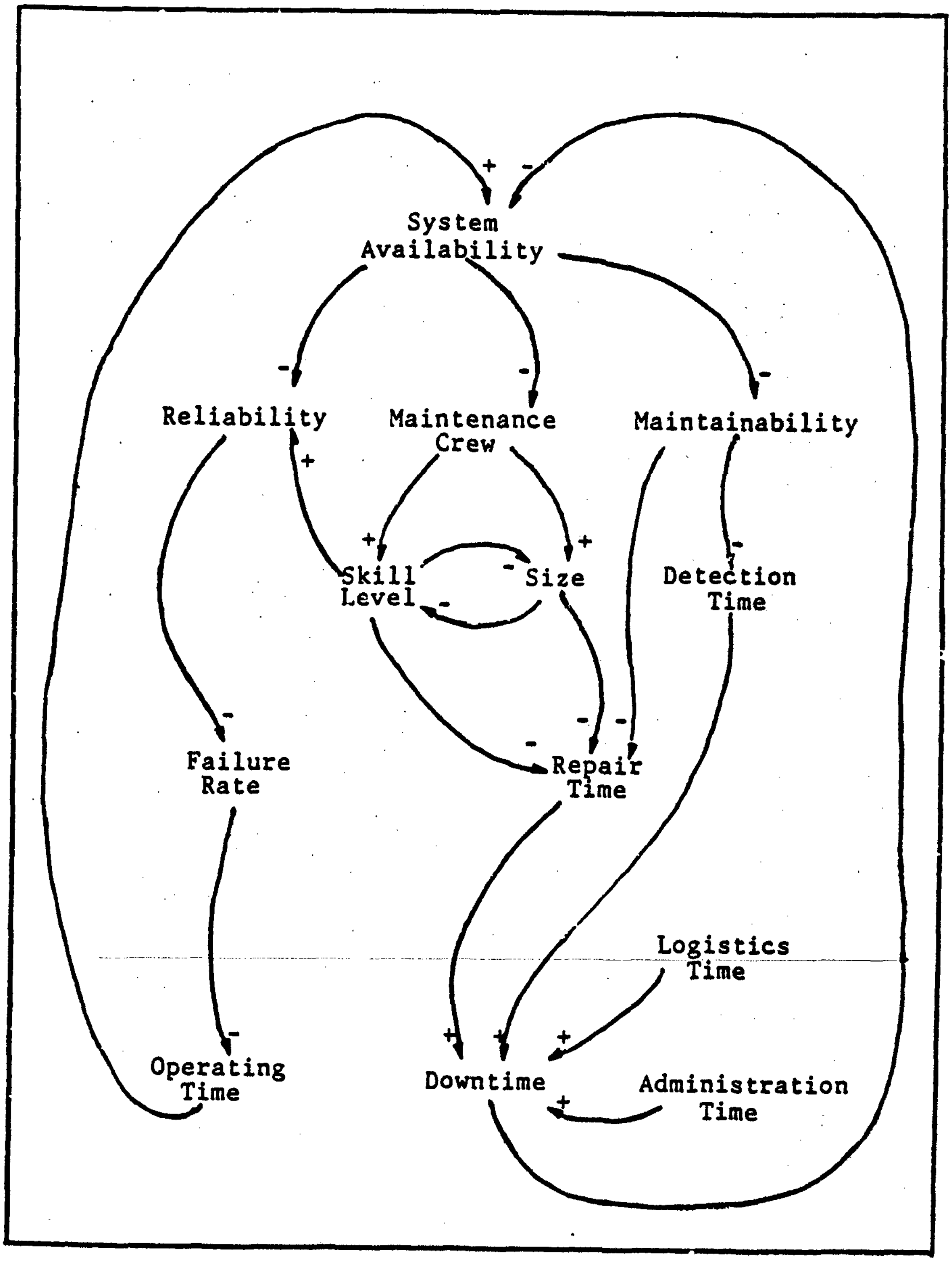

Figure 2. Causal-loop Diagram of the Factors Affecting Availability

rate which in turn increases the operating time. An increase in operating time, then, results in an increase in system availability.

Similarly, sound engineering practices can increase maintainability. Methods for improving maintainability include designing systems to provide fault detection and isolation, and easy access for replacement of failed components. Increased maintainability, therefore, reduces the detection and repair time, which in turn reduces downtime, thereby increasing system availability.

Low availability usually has its most pronounced impact on the maintenance crews. A low availability causes increased pressure on the maintenance crew's capabilities. This increased pressure, then, causes an increase in maintenance size and skill level. As shown in Figure 2, crew size and skill level are inversely proportional. That is, the higher the worker's skill level the fewer the number of workers required, and the larger the crew size the less skill required.

As maintenance crew size or skill level increases the repair time generally decreases. This happens because the more skilled maintenance personnel can perform faster repairs, and the larger crews can perform more simultaneous repairs. Increased maintenance skills can also result in increased reliability because maintenance personnel with better skills generally induce fewer maintenance related failures. Therefore, increasing the size and skill level of the maintenance crews decreases repair time and increases reliability. As before, operating time will increase and downtime will decrease resulting in a higher system availability.

Logistics time is the time required to retrieve spare parts necessary to repair the equipment. If the parts need to be ordered, downtime increases significantly. Therefore, a low availability due to a lack of spare parts causes the spare parts level to increase, thereby reducing the logistics time and increasing the system availability.

Administration time is the time it takes to notify the maintenance personnel that a failure has occurred plus the time it takes for the maintenance supervisor to assign a repairman to the repair. In general, the administration time is fairly constant, and consists of the operator of the failed equipment calling Job Control and Job Control notifying the work center. In this thesis administration time is included as a part of the mean time to repair and is assumes to take about five minutes or one tenth of an hour.

In addition to being too low, availability can be higher than expected. Usually considered good, high availability can indicate waste, such as idle maintenance personnel and too many spares. When this occurs, excess maintenance personnel and spare parts can be eliminated, as long as the availability remains higher than the required availability.

The causal-loop diagram in Figure 2, then, shows the relationship of system availability with reliability and maintanability, and maintanance crew size and skill level. The next section describes the function of the five electronic systems planned for the SAC Command Post upgrade.

Function

SAC plans to integrate five state-of-the-art electronic systems into the upgraded Command Post. Each of these systems - upgraded voice communications, Improved Large Wall Screen Display (ILWSD) systems, secure closed circuit television(CCTV), local area network, and automated data processing (ADP) support - provide a unique function and all five systems will be integrated to benefit the Command Post users (Ref 5:35).

Voice Communications Upgrade. The voice communications upgrade will expand the existing voice communications capabilities while consolidating these capabilities into one system. SAC will accomplish this consolidation by installing a Special Private Line Telephone System (SPLTS). SPLTS will provide the following capabilities: (Ref 5:39-44)

1. Each SPLTS console will contain only one handset.
2. Users can make both secure (Red) and unsecure (Black) calls from the same instrument.

3. Users can place a Red (or Black) call on hold while making (or answering) another call on any Black (or Red) line.

4. SPLTS will use Dual-Tone Multiple Frequency (DTMF) touchtone dial pads.

5. The system provides three Red conference circuits.

6. SPLTS will interface with the following voice communications lines: (Ref 5:44)

   - SPEAKEASE secure voice terminals
   - AUTOSEVOCOM
   - PARKHILL secure voice terminals
   - Hotlines
   - Command Post PBX (including SOCS)
   - Base Central Office dial lines
   - Public address (PA)
   - Intercom
   - Radio
   - Line monitors

The SAC Command Post voice communications upgrade will also include installation of SPEAKEASY (formerly VINSON) secure voice terminals. SPEAKEASY terminals will provide high quality, full duplex secure voice communication over unconditioned narrowband transmission media. In addition, SPEAKEASY is compatible with the existing AUTOSEVOCOM system (Ref 5:36-38).

Finally, the voice communications upgrade will include expanding the newly acquired SOCS Diminsion PBX to accomodate all external Command Post communications. External lines include AUTOVON, DDD, Off-Premise extensions, foreign exchanges, WATS, hotlines, Command Post PBX Subscribers, and a tie-trunk to the Base telephone exchange (Ref 5).

Improved Large Wall Screen Display (ILWSD). The ILWSD system will consist of image generation and display equipment. The image generation equipment will accept data from one or more host computers and convert the data into text and graphics images, and send the images as video signals to the display devices.

The display equipment will consist of eight high resolution television projectors and approximately 12 high resolution color television monitors. The projectors will provide displays to the Senior Battle Staff on eight large wall projection screens. These large screen displays will be used for briefings, tours, and other Command Post functions requiring a large number of people to view the same displays. The high resolution color television monitors will provide other users with the same displays as projected on the large wall screen.

Closed Circuit Television (CCTV). Consisting of briefer stations, television recording and playback equipment, television monitors, and a distribution network, the CCTV system will provide the live and recorded audio and video capabilities required by the SAC Command Post and its support centers. The briefer stations, consisting of television cameras and microphones, and the color monitors will allow remote briefings and video conferencing over the distribution network. The television recording and playback equipment will supplement this capability by providing pre-recorded briefings for tours and training.

Local Area Network (LAN). The LAN proposed for the SAC Command Post upgrade will have several functions. First, the LAN will connect Command Post ADP equipment to a common data base for routine tasks such as rosters and checklists, and could allow interpositional conferencing for Command Post and support center users. Second, the LAN will connect the Command Post and support center users with external networks such as the WWMCCS Information System (WIS) to provide quick access to information. Finally, the LAN could connect the image generation equipment (of the ILWSD system) to the host computers.

Automated Data Processing (ADP). The ADP upgrade will consist of two separate activities. The first activity involves upgrading the WWMCCS computer at SAC by adding memory, upgrading the five CPU's, and replacing the communication front end (Datanet 335's) with new Datanet 6678's. This upgrade will provide the SAC Command Post with the necessary response time and computer power to last until the WWMCCS replacement system becomes available in the late 1980's(Ref 5).

The second activity involves installing mini- and micro-computers in the Command Post. These small computers will attach to the LAN to provide the following features:

a. Local File Management and Computational Support
b. Remote Data Retrieval and Display
c. Automated Text Message Handling
d. Graphic Display Support
e. Inter-Positional Conferencing

To understand how the five functional systems will operate as one integrated system it is necessary to understand the configuration of the upgraded SAC Command Post. The following section describes the proposed SAC Command Post configuration.

Configuration

Figure 3 illustrates the proposed SAC Command Post equipment configuration. With this proposed configuration the ILWSD and Command Post ADP will interface with the host computer systems through the LAN. The network, then will allow all terminals to communicate with the host computer, Command Post mini-computer, ILWSD display computers, and other Command Post ADP terminals. Also, with this configuration the CCTV distribution network interfaces the live and recorded video signals with the color television monitors and large screen projectors. Finally Figure 3 illustrates that all telephone handsets will interface with Red and Black communications circuits via the SPLTS equipment. The following paragraphs provide a detailed description of the equipment configuration in the upgraded SAC Command Post.

Voice Communications. The upgraded SAC Command Post will contain three categories of voice communications equipment, all three categories based on SPLTS implementation. Category I equipment will provide the Senior Battle Staff with access to the Base PBX, Command Post/SOCCS PBX, Foreign

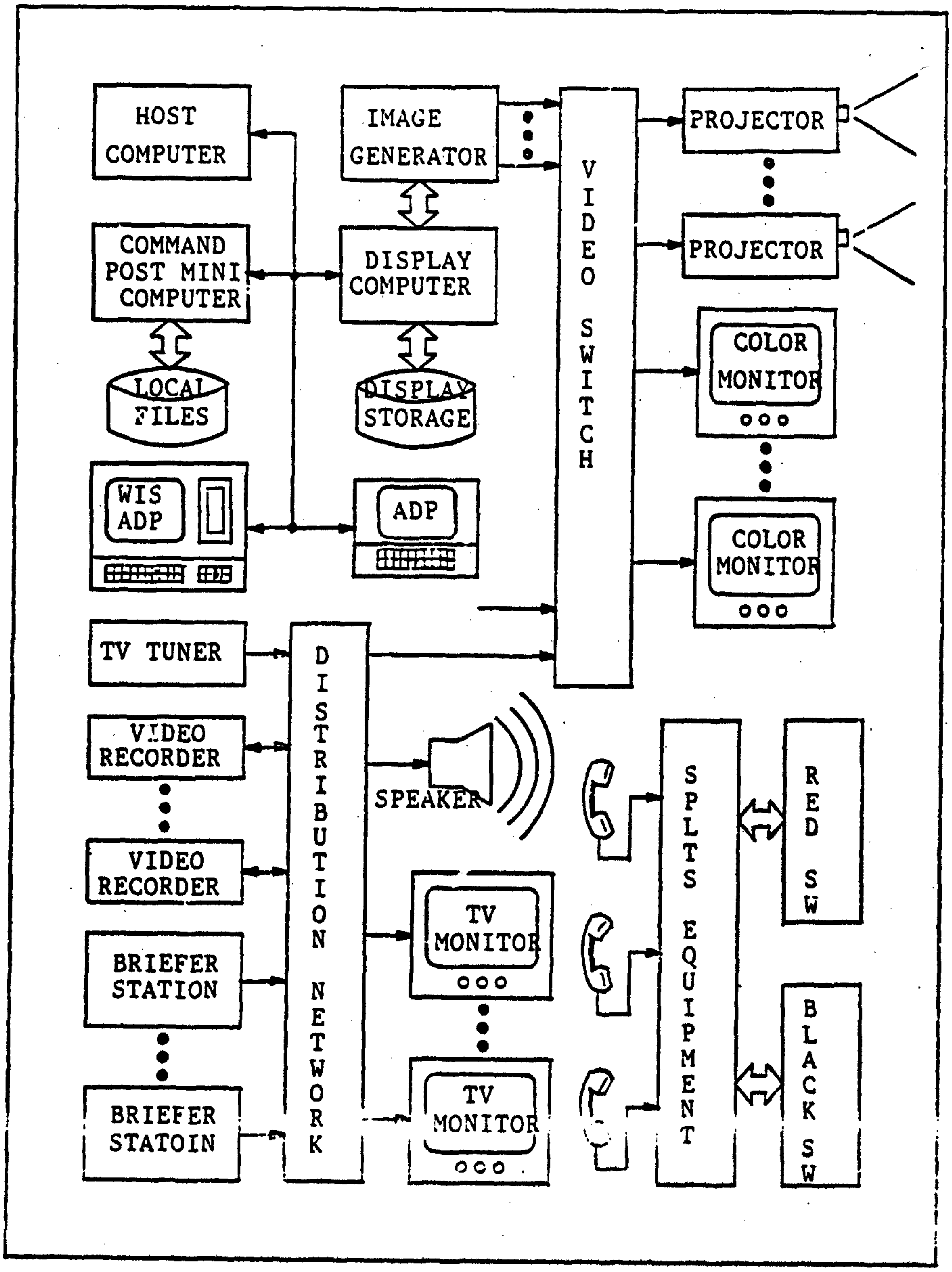

Figure 3. Proposed SAC Command Post Configuration simplified Block Diagram

exchanges, internal secure voice, intercom, and PA microphones. Current plans call for 18 Category I SPLTS console positions. Figure 4 provides a sample layout for Category I SPLTS consoles.

Category II equipment will provide the Support Battle Staff with the same service as the Category I equipment plus direct access to AUTOVON and SPEAKEASY secure voice. Currently SAC has not determined the exact number of Category II consoles needed but based on the current number of Support Battle Staff positions and conversation with MITRE personnel working on the Command Post upgrade approximately 30 Category II consoles will be installed (Ref 5). Figure 5 contains a sample layout for Category II consoles.

Similarly, Category III SPLTS consoles contain the capabilities of the other two consoles plus AUTOVON precedence/preemption, AUTOSEVOCOM, PARKHILL secure voice, hot lines, and radio. Currently SAC plans to install five Category III consoles, one each for the Senior Controller, Warning Systems Controller, and Emergency Actions Team, and two for the Communications Controller. Figure 6 provides a sample layout of the Category III SPLTS consoles.

Figure 7 contains a block diagram of the proposed upgraded voice communications system. The diagram shows that each position contains a telephone handset connected to a SPLTS console. Each SPLTS console, then, connects to a transfer circuit which separates and isolates the Red and

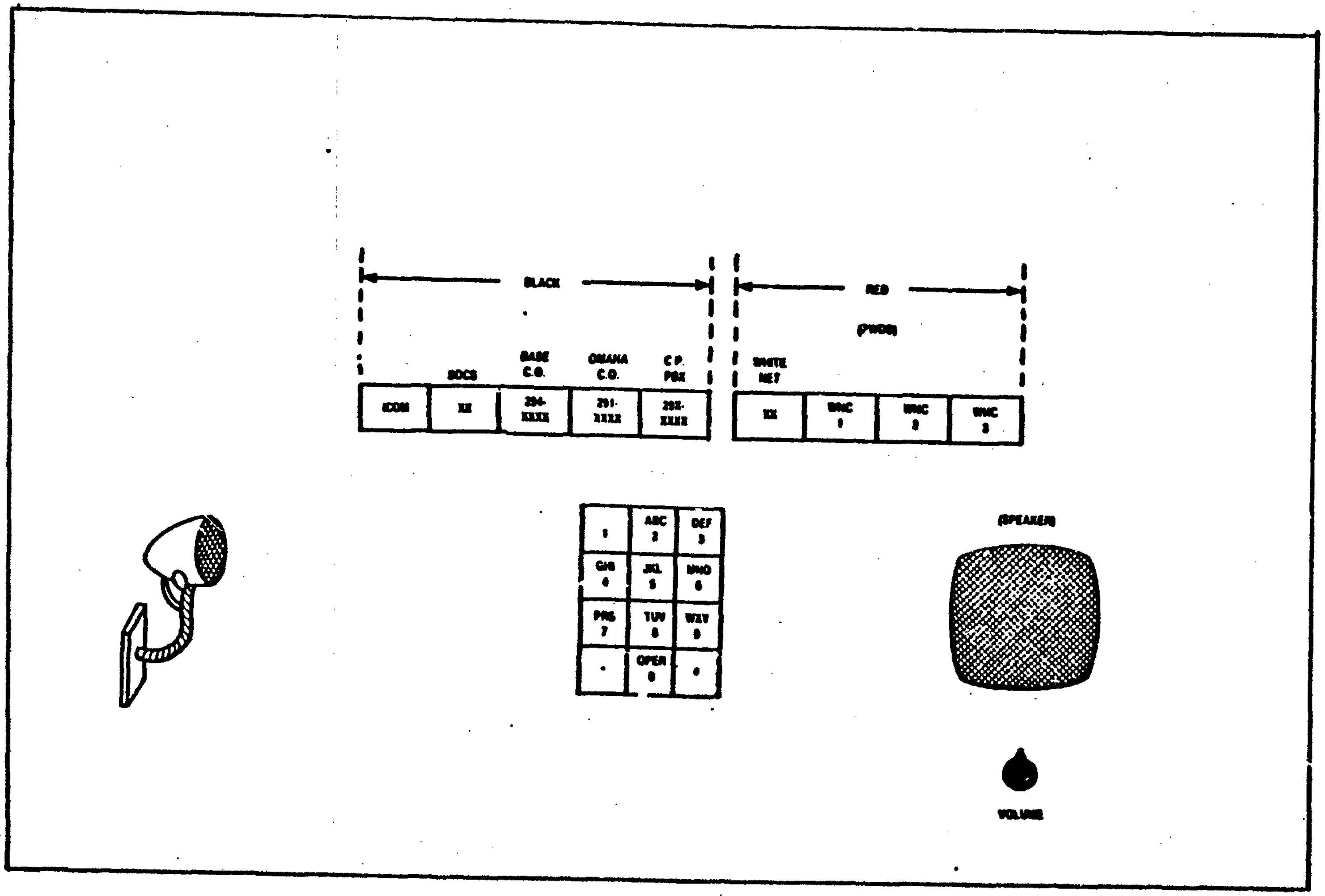

Figure 4. Category I - Senior Battle Staff Console (Ref 5)

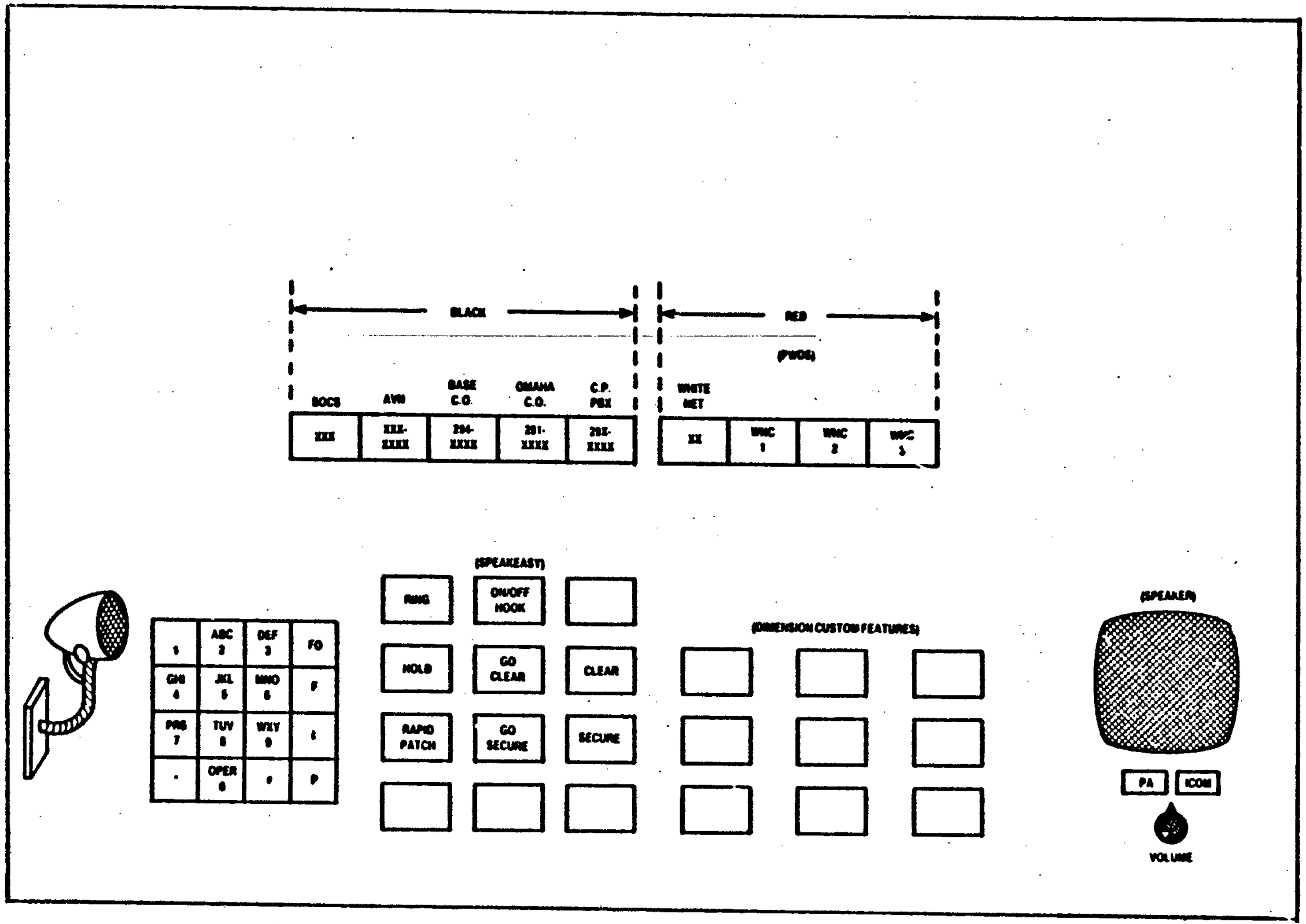

Figure 5. Category II Support Battle Staff Consoles (Ref 5)

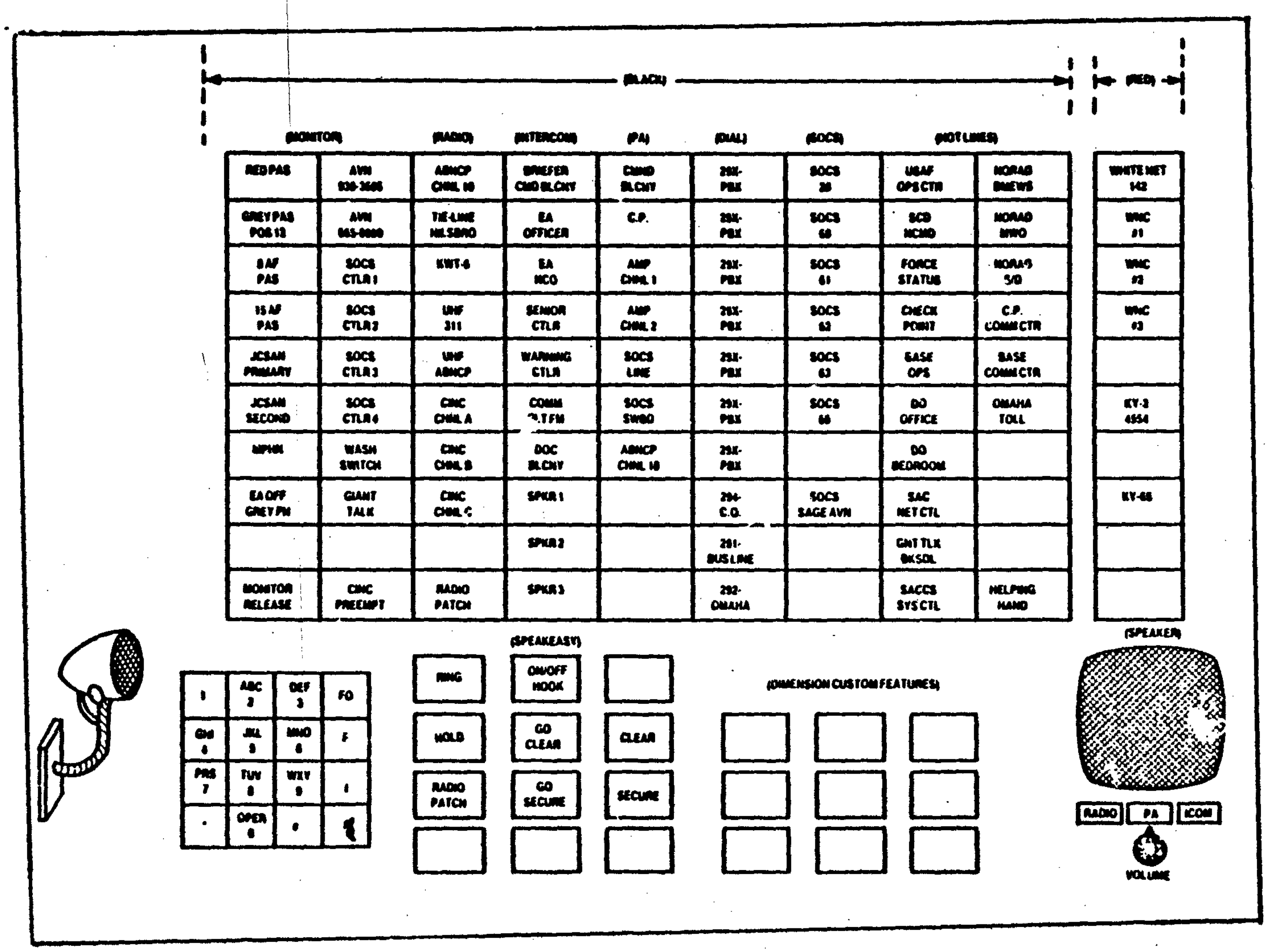

Figure 6. Category III - Communications Controller Console (Ref 5)

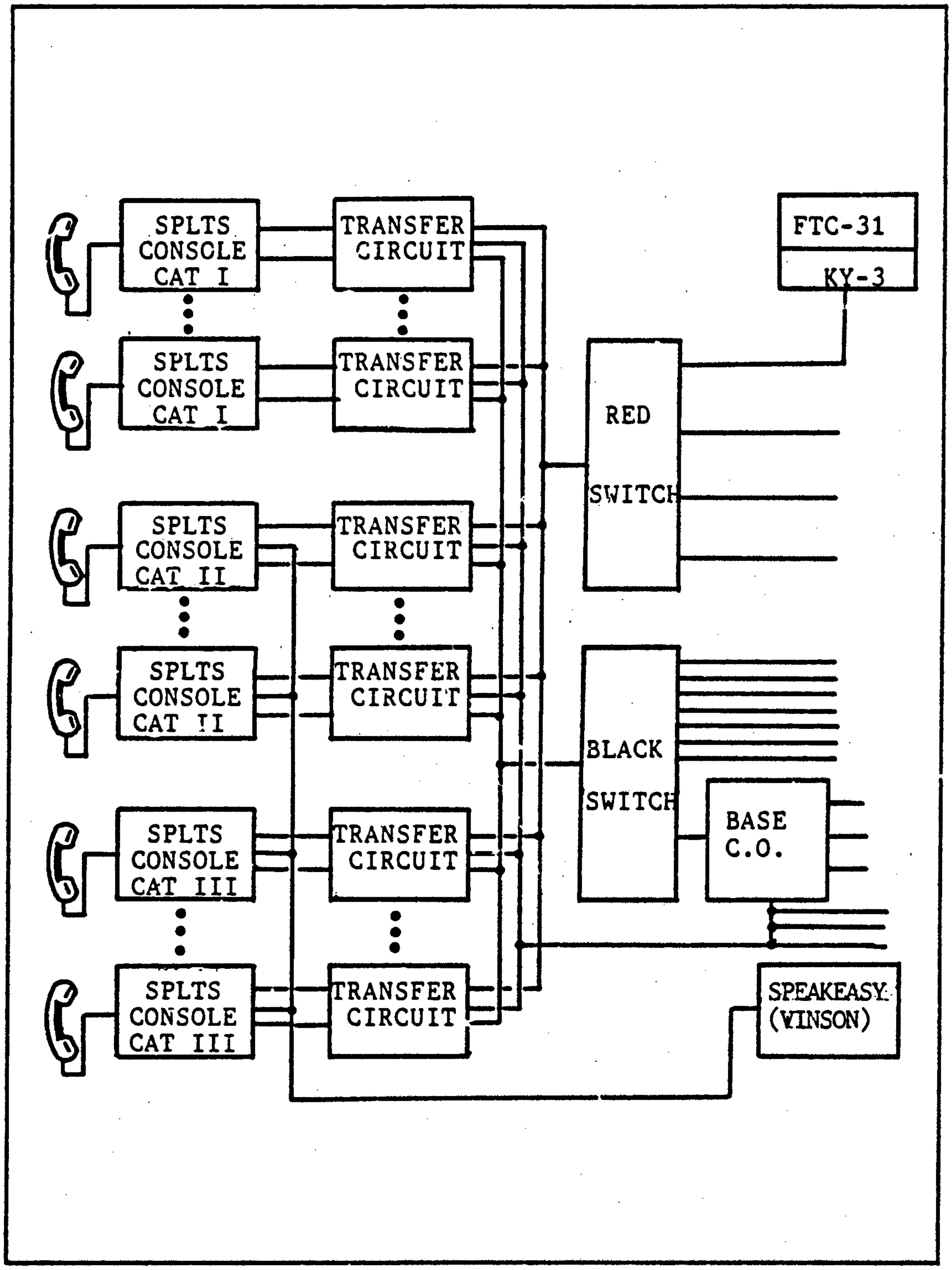

Figure 7. Upgraded Voice Communications System Block Diagram

Black circuits. In addition, the Category II and III SPLTS consoles are connected directly to the SPEAKEASY secure voice equipment. From the transfer circuits the Red telephone lines are connected to the Red Switch for connection with internal secure voice circuits and world wide secure voice. Similarly, the Black telephone lines connect the transfer circuits to the dedicates Command Post and SOCCS PBX (Black Switch), the base telephone system, and the off base telephone system.

Improved Large Wall Screen Display (ILWSD) System. The ILWSD System consists of display computers and storage devices, image generators, video switches, large screen projectors, and color television monitors. Figure 8 illustrates the configuration of the ILWSD system. With the proposed configuration, the display computer will receive display data from the host computer either directly or via the LAN. The display data, then, will be stored on the display storage devices for recall at a later time. When the display computer receives a request for a display from the Display Controller, via the LAN, the display data will be read from the display storage device and sent to one of the image generators. The image generator will then convert the display data into a display and send it to the video switches as video signals. Using the switch controls, the Display Controller will route the video signals to the desired display device.

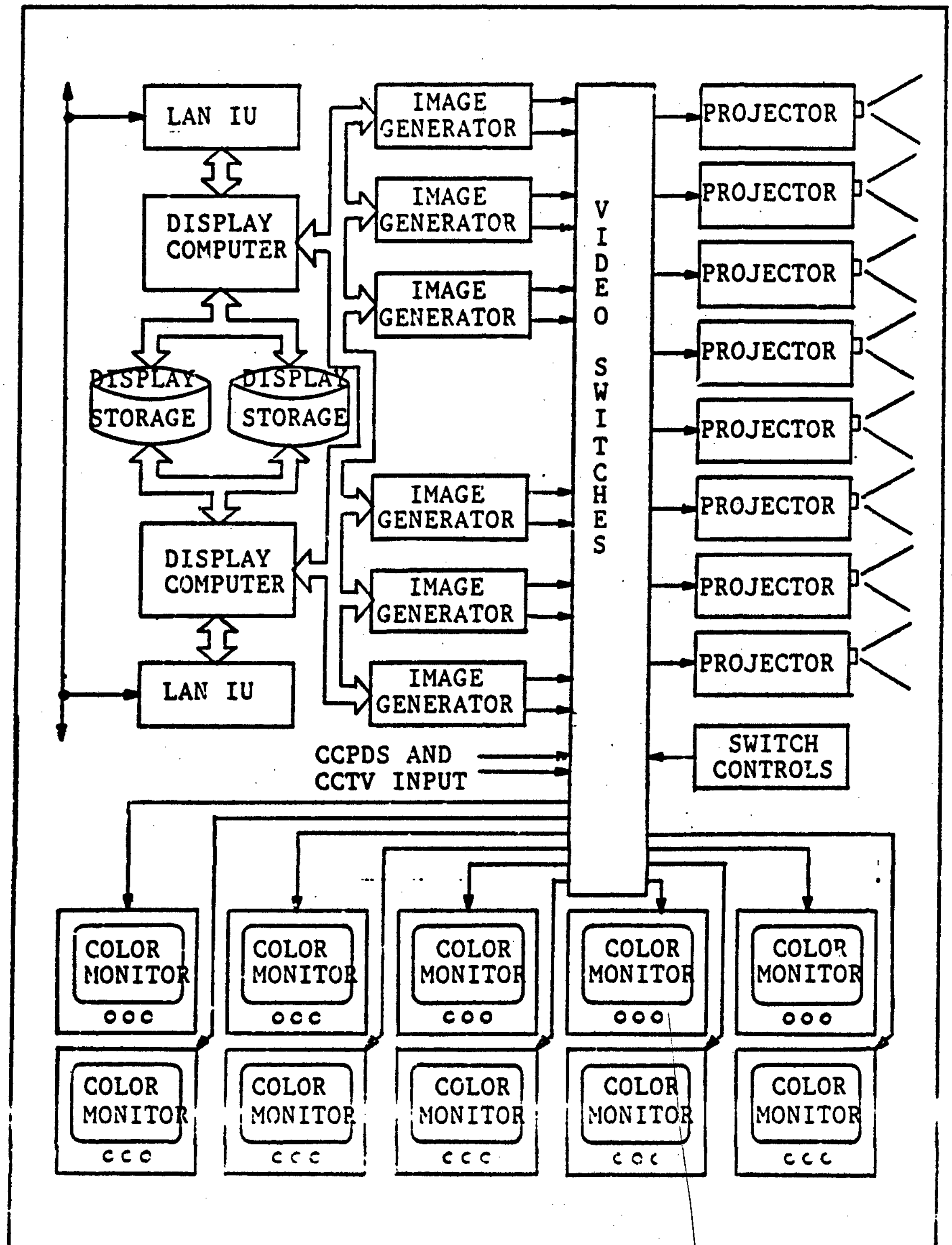

Figure 8. Improved Large Wall Screen Display System Block Diagram

Figure 9 contains a block diagram of the display computer and storage device. Data from the host computer and requests for displays from the Display Controller will be received by the interface board and sent to the memory board for temporary storage. The CPU board, then, decodes the data to determine if it is a display for storage or a request for a display. If the data is a display for storage the CPU board sends the data to the 100 megabyte disk (the display storage device) to be stored for future use. If, however, the data is a request for a display the CPU gets the proper display from the disk and sends it to an image generator via the image genetator interface board. In this configuration two display computers and display storage devices will be used for greater system reliability.

The image generator will contain seven boards - one processor board, four refresh (display) memory boards, and two blink and output control boards (see Figure 10). The processor board will receive the display data directly from an image generator interface board in the display computer and store the data in an on-board memory. It will then process the data and store the resulting display in two of the four refresh memory boards. The display in the memory boards is an exact replica of the display to be provided to the display devices. After the display is built in the image generator refresh memory boards, the blink and output control board associated with the memory

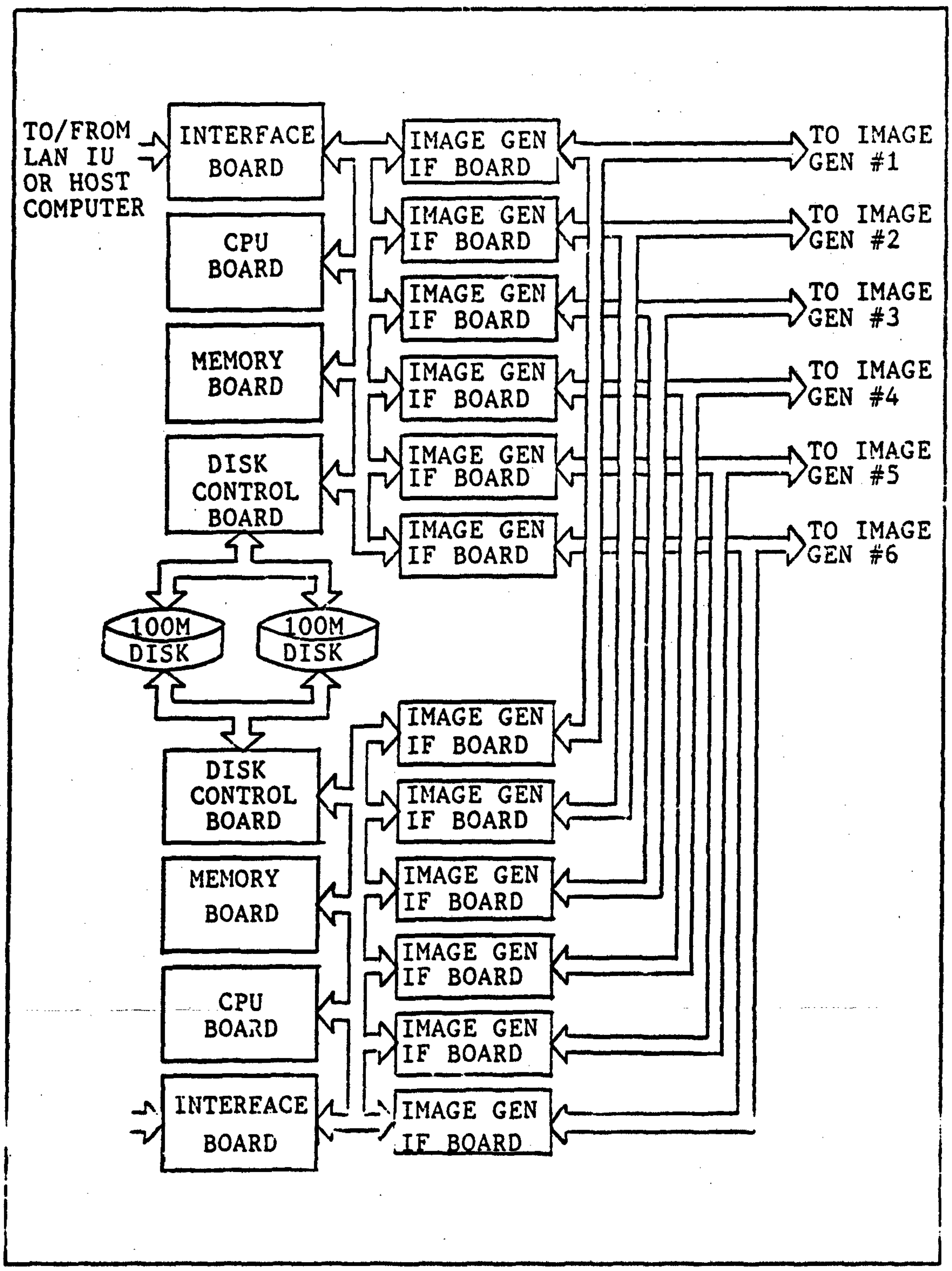

Figure 9. Display Computer and Display Storage Device Block Diagram.

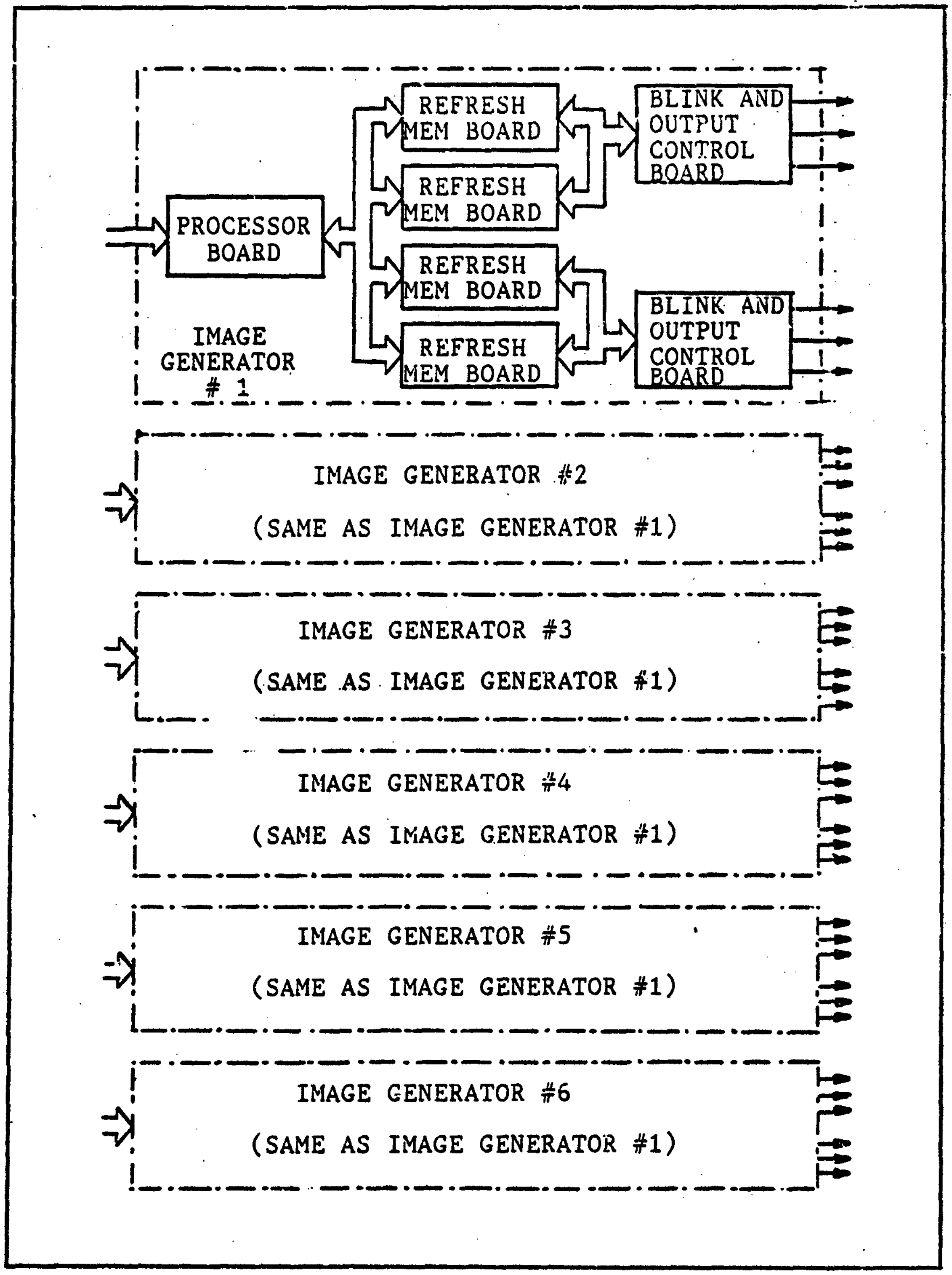

Figure 10. Image Generator Block Diagram

boards containing the display converts the stored image into video signals and sends the video signals to the video switches for distribution. In addition to converting the stored image into video signals, the blink and output control board also controls the blinking of selected portions of the display. The video signals sent to the video switch will be broken down into the three primary colors, red, green and blue, so that the display projected on the large screens and provided on the color monitors will be in full color.

Figure 11 provides a block diagram of the video switches. In this diagram, only one-third of the switches is shown, the other two-thirds being identical and each third carrying one of the primary color video signals. The proposed switch will be a 20 by 20 matrix, 12 of the input signals provided by the image generators and the other input signals provided by the CCTV system and the Command Center Processing and Display System (CCPDS). Each of the input signals will be applied to twenty 20 by 1 video switches. Each of the 20 by 1 video switches is independent from the other switches, and failure of one switch does not affect any of the other 20 by 1 video switches. Only the power supplies are common to all of the switches, and redundant power supplies are used to increase the system reliability. In the proposed configuration,any combination of input video signals will be capable of being routed to any output line. Furthermore, the controls for switching

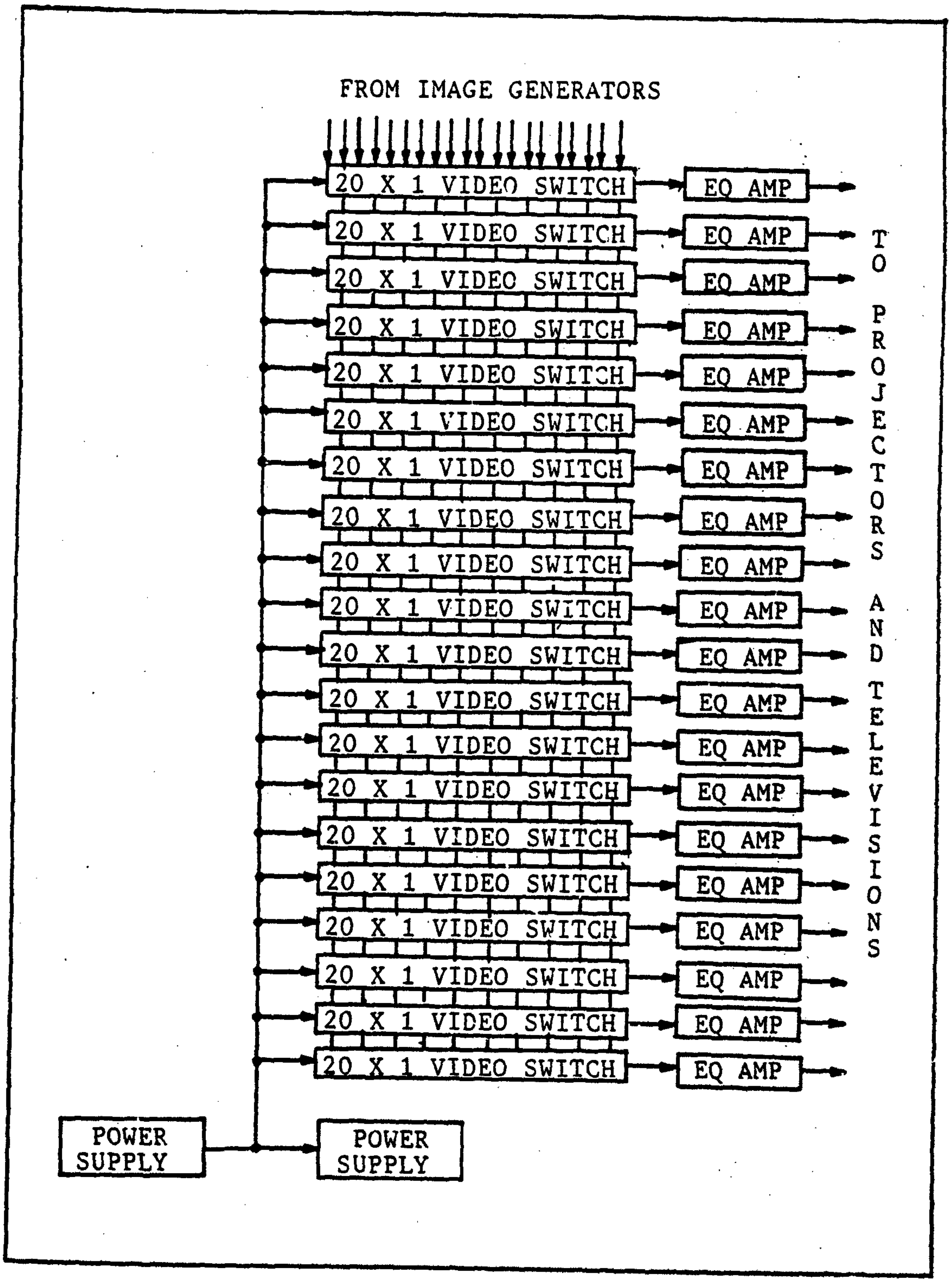

Figure 11. Video Switches Block Diagram

is independent for each switch. After the video signals are switched the output video signals will be sent to the appropriate large wall screen projector or color television monitor.

Closed Circuit Television System. The CCTV system consists of television cameras, microphones, television monitors, and a distribution network. Figure 12 illustrates the configuration proposed for a broadband (CATV) system. In this configuration 12 television cameras and microphones, one in each support center and four in the Command Post, feed video and audio signals into an RF modulator. The RF modulator then puts each channel of information on a separate carrier frequency and sends all channels of information to the CCTV monitors on one cable. Each television monitor, then, selects the desired channel and demodulates the signal for display.

Local Area Network and Command Post ADP. The local area network (LAN) will consist of a coaxial cable connecting interface units. Four types of interface units will be used with the Command Post LAN, host computer unterface units (IU), work station IUs, common user IUs, and gateways to other local area networks. The host computer IUs will interface the WWMCCS computer and possibly the SACDIN and CCPDS computers with the LAN; work station interface units (WSIUs) will interface all of the ADP with the LAN; and common user or computer IUs will interface the display computers and

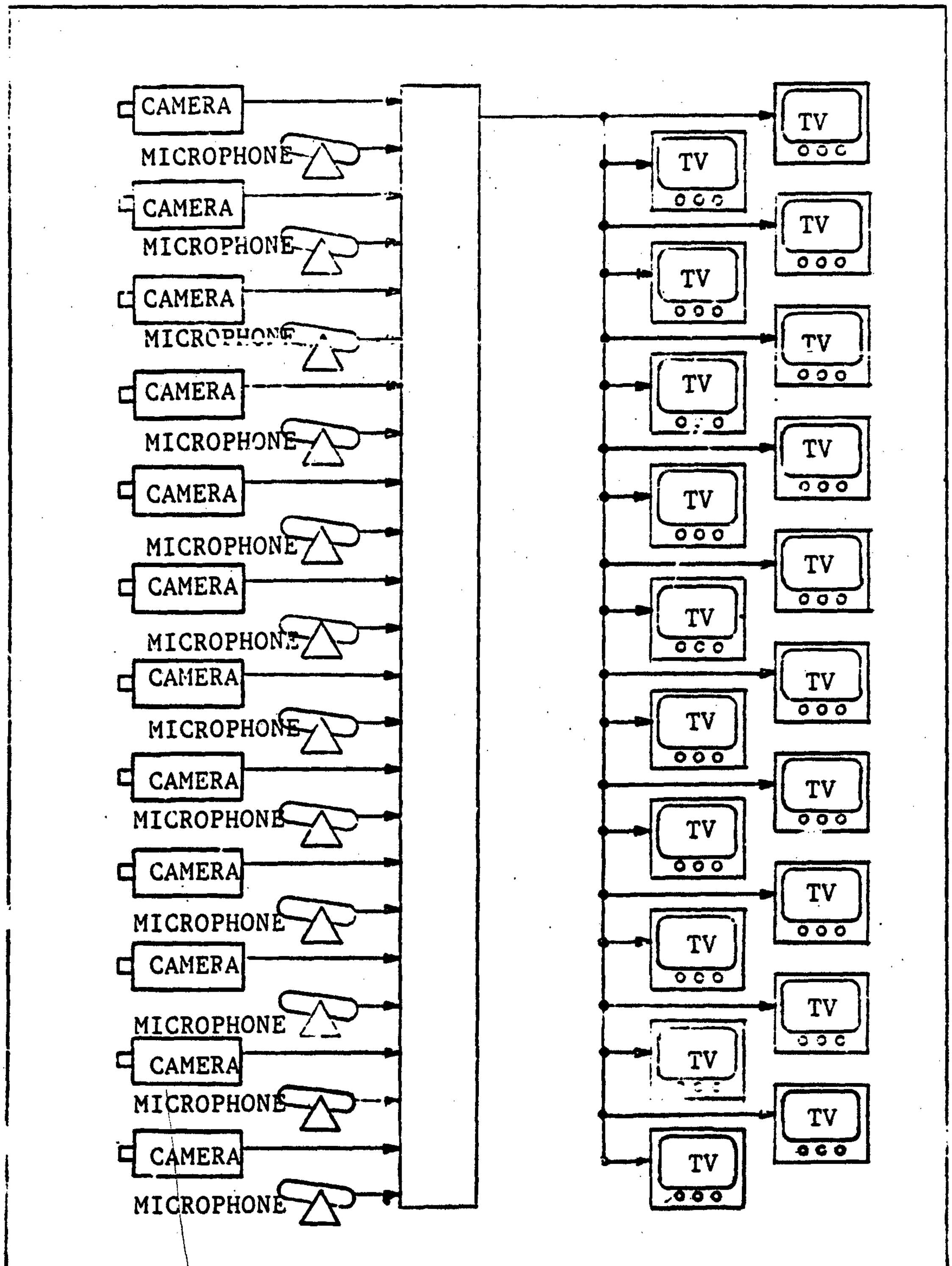

Figure 12. CCTV Block Diagram

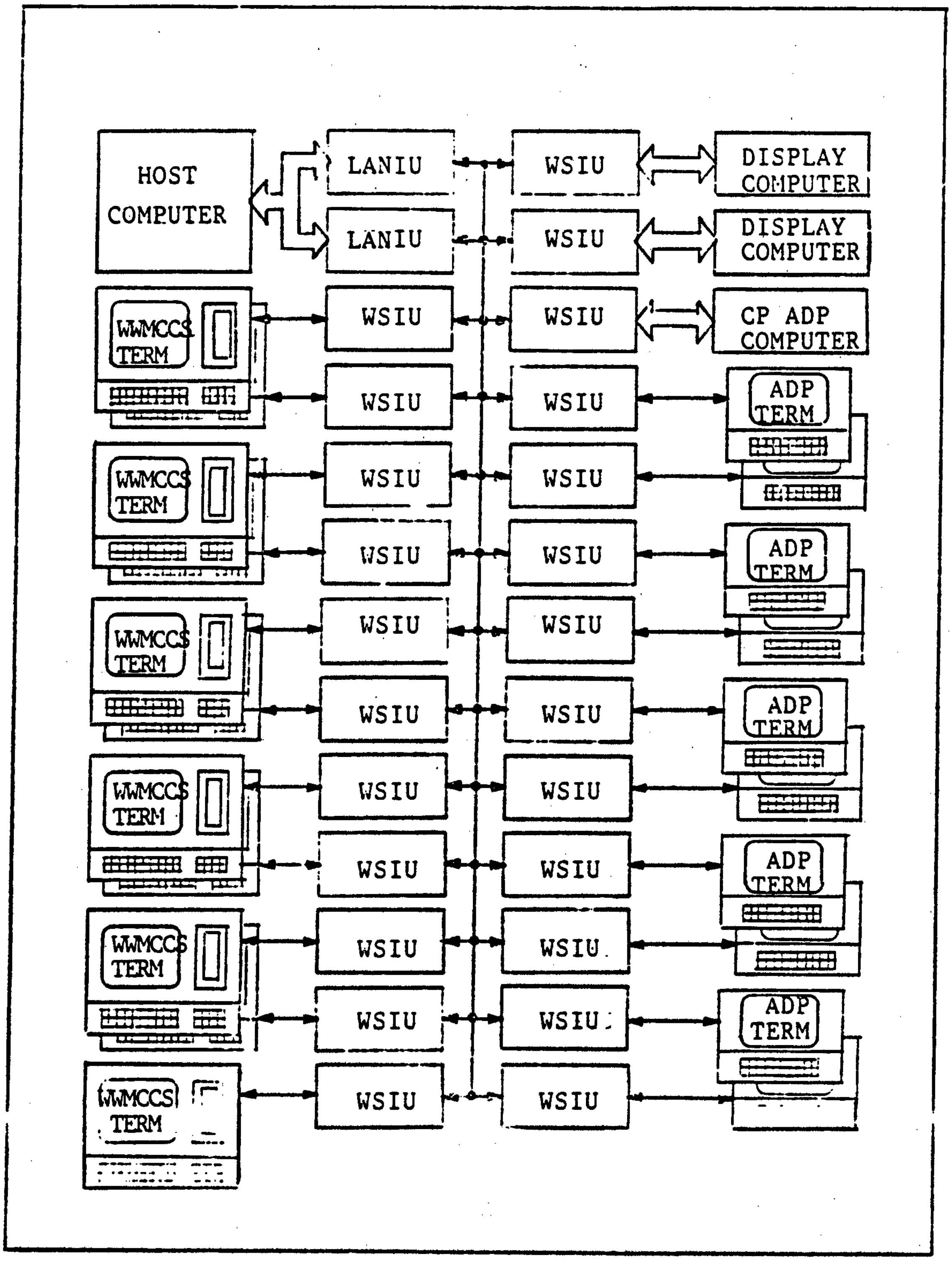

Figure 13. LAN Block Diagram

the Command Post mini-computers with the LAN. Figure 13 illustrates the proposed configuration of the LAN and the Command Post ADP for the SAC Command Post upgrade.

In this figure it can be seen that the LAN will connect the host computer, display computers, Command Post mini-computer, graphics terminals and alphanumeric terminals to the LAN. In this configuration the graphics terminals are the WWMCCS terminals currently being used in the Command Post and the Support Centers. The alphanumeric terminals, on the other hand, represent new equipment and will include hard copy units.

The above sections have described the cones of resolution technique used to narrow the problem into a manageable size, and have explained the factors affecting the availability, function and configuration of the Command Post equipment. The following chapter will use the information discussed above in the formulation of a parametric model of the Command post equipment. The model, when computerized, will be helpful in determining the number of maintenance personnel required to maintain the equipment planned for the SAC Command Post upgrade.

III. ANALYSIS AND MEASUREMENT

The conceptualization phase of the system science paradigm, as it applies to the problem addressed in this thesis, was presented in Chapter II. In that chapter the cones of resolution technique, a causal-loop diagram, and several block diagrams were employed to illustrate the interactions between the SAC Command Post and its environment, as well as the interactions and relationships of the sectors of concern within the Command Post environment. The analysis and measurement phase presented in Chapter III builds on the conceptual model developed in Chapter II.

Parameterization of the conceptual model begins with an explaination of why Q-GERT was chosen to be the language that the model was written in, and continues by explaining how a system is modeled using Q-GERT. The following section explains how the operation and maintenance of the upgraded Command Post equipment was described using a schematic diagram. Next, the Q-GERT symbols used in this thesis are explained. Finally, the last section explains the Q-GERT network that forms the parametric model developed in this chapter.

Language

The Q-GERT language was chosen for this simulation because of its simplicity of use and its adaplability to modeling waiting line situations. Q-GERT is a language developed by A. Alan B. Pritsker as "... a network modeling vehicle and a computer analysis tool."(Ref 16:vii) GERT, an acronym for Graphic Evaluation and Review Technique, allows the analyst to model projects that can be analyzed using PERT and CPM techniques. In addition, the Q in Q-GERT indicates the capability of the language to model queueing systems (Ref 16:vii).

When modeling with Q-GERT, the analyst must clearly and unambiguously describe the system being modeled. One particularly helpful tool in describing a system is schematic or pictorial diagrams. With a schematic diagram the analyst usually represents transactions or entities within the system as symbols and represents activities associated with the transactions as arcs or lines connecting the symbols. Figure 14 is a schematic diagram of the system being modeled in this thesis.

Next, the analyst must draw a Q-GERT representation of the system being modeled. The Q-GERT diagram consists of nodes, which can represent starting points, queues, decision points, and so forth; and arcs, which represent activities. Figure 15 contains examples of the types of nodes and activities used in this thesis. For a complete list of Q-GERT nodes and activities see Pritsker (Ref 16).

After representing the system in a Q-GERT diagram, the analyst must convert the diagram into Q-GERT and FORTRAN code. Conversion of the diagram into computer code is part of the computerization phase of the system science paradigm and thus will be discussed in Chapter IV. The following sections are devoted to describing, in detail, the schematic diagram and the Q-GERT diagrams of the system being modeled for this thesis.

Schematic Diagrams

As stated earlier, Figure 14 is a schematic diagram of the maintenance of the equipment planned for the SAC Command Post upgrade. The clear circles at the left of the figure represent the equipment as they operate satisfactorily. Equipment failure, represented by the arcs labeled "failure", occurs when an equipment no longer operates satisfactorily. When an equipment failure occurs, the equipment operator calls Job Control who in turn notifies the responsible shift supervisor. The shift supervisor, then, assigns technicians to repair the broken equipment (represented by the squares) or places the equipment in a queue called awaiting maintenance (AWM) (represented by the circled Xs) based on the following conditions:

1. If the required number of qualified technicians are idle, the technicians will be assigned the repair task.
2. If the required number of qualified technicians are busy repairing spare line replaceable units (LRUs), repair of the spare LRUs will be interrupted and the technicians assigned to repair the broken equipment.

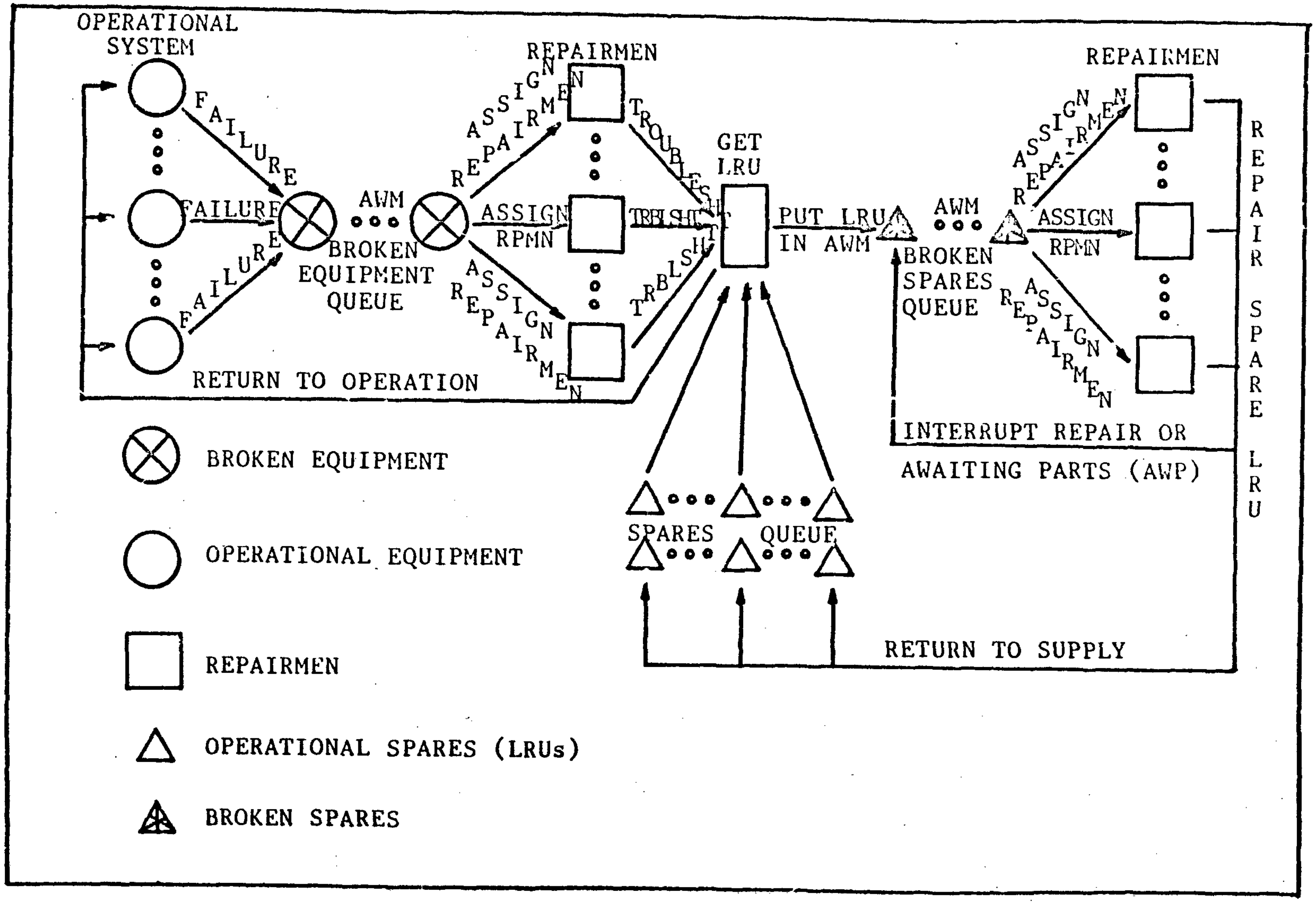

Figure 14. Schematic Diagram of the Operation, Failure, and Repair of Equipment Planned for the SAC Command Post Upgrade.

3. If all qualified technicians are busy repairing broken equipment, the new failure will be placed in AWM status (the broken equipment queue) until qualified technicians become available. If more than one equipment piece is AWM, available technicians will be assigned based on a predetermined priority scheme.

When maintenance technicians are assigned to a job, they troubleshoot the equipment to determine which LRU caused the equipment failure. After determining which LRU is defective, the technicians get a spare LRU from supply and replace the defective unit. The equipment is then returned to operation and the broken LRU is placed in AWM status until a technician is available to work on it. If, however, there is no spare LRU in supply, for example,if the spare LRU is also broken, the technician will remove the defective LRU from the equipment, repair it in the shop, and replace it in the equipment.

Once a defective LRU is placed in AWM status,it remains in the broken spares queue until a qualified technician is idle and no equipment is in the broken queue. At that time a technician is assigned to repair a broken LRU. The priority for assigning repairmen to broken LRUs is also based on a predetermined priority scheme.

After a maintenance technician is assigned to repair a broken LRU three things can happen: the LRU can be repaired, parts can be ordered to repair the LRU, or repair can be interrupted. If the LRU is repaired, it is placed in supply and the technicians are freed to work on other defective LRUs. However, if spare parts to repair the LRU are not on hand, the LRU is placed in awaiting parts (AWP) status and the parts are ordered. After the spare parts arrive the LRU is placed in AWM status until a technician is available to repair it. Finally, if an equipment fails, repair of the LRU is interrupted, the LRU is returned to AWM status, and the technicians are assigned to repair the broken equipment.

The above paragraphs describe the typical operation, failure, and repair of electronic equipment. However, the description itself raises a number of questions that must be addressed before the system can be modeled. The particular questions raised in the above paragraphs are as follows:

1. What criteria is used to determine if a repairman is qualified to repair a particular equipment?
2. How is repair time affected if an unqualified technician assists a qualified technician on a repair action?
3. How many technicians are required to repair a particular equipment and why is that number required?
4. What mix of qualified and unqualified technicians will be used on a particular repair action and why is that mix used?

5. What is the MTBF for each equipment, what is the reliability distribution for each equipment, and how were the MTBF and reliability distribution determined?
6. What is the MTTR for each equipment and LRU, what probability distribution does the repair time follow, and how were these MTTRs and probability distribution determined?
7. What is the priority scheme for repairing equipment and LRUs in AWM status and how was it determined?
8. What is the probability that the parts are not available to repair an LRU and how long does it take to get the required part once ordered?
9. What happens when there is no spare LRU and the parts needed to repair an equipment failure are not on hand?

The following paragraphs address these issues.

In the model developed for this thesis, all maintenance personnel are considered to be either 3-level or 5-level technicians. A 3-level technician is an apprentice and thus requires supervision on all maintenance activities. The 5-level technician, on the other hand, is fully qualified to repair all equipment assinged to his shop. Since 3-level technicians must be supervised, they are usually assigned to assist 5-level technicians in repair activities.

While helping the 5-level repairmen,the 3-levels recieve training to help them become fully qualified 5-level technicians.

According to SMSGT Nokes, Superintendent of DTVE Maintenance at SAC Headquarters, when a 3-level assists a 5-level technician repair times increase by a factor of one and a half to two. This increase in repair time is primarily due to the training being provided during the repair activity. Sgt. Nokes also points out that if an equipment failure results in a system failure the training is eliminated and the equipment is restored to operation as quickly as possible.(Ref 14)

The number of technicians assigned to a particular maintenance activity depends on three factors: the physical size and weight of the LRUs, safety requirements, and security requirements. With the proposed equipment configuration,two technicians are required to remove and replace disk drives, television monitors, and ILWSD projectors; all other LRUs are small enough and light enough to be lifted by one technician. Safety regulations require two technicians to work on equipment when exposed to voltages hazardous to human life. Two LRUs fall into this category, television monitors and ILWSD projectors. Finally, SAC requires that two qualified persons be present when maintenance is performed on certain sensitive equipment. Currently, none of the equipment modeled for this thesis falls into the sensitive category. However, since some of the equipment, for example the ADP terminals, could be recategorized, this model is capable of incorporating a simple change to reflect the new requirement. Therefore, the model developed for this thesis assumes two technicians are required to repair disk drives, television monitors and ILWSD projectors, while all other equipment requires only one technician.

Current manning documents authorize approximately one third of the computer maintenance technicians to be 3-levels. However,actual assignment data indicates that the current and projected level is closer to one half. Therefore, the model developed for this thesis assumes that between one third and one half of each maintenance crew will be 3-level technicians. Furthermore, if two technicians are assigned to a repair action one of the repairmen is assumed to be a 5-level and the other a 3-level.

As prescribed in MIL-HDBK-217D,this thesis models the reliability of the electronic equipment using the exponential distribution. The MTBF for each equipment was computed using predicted values obtained from the minutes of a critical design design review, vendor advertisements,peroidical articles, and conversations with MITRE Corporation (Washington D.C.) personnel. The MTBFs used in this thesis are contained in Table 1 and a detailed description of how these MTBFs were derived is contained in Chapter V.

TABLE I

MTBF Estimates for the Upgraded SAC Command Post

Equipment	MTBF (hours of operation)
ADP Work Station	3,300
Display Computer	2,400
Command Post Computer	2,800
Disk Drive	10,000
Video Switch Power Supply	40,000
Image Generator	3,000
Television Monitor String	6,350
ILWSD Projector String	4,700
Television Camera	40,000
Microphone	40,000
RF Modulator	20,000
Television Monitor	10,000
Category I Console String	25,000
Category II Console String	20,000
Category III Console String	15,000

Kapur and Lamberson, as well as others, suggest that repair times frequently follow the Lognormal distribution. Since actual repair time data is not available, and will not be available for several years, the model in this thesis assumes lognormally distributed repair times. In addition, the model assumes that the MTTR for all equipment is .5 hours and the MTTR all LRUs is 8 hours. Justification for using these MTTRs is provided in Chapter V.

Usually the operations and maintence organizations determine a priority for repair of equipment failures. This priority is usually based on the impact of an equipment failure on the system availability. Similarly,maintence organizations frequently determine the priority of LRU repair based on the impact of not having a spare LRU or on the expected time to repair an LRU. However, since it is early in the acquisition of the upgraded Command Post equipment repair priorities have not been established. Furthermore, Elsayed has shown that repair priorities based on shorter repair times are not as good repair priorities based on the first-in-first-out (FIFO) method when cost is used as the criteria (Ref 3). Thus the model developed for this thesis uses a FIFO priority scheme for all repair queues.

When an LRU is repaired,there is a possibility that the parts required to complete the repair are not on hand. When this occurs,the maintenance personnel order the parts and place the broken unit in AWP status. Since the bit part sparing level has not been determined, it is not possible to determine the percentage of LRUs that must be placed in AWP status. The model developed for this thesis, therefore, assumes that 90 percent of the time the spare parts will be on hand.

As with the case of LRUs, parts may not be on hand to repair broken equipment. When this occurs parts are ordered with a high priority. If the required parts are at the base supply warehouse, they will be delivered in a relatively short time, otherwise the parts will be back-ordered. The model used for this thesis assumes that the required parts are always on hand at base supply.

Q-GERT Symbols

Before the system described above can be represented by a Q-GERT network, it is necessary to understand the systems and terminology used in Q-GERT. Q-GERT diagrams are networks that consist of activities, servers, and queues. As stated earlier, Figure 15 contains the symbols for the nodes and activities used in the model prepared for this thesis.

The first node in Figure 15 is a regular node. Regular nodes do not have a special function other than to receive and route transactions. Receipt of a transaction is called an arrival, and routing of a transaction is called a release. In Figure 15, the symbol for a regular node contains the characters F,S, and #. F stands for the

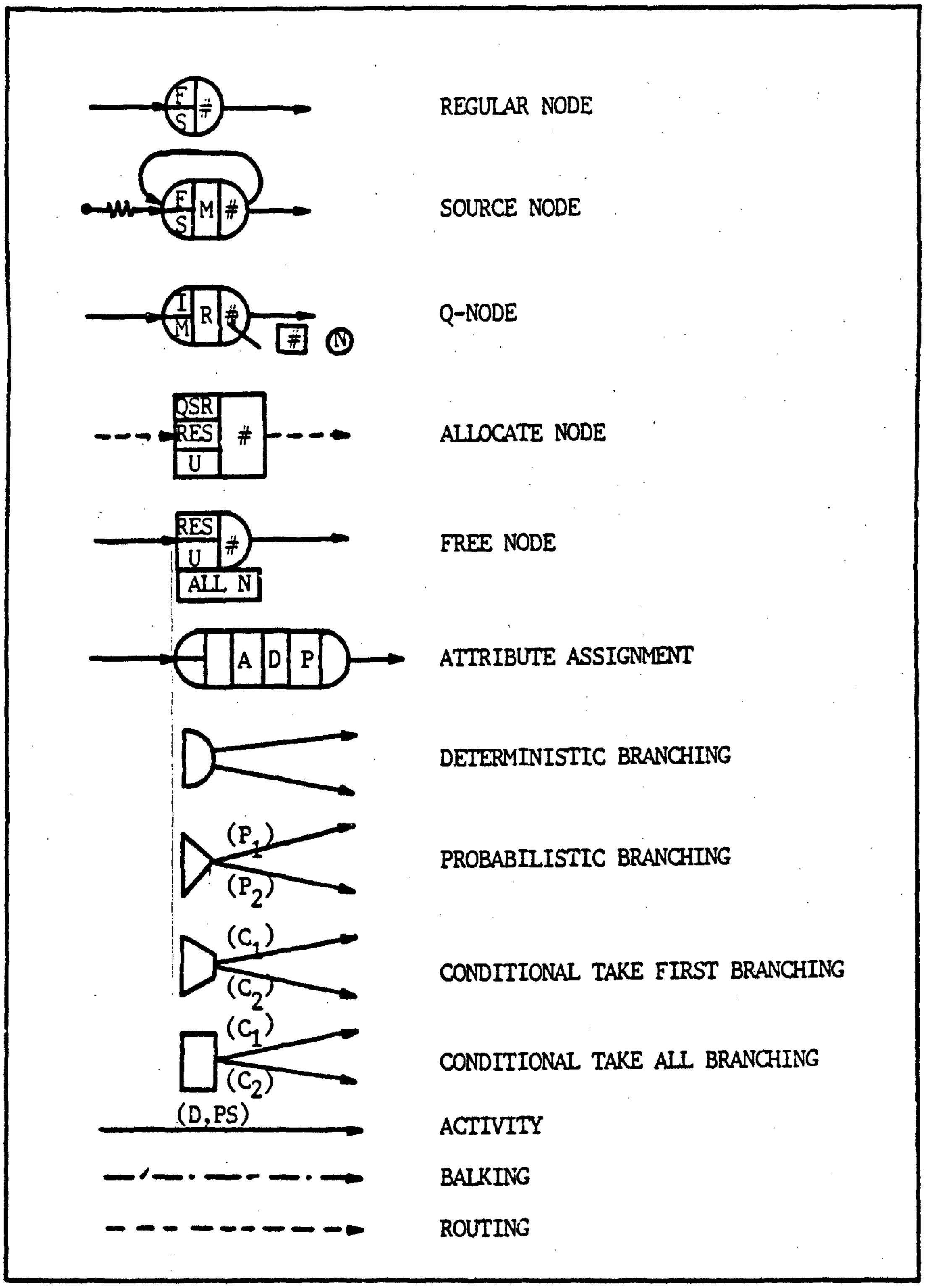

Figure 15. Nodes and Activities used in Q-GERT.

number of arrivals required to release the node for the first time; S stands for the number of arrivals required to release the node for all subsequent times; and # represents the node number.

The second node represented in Figure 15 is the source node. The distinguishing difference between the regular node and the source node is the pointer ( ), which symbolizes that source nodes can generate as well as receive and route transactions. As with regular nodes, F represents the number of arrivals required for the first release, S represents the number of arrivals required for all subsequent releases, and # represents the node number. The M in the source node symbolizes that source nodes mark each transaction with its time of generation (mark time). Regular nodes can also mark time if desired. Once a transaction is marked, the mark time remains with the transaction until another node marks it or until the transaction departs the system.

The third node is a Q-node. The Q-node can be distinguished from all other nodes by the hash mark (\) on the right side of the node, which makes the node look somewhat like the letter Q. Q-nodes are nodes at which transactions wait for service activities. As long as at lease one server is idle, each transaction arriving at the Q-node passes through the node and is routed through a service activity. When all servers associated with the service activity eminating from the Q-node are busy, the arriving transactions are placed in a queue where they wait for a server to become idle. Transactions are ranked in the queue based on a predetermined ordering scheme. In the model developed for this thesis all queues use a first-in-first-out (FIFO) ranking scheme. The Q-node in Figure 15 contains the characters: I, which represents the initial number of transactions in the queue; M, which represents the maximum number of transactions allowed in the queue; R, which represents the ranking procedure for ordering the transactions in the queue; and #, which represents the node number. The symbols $\boxed{\#}$ and (N) are, respectively, the activity number and the number of parallel servers associated with a service.

The fourth node in Figure 15 is an allocate node. Allocate nodes must be preceeded by a Q-node. The allocate node is used to allocate resources to a transaction. As long as resources are available, the allocate node will take the next transaction in the preceeding Q-node, assign a resource to the transaction, and place the transaction in the following node. When resources are not available, however, the allocate node blocks the output of the preceeding Q-node and transactions are queued until another resource becomes available. On the symbol for the allocate node, QSR stands for the Q-node selection rule (used only if more than one Q-node preceeds the allocate node); RES stands for the resource number; U represents the number of resources to be allocated to each transaction; and # represents the node number. Allocate nodes are connected to the preceeding and following nodes with dashed lines (---▶) which signify the allocation of resources and routing of transactions without an associated activity.

The fifth symbol in Figure 15 represents a free node. Free nodes are used to release resources when they are no longer needed. The characters RES, U, #, and ALLN, respectively, stand for the resource number, the number of resources freed, the node number, and the allocate nodes associated with the freed resources.

The next symbol in Figure 15 represents attribute assignment. Attributes are characteristics associated with transactions, and the values assigned to attributes give a transaction an identily. According to Pritsker attributes are used for the following three reasons: (Ref 16)

1. The specification of the time required for an activity to process the transaction;
2. The ranking of transactions in queues; and
3. The routing of transactions (branching).

Attributes can be assigned to transactions by regular nodes, source nodes, and Q-nodes. In the symbol illustrating attribute assignment, A represents the attribute number (up to eight attributes can be assigned to each transaction); D represents the probability distribution from which the value of the attribute is derived; and P represents the parameter specification for the probability distribution.

The next four symbols in Figure 15 illustrate the four types of branching used in Q-GERT. The first branching type, deterministic, routes a transaction along all activities eminating from the node; a maximum of 50 activities can eminate from each node. The second type of branching illustrated is probabilistic branching. With probabilistic branching, only one activity is selected each time the node releases; P_1 and P_2 represent the probabilities that the associated activity will be selected. With conditional take first branching, the third type of branching, Q-GERT sequentially tests conditions for selecting an activity and routes the transaction on the first activity to satisfy the condition. Conditional take all branching, on the other hand, routes a transaction on all activities that meet the condition. C_1 and C_2 represent the conditions that must be met to route a transaction on the activities.

The last three symbols in Figure 15 are arcs. The first arc (the solid line) represents an activity. Each activity can have an associated probability distribution (D) and parameter statement (PS). The probability distributions used used in this theses are exponential, lognormal, and uniform; the parameter statements are defined in Chapter IV. Also associated with activities are probabilities (P_1), conditions (C_1), activity numbers ($\boxed{\#}$), and number of servers (N) (used only with service activities).

The broken line (-·-·-▶) represents balking. Balking occurs when a transaction arrives at a Q-node that already contains the maximum allowable number of transactions. If balking is not specified the transaction is lost to the system. However, if balking is specified the transaction is routed to another node as indicated by the broken line. Balking is not an activity, and as such time cannot be associated with balking.

Finally, the dashed line (----▶) in Figure 15 represents routing associated with an allocate node. As stated earlier, the dashed lines are not activities and cannot have times associated with them. The dashed lines are used by Q-GERT to indicate that the allocate node allocates a resource to the transaction as the transaction is routed from the preceeding Q-node to the following node.

Q-GERT Network

In the Air Force, technicians are assigned to repair electronic equipment based on their Air Force Specialty (AFS). Three AFSs are required to maintain the types of equipment modeled in this thesis: telephone maintenence technicians, television maintenance technicians, and computer maintenance technicians. Telephone maintenance technicians repair the type of equipment planned for the upgraded voice communications system; television maintenence technicians maintain the type of equipment planned for the CCTV system; and computer maintenance technicians maintain the type of equipment planned for the ADP, LAN, and ILWSD systems. To simplify modeling and programming, the maintenance of the equipment planned for the SAC Command Post upgrade was modeled using three nearly identical models, based on the AFSs of the technicians who maintain the equipment. This section describes the Q-GERT network used to model the maintenance of the ADP,LAN,and ILWSD systems by computer maintenance technicians.

Figure 16 (Sheets 1-4) contains a diagram of the Q-GERT network used to model the maintenance of the ADP, LAN, and ILWSD systems. On sheet 1, source node 1 generates 44 entities which represent the equipment maintained by the computer maintenance technicians. Entities 1 through 10 represent ADP work stations, 11 and 12 represent display generator computers, 13 represents a Command Post computer, 14 through 16 represent disk drives, 17 and 18 represent video switch power supplies, 19 through 24 represent image generators, 25 through 36 represent television monitor strings, and 37 through 44 represent ILWSD projector strings. The first 43 entities released by node 1 are routed back to node 1 to generate the next entity. All entities released by node 1 are routed to node 2.

Node 2 is a Q- node with capacity 0. Therefore each entity arriving at node 2 is placed directly into service with one of the 44 servers associated with the activity eminating from node 2. While the entities pass through it, Q-node 2 assigns values to attributes 2 through 8.

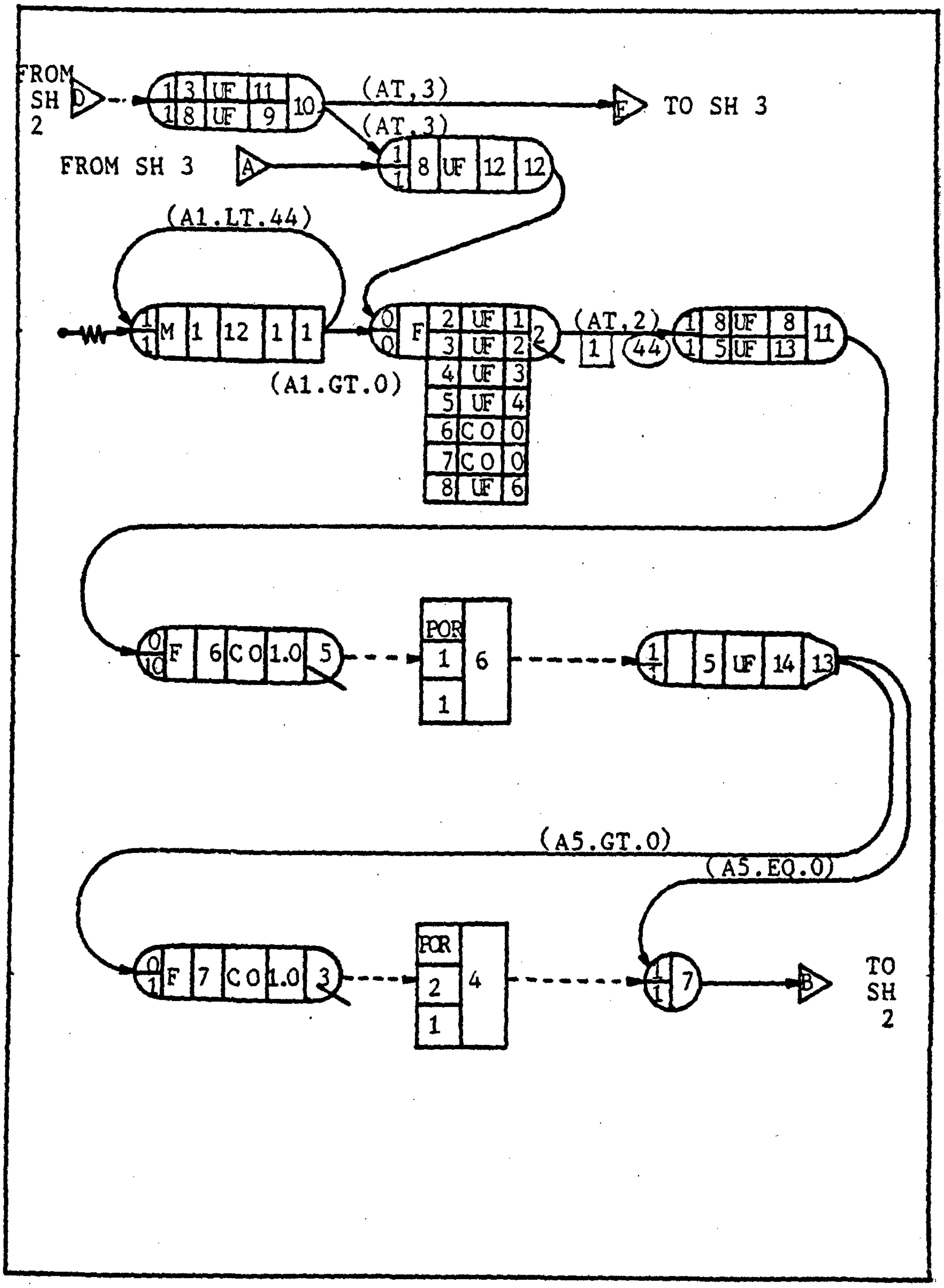

Figure 16 (Sheet 1). Q-GERT Diagram of Maintenance on the Upgraded SAC Command Post.

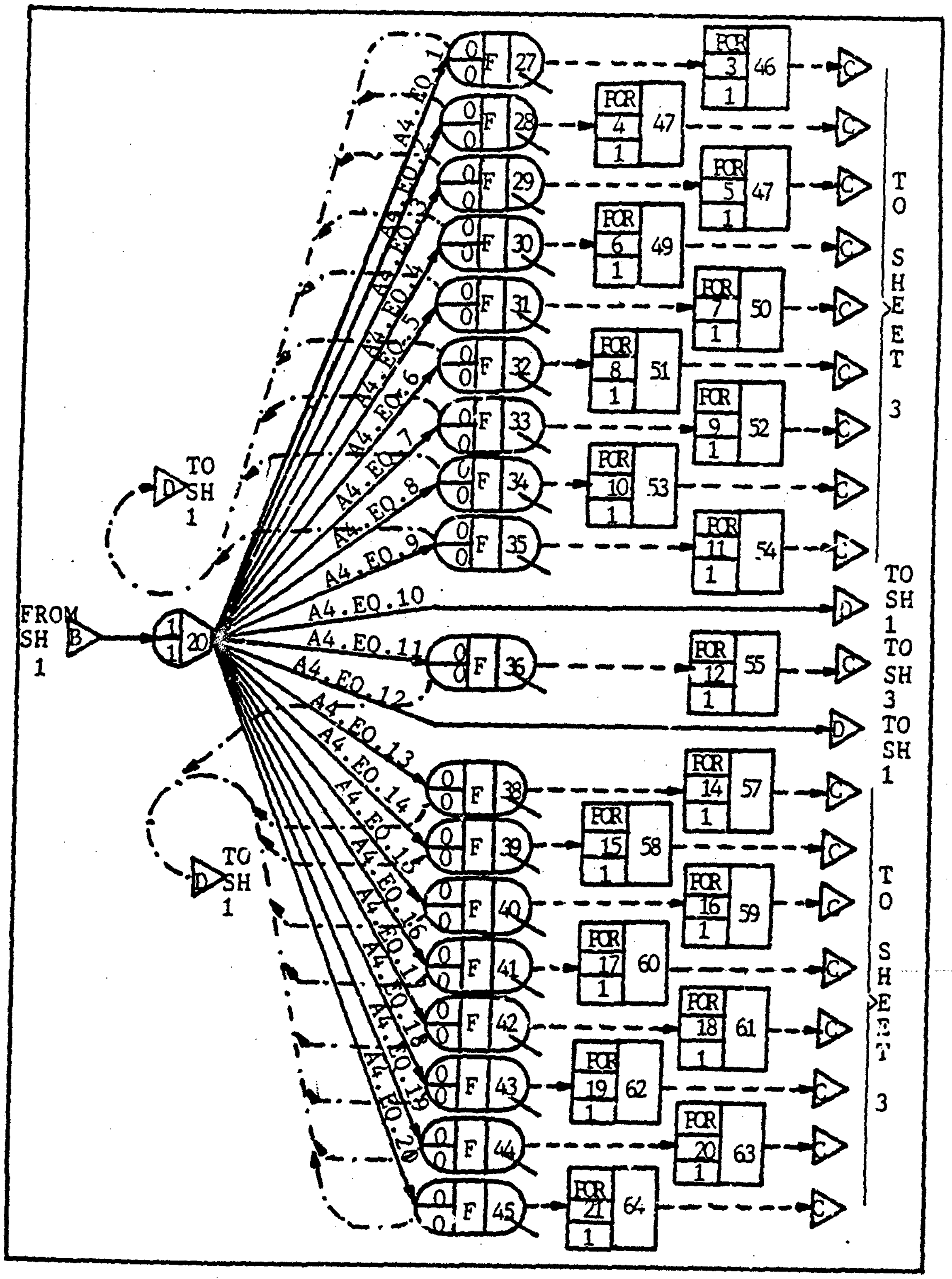

Figure 16 (Sheet 2). Q-GERT Diagram (Continued).

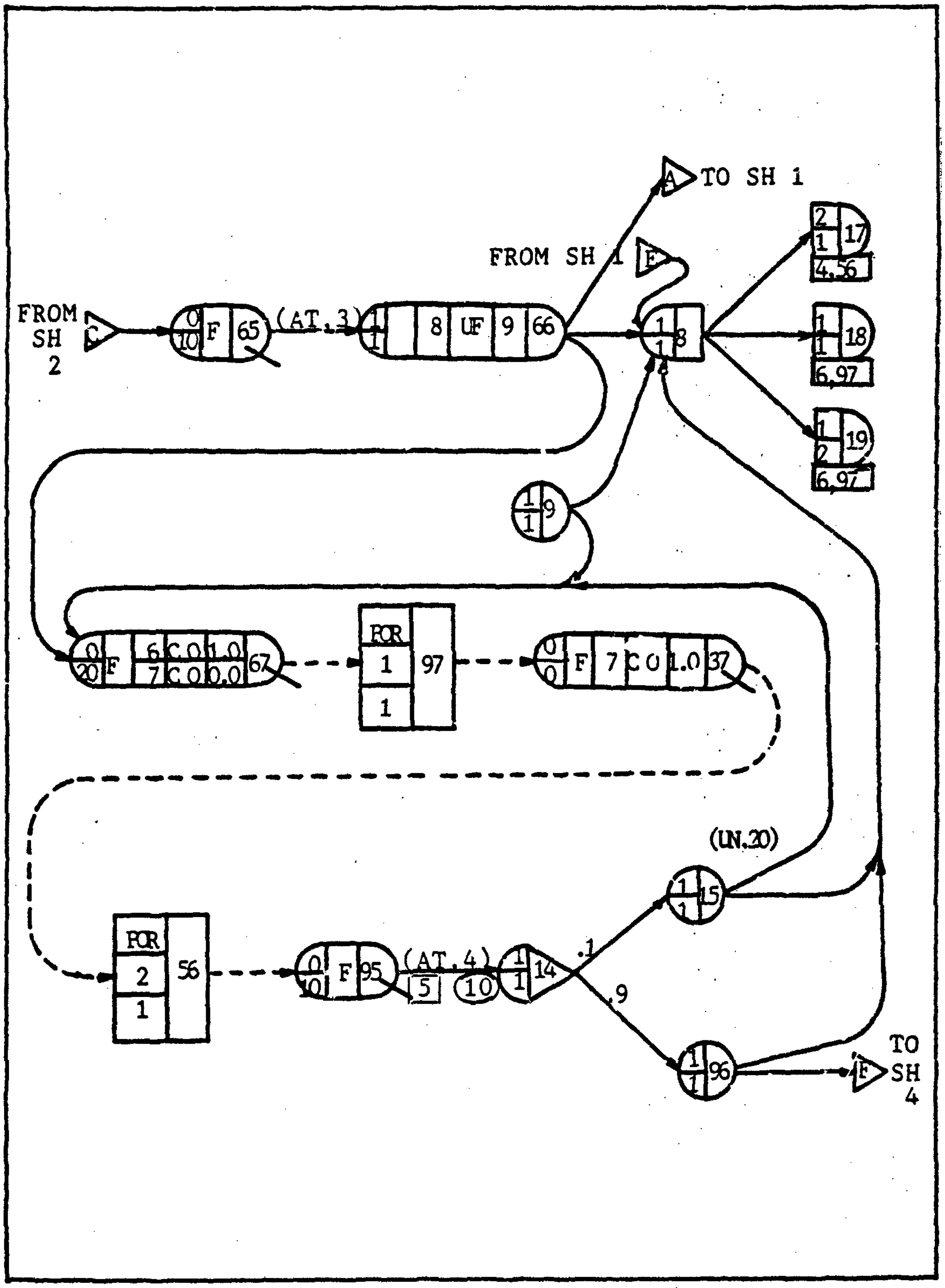

Figure 16 (Sheet 3). Q-GERT Diagram (Continued).

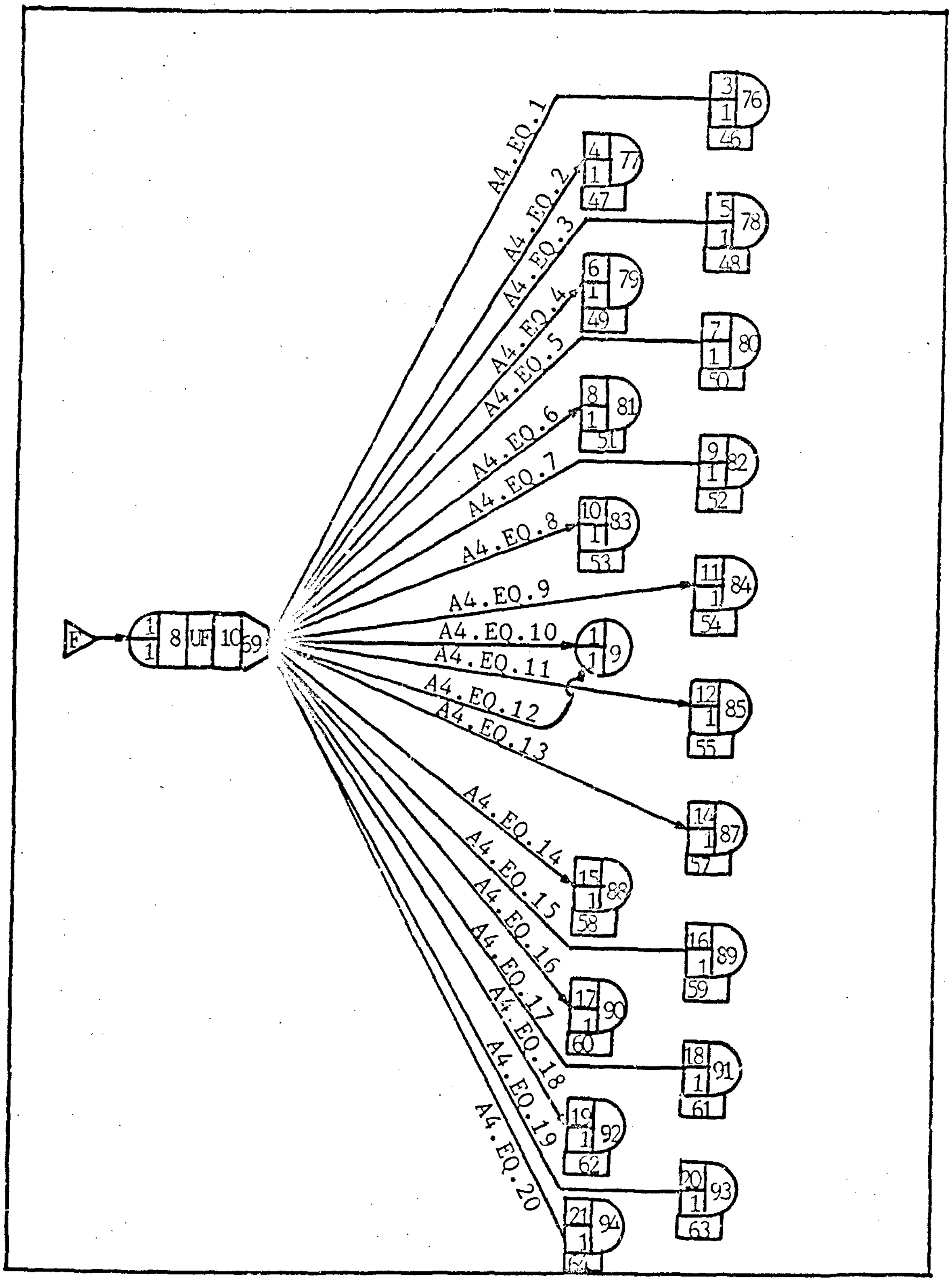

Figure 16 (Sheet 4). Q-GERT Diagram (Continued).

Attribute 2 of each entity is the MTBF for the equipment it represents; attribute 3 is the MTTR the equipment by removing and replacing the defictive LRU, including the administrative time; attribute 4 is the MTTR the defective LRU; attribute 5 is the number of technicians required to repair the equipment; attributes 6 and 7 are the number of 5- and 3-level technicians, respectively, assigned to the repair; and attribute 8 records the time that the equipment is placed into operation. The values assigned to attributes 2, 3,4,5,and8 are determined by user functions (UFs) 1,2,3,4, and 6, respectively (User functions are user written FORTRAN functions used to perform tasks not easily performed by Q-GERT). Activity 1, which eminates from Q-node 2, has 44 servers which represent the equipment operating satisfactorily, and the time of each service activity is determined by the value assigned to attribute 2, the MTBF.

The arrival of an entity at node 11 represents an equipment failure. Upon the arrival of an entity, node 11 records the time, simulating the notification of Job Control and the maintenance shift supervisor of an equipment failure. After recording the equipment failure time node 11 determines if enough qualified technicians are available to repair the equipment. If enough qualified technicians are not available, user function 13 will interrupt the repair of a spare LRU, if an LRU is being repaired, to free the technicians. User function 13 will not, however, interrupt the repair of equipment failure. Regardless of whether the technicians are busy or available, node 11 routes the entity to Q-node 5.

Node 5 is the broken equipment queue. Entities arriving at node 5 represent broken equipment waiting for technicians to be allocated to the repair. If at lease one unit of resource 1 is available node 6 allocates one unit to the entity, simulating the assignment of one 5-level technician to the repair task, and routes the entity to node 13. As the entity is routed to node 13 the value of attribute 6 is set to 1 to indicate that one 5-level technician is allocated to the repair of this equipment.

User function 14, called by node 13, checks to see if a 3-level technician should be assigned to the repair task. If a 3-level technician is idle or if the task requires two technicians the entity is routed to node 3, otherwise the entity is routed to node 7. If the entity is routed to node 3, the value of attribute 7 is set to 1 and node 4 allocates one unit of resource 2 to the transaction, simulating the assignment of a 3-level technician to the repair activity. Node 4 also routes the entity from node 3 to node 7.

When an entity arrives at node 7, either from node 13 or node 3, through node 4, node 7 releases routing the entity to node 20, on sheet 2. Node 20 uses conditional take first branching to identify the which LRU caused the equipment failure, simulating the troubleshooting of the equipment. Two of the equipment failures are not caused by LRU failures, computer chassis failure, and video switch power supply failure. When these failures occur node 20 routes the entity to node 10, on page 1, which simulates the repair of an equipment without the replacement of an LRU. On the other hand, if the equipment failure is caused by an LRU failure, node 20 routes the entity on the activity associated with the LRU. Arrival of the entity at one of the Q-nodes, nodes 27 through 45, represents the technician going to supply to get a spare LRU. If a resource is available the associated allocate node (nodes 46 through 64) one unit of the resource is allocated and the entity is sent to node 65, simulating the retrieval of of one spare LRU from supply. However, if there are no free units of the required resource, simulating that no spare LRU is at supply, the entity balks to node 10 on page one where repair of the equipment withour replacement is simulated.

When an entity arrives at node 10, either from node 20 or by balking from one of the Q-nodes, user function 11 computes the time to repair the equipment and user function 9 records the time that the repair starts. Node 10 also routes the entity to nodes 8 and 12 with the duration of the activity determined by the value of attribute 3, simulating the time required to repair the equipment. The arrival of an entity at node 12 causes user function 12 to record the time that the equipment was repaired and results in node 12 routing the entity to node 2, which simulates the equipment returning to service. When the entity arrives at node 8 it is routed by conditional take all branching to nodes 17, 18, and 19 to free the appropriate number of resources 1 and 2, the technicians.

If, however, the equipment is repaired by removing and replacing the defective LRU, the entity is routed to node 65 instead of node 10. Node 65 routes the entity to node 66 with a service time of the value associated with attribute 3. The activity routing the entity from node 65 to node 66 represents the time required to remove and replace the defective LRU. Arrival of the entity at node 66 simulates completion of the equipment repair.

When the entity arrives at node 66 user function 9 records the time that the LRU was removed from the equipment and node 66 routes the entity along three activities. The first activity goes to node 12 which records the time that the equipment was repaired and returns the equipment to operation. The second activity goes to node 8 which, as described previously, frees the appropriate number of resources 1 and 2. The third activity goes to node 67 which represents placing the defective LRU in the broken spares queue.

Two things can happen when an entity arrives at node 67. If a unit of resource 1 is available it will be allocated and the entity routed to node 37, simulating the allocation of a 5-level technician to repair an LRU. However, if no units are available the entity is placed in the queue until a unit of resource 1 is freed, simulating the placement of the LRU in AWM ststus. If a unit of resource 2 is available when the entity is routed to node 37, node 56 will allocate one unit of resource 2 and route the entity to node 95; otherwise the entity will balk to node 95. In either case when the entity arrives at node 95 it is routed to node 14 with a service time determined by attribute 4, simulating the repair of an LRU.

As stated earlier in this chapter, three things can happen during the repair of an LRU:

1. The LRU is repaired,
2. Parts are not on hand and the LRU must be placed in AWP status, or
3. Repair is interrupted to service an equipment failure.

Completion of the LRU repair 90 percent of the time is simulated by the probabilistic branching from node 14. With a probability of .9 repair will be completed and the entity will be routed to node 96. Node 96, in turn, routes the activity to node 8 to free resources 1 and 2, and to node 69, on sheet 4 which frees the resource that represents the LRU, simulating the return of the LRU to supply.

Ordering a part and placing the LRU in AWP status is reflected in the .1 probabilistic branch from node 14 to node 15. In this case, node 15 routes the entity to node 8 to release the technicians, resources 1 and 2, and to node 67, the broken spare queue, with a delay of 24 to 336 hours, simulating the placement of the LRU in AWP ststus.

As stated earlier, user function 13 interrupts the repair of an LRU if the technicians are needed to repair an equipment failure. To model the interruption, user function 13 stops activity 5, eminating from node 95, and routes the entity to node 9 without delay. When the entity arrives node 9 routes it to node 8 to free the technicians, and to node 67 to place the entity back in the broken spares queue.

This chapter has described the analysis and measurement phase of the system science paradigm by developing and presenting a parametric model of the system. The actual measurement approach is presented in Chapter V, the validation and verification chapter. Chapter IV continues the presentation of the system science paradigm as it applies to the problem addressed in this thesis by presenting the computerizarion of the model.

IV COMPUTERIZATION

The computerization phase of the system science paradigm involves translating the parametric model into a computer recognizable code. In this chapter, the computerization of the parametric model developed in Chapter III is described in four sections. The first section provides a description of the code used in the user written FORTRAN functions and subroutines. The second section lists and explains the various Q-GERT statements used in the model and explains the relationship between the statements and the symbols described in the prevoius chapter. Section three provides a description of the Q-GERT code used in this thesis. Finally, the fourth section explains how the Q-GERT program works with the user functions and subroutines to process transactions.

FORTRAN Functions and Subroutines

The Q-GERT executive program (exec) makes calls to user written FORTRAN subroutines and functions under four different conditions. User subroutine UI is called before each run of the Q-GERT analysis program to allow the modeler to initialize user defined variables and to set up initial conditions. User function UF and user subroutine US are called by the Q-GERT program to perform tasks not easily performed by Q-GERT. Finally, user subroutine UO is called at the end of each analysis run to perform special computations and to output ststistics not provided in the Q-GERT summary reports (Ref 16:235-254). The following subsections describe the user written functions and subroutines used with this thesis. The FORTRAN code for the subroutines and functions can be found in appendix A and the definition of terms and variables in Table II.

User Function UI. Q-GERT calls user function UI at the beginning of each analysis run. In the model written for this thesis UI is used to initialize the values of AVAIL and ATRB8. AVAIL is an 800 by 7 array used to record (1) the name or number associated with each equipment,(2) the time the equipment started or returned to operation, (3) the time the equipment failed,(4) the name or number associated with the failed LRU,(5) the time the LRU was removed from the equipment, (6) the time the LRU was repaired, and (7) the time the equipment was returned to operation. UI sets the values of AVAIL(I,1) to 0 and all other values of AVAIL to 20000. ATRB8 is used to count the number of failures and is initialized to the value 0.

The values of parameters used for sampling from the lognormal distribution differ from the parameters specified in the Q-GERT program. The values specified in the program are the mean and standard deviation of the lognormal distribution, but Q-GERT needs to know the mean and standard deviation of the parent normal distribution in order to generate data from the lognormal distribution. Q-GERT

Table II

Definition of variables used in UI, UF, and UO.

Variable Name	Definition
ATRB8	A real variable used to count the number of failures.
AVAIL1-AVAIL7	Real variables used in sorting the array AVAIL(I,J) according to failure times stored in AVAIL(I,3).
AVAIL(I,J)	An 800 by 7 array used to resord the history of the equipment operation and maintenance.
DAY1	A real variable corresponding to the day that an equipment starts operation.
DAY2	A real variable corresponding to the time that an equipment fails.
DAY3	A real variable corresponding to the day that an LRU is removed from the equipment.
DAY4	A real variable corresponding to the day that an LRI is repaired.
DAY5	A real variable corresponding to the day that an equipment returns to operation.
EQAV(I)	A real variable corresponding to the equipment availability, and used in printing the equipment history.
EQUIP	A character variable set to the name of an equipment when printing the equipment history.
EX(I)	A Q-GERT function that returns a sample from the exponential distribution with parameters specified by I.

Table II (continued)

Variable Name	Definition
GATRB(I)	A Q-GERT function that returns the value of attribute I associated with the current transaction.
CPLO(I)	A Q-GERT subroutine that converts the parameters specified fir the lognormal distribution into the parameters for parent normal distribution.
ICSRA(I)	A Q-GERT function that returns the number of units of resource I available.
ISTUS(NODE,ACT)	A Q-GERT function which returns the status of activity ACT eminating from node NODE.
LO(I)	A Q-GERT function which returns a sample from the lognormal distribution with parent normal parameters specified by parameter set I.
MIN1	The integer value of XMIN1.
MIN2	The integer value of XMIN2.
MIN3	The integer value of XMIN3.
MIN4	The integer value of XMIN4.
MIN5	The integer value of XMIN5.
NDAY1	The integer value of DAY1
NDAY2	The integer value of DAY2
NDAY3	The integer value of DAY3
NDAY4	The integer value of DAY4

Table II (continued)

Variable Name	Definition
NDAY5	The integer value of DAY5.
NTIM1	The integer value of TIM1.
NTIM2	The intager value of TIM2.
NTIM3	The integer value of TIM3.
NTIM4	The integer value of TIM4.
NTIM5	The integer value of TIM5.
LRU	A character variable set to the name of an LRU when pronting the equipment history.
NUM1	The integer value of AVAIL(I,1), used in computing equipment availability and determining the equipment name when printing the equipment history.
NUM4	The integer value of AVAIL(I,4),used when printing the name of the LRU in the equipment history.
NUM8	The integer value of ATRB8 or attribute 8, used as an index for array AVAIL(NUM8,I).
PROB	A real variable with a value determined by a sample from the uniform distribution (1,100) used to assign an LRU to an equipment failure
STAGO(A,D,0,AT)	A Q-GERT subroutine which stops service activity A and routes the transaction to node N with delay D. 0 and AT are dummy variables.

Table II (continued)

Variable Name	Definition
TIM1	A real variable corresponding to the hour that an equipment starts operation.
TIM2	A real variable corresponding to the hour that an equipment fails.
TIM3	A real variable corresponding to the hour that an LRU is removed from the equipment.
TIM4	A real variable corresponding to the time that an LRU is repaired.
TIM5	A real variable corresponding to the time that an equipment returns to service.
TNOW	The current time.
UF(IFN)	User function IFN.
UN(I)	A sample from the uniform distribution defined by parameter set I.
XMIN1	A real variable corresponding to the minute that an equipment starts operation.
XMIN2	A real variable corresponding to the minute that an equipment failed.
XMIN3	A real variable corresponding to the minute that an LRU is removed from the equipment.
XMIN4	A real variable corresponding to the minute that an LRU is repaired.
MIN5	A real variable corresponding to the minute that an equipment is returned to operation.

automatically modifies these parameters when the sample is taken by the Q-GERT program, but when a user function is used to take the sample the parameters must be modified by the modeler. The call to CPLO(N) statement in the subroutine UI performs that modification. Figure 17 contains a flow diagram of user subroutine UI.

<u>User Functions UF(IFN)</u>. The user function UF(IFN) is called by Q-GERT whenever the function type UF is prescribed in an attribute assignment. Q-GERT can call UF from both activities and nodes, but in the model used for this thesis calls are made only from nodes. In the call statement the value of IFN determines which user function is actually performed when UF is called. This is accomplished with the computed GO TO statement

```
GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14),IFN.
```

The following paragraphs describe the user functions in UF.

Figure 18 contains a flow diagram of UF(1). Based on the value of attribute 1, UF(1) assigns a value from an exponential distribution to attribute 2 of the transaction passing through node 2 when UF(1) is called. The mean of the exponential distribution is the MTBF for the corresponding equipment. In a similar manner, UF(2) assigns values to attribute 3 taken from the lognormal distribution with a mean corresponding to the MTTR of the associated equipment (see Figure 19).

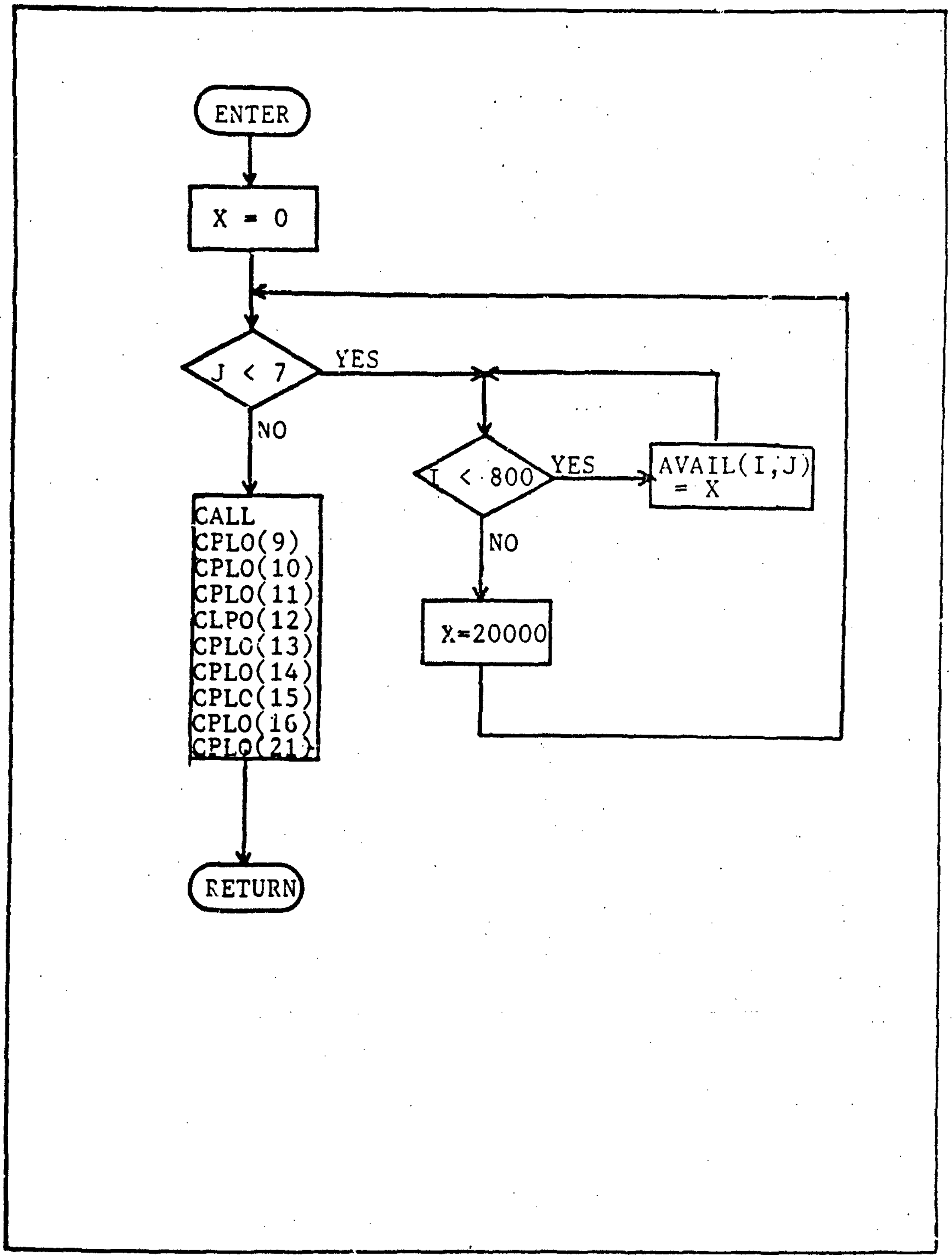

Figure 17. User Subroutine UI Flow Diagram.

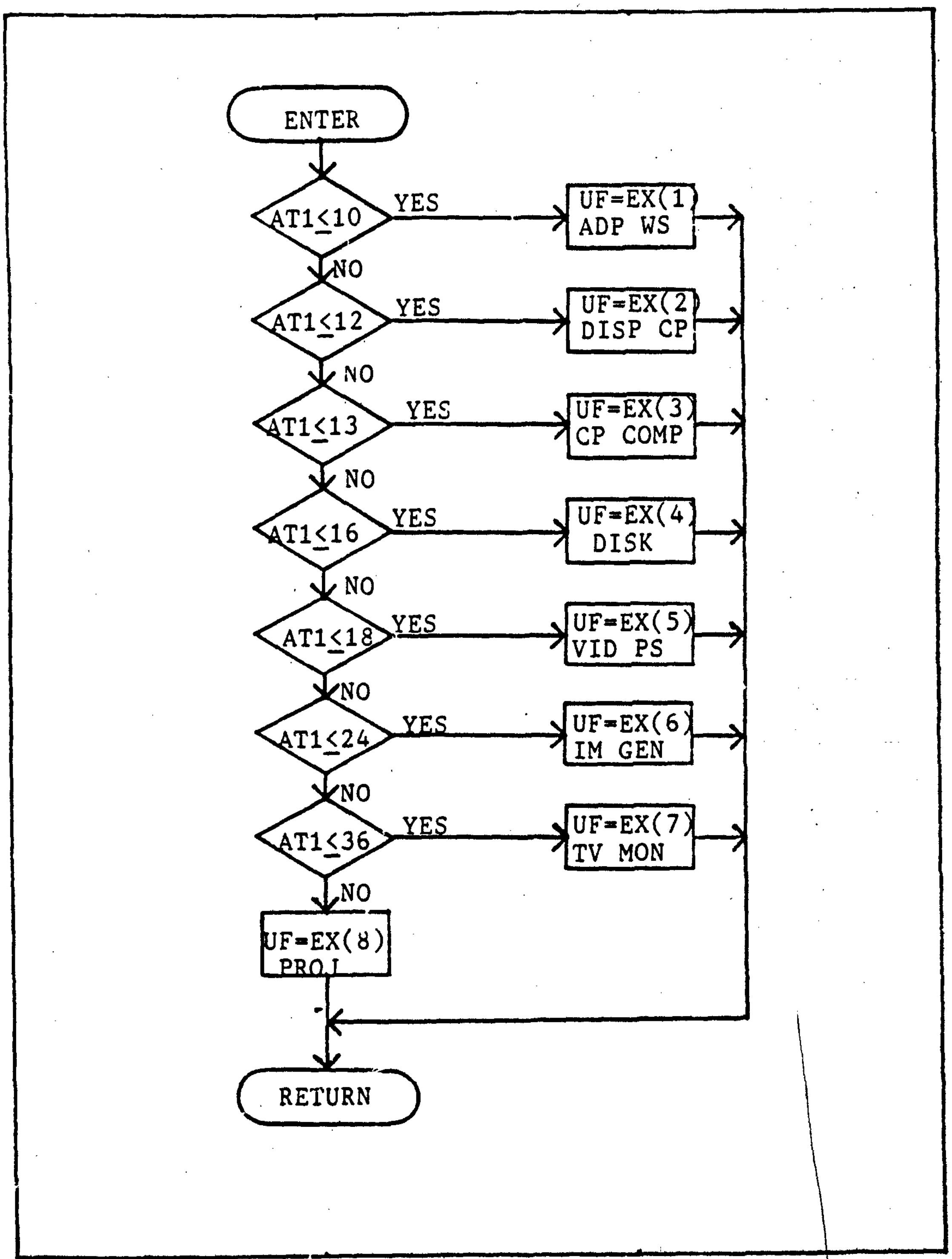

Figure 18. User Function UF(1) Flow Diagram

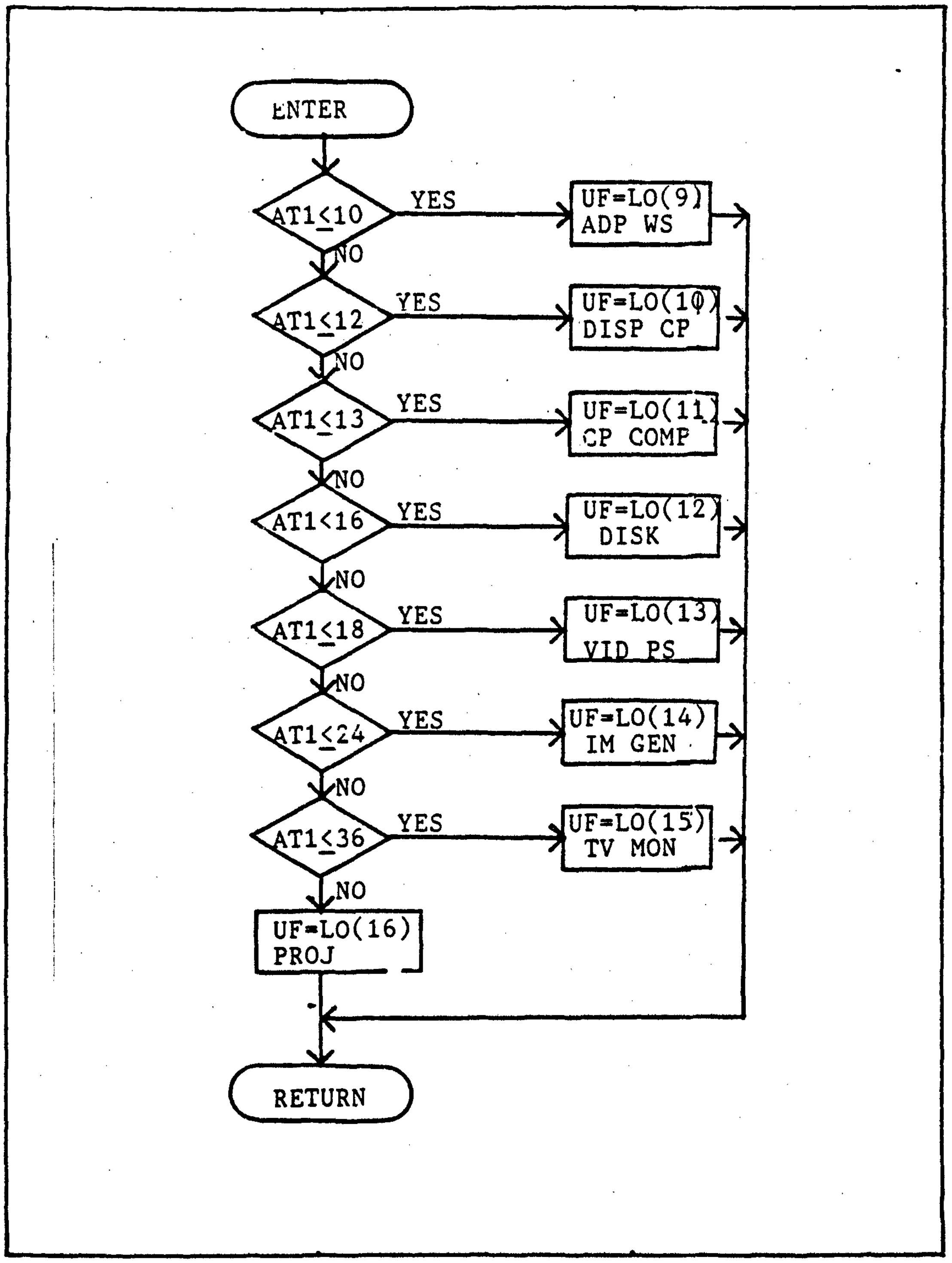

Figure 19. User Function UF(2) Flow Diagram.

User function UF(3) determines which LRU caused an equipment failure by taking a sample from a uniform (1,100) distribution and comparing the sample with the cumulative probability that a particular LRU caused the failure. The calculations for determining those cumulative probabilities are contained in Chapter V. Figure 20 contains the flow diagram for UF(3).

User Function UF(4) is used to compute the number of repairmen required to repair an equipment failure by checking the value of attribute 3. If the value of attribute 3 is 17 or 20 the defective LRU is a television monitor or an ILWSD projector and two maintenance technicians are required. Otherwise only one technician is requires. Figure 21 contains a flow diagram of user function UF(4).

To compute the time required to repair an equipment failure, user function UF(5) multiplies the usual repair time, attribute 3, by a sample from a uniform (1.5,2) distribution. A flow diagram for user function UF(5) is contained in Figure 22.

User function UF(6) is used to record the time an equipment starts or returns to operation , and counts the number of equipment failures. To record the time that an equipment returns to operation, user function UF(6) increments ATRB8 and converts ATRB8 to integer form to use as an index in AVAIL(NUM8,I). Then UF(6) records the equipment number in AVAIL(NUM8,1) and the start time in AVAIL(NUM8,2).

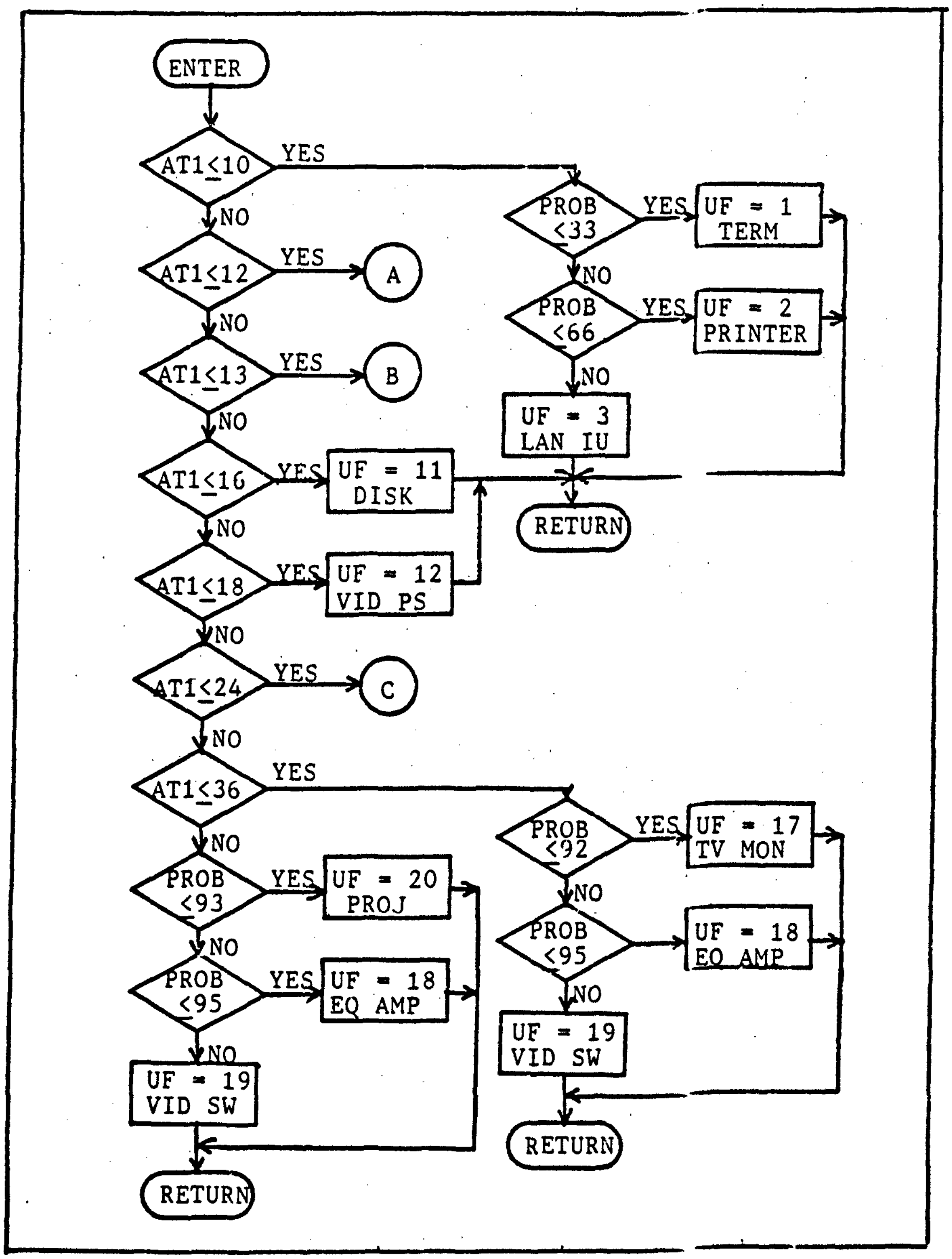

Figure 20 (Sheet1). User function UF(3) Flow Diagram.

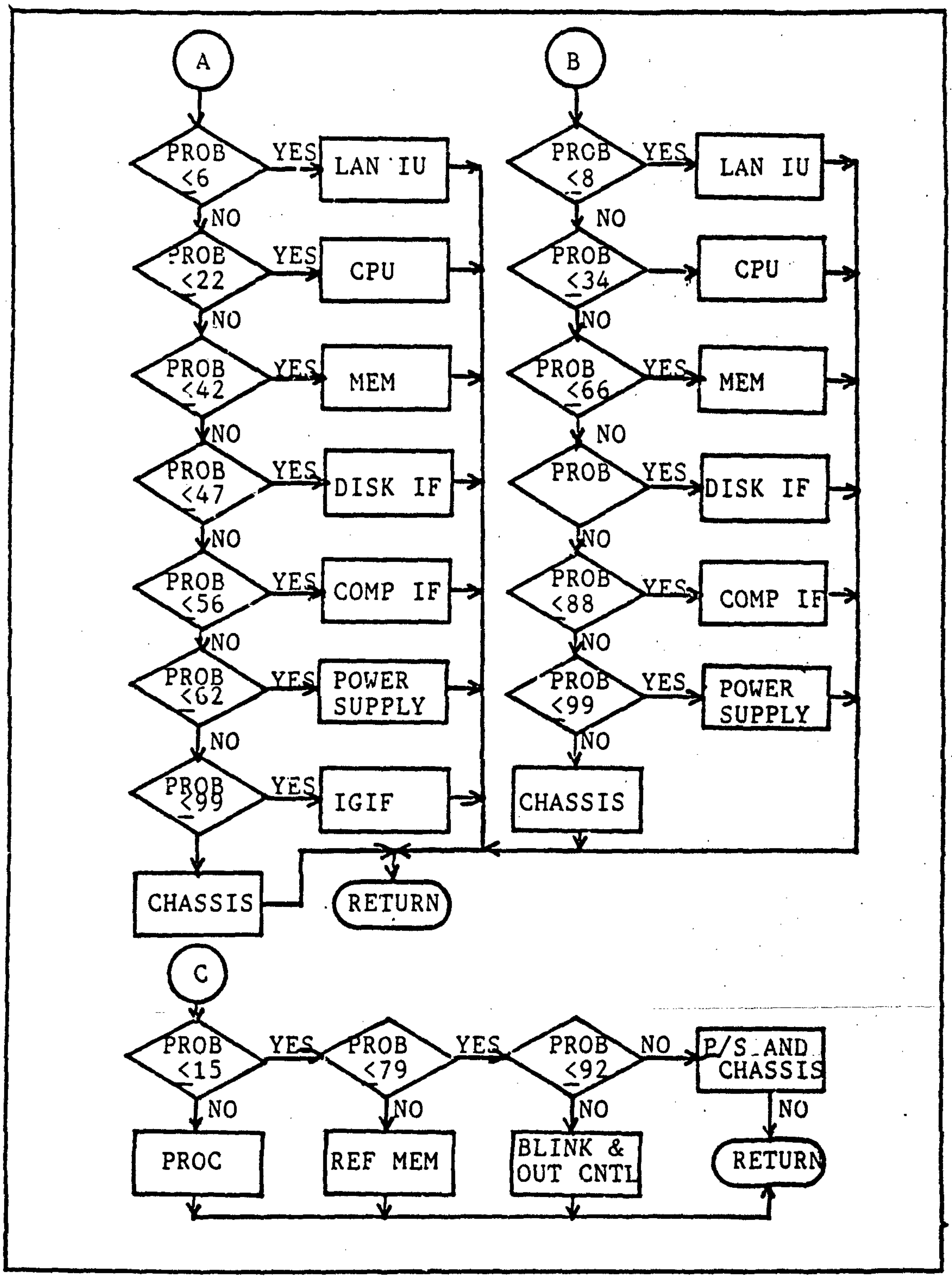

Figure 20 (Sheet 2). UF(3) (continued).

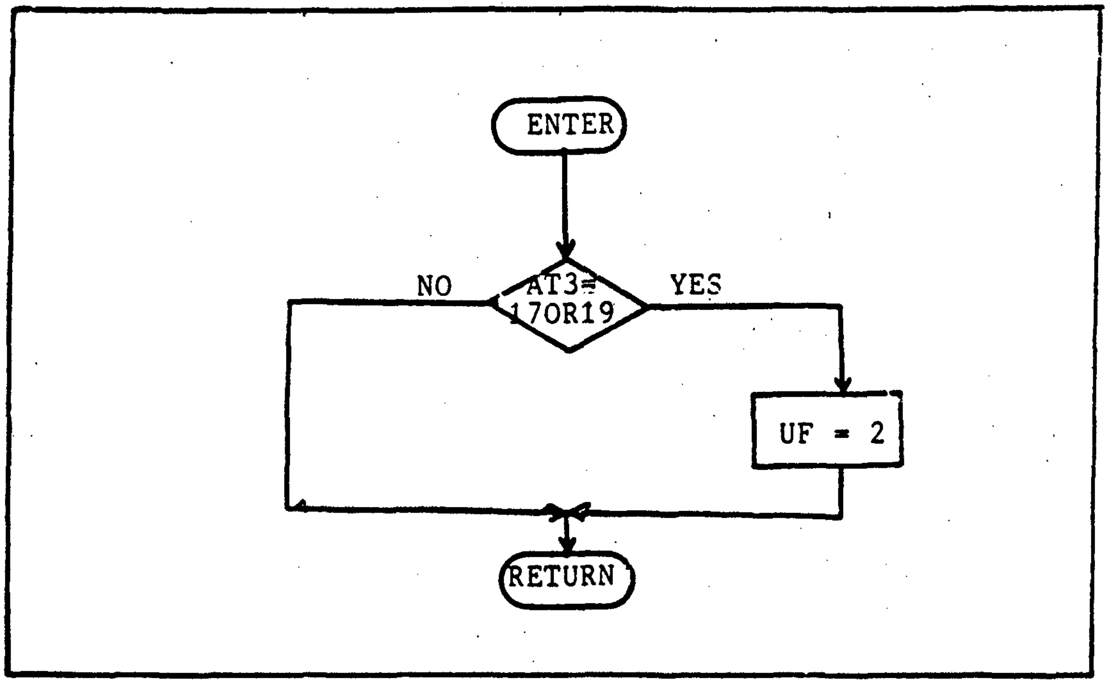

Figure 21. User Function UF(4) Flow Diagram.

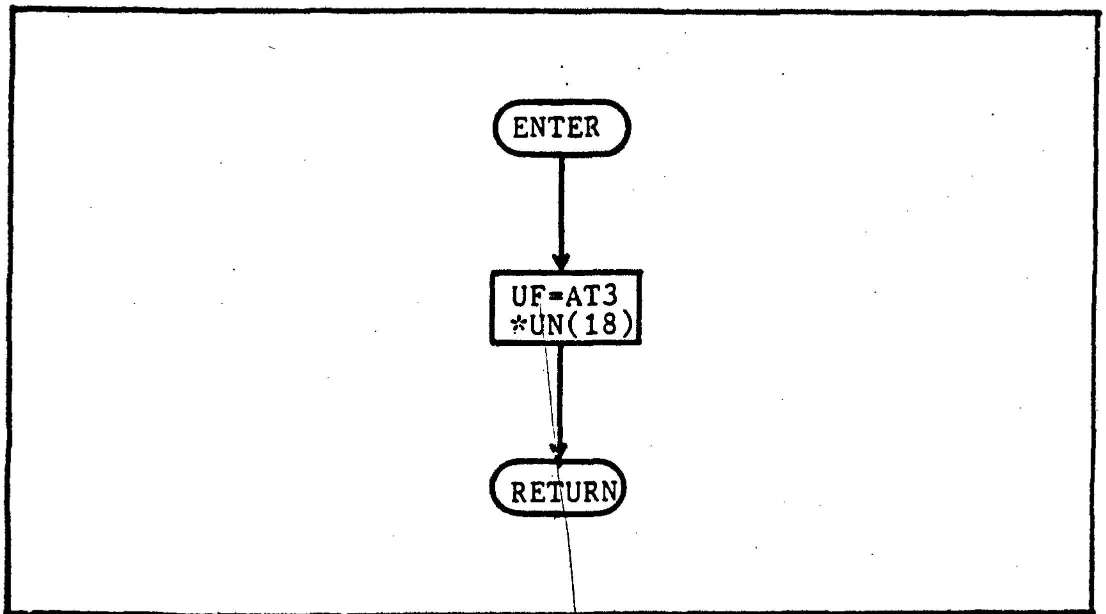

Figure 22. User Function UF(5) Flow Diagram.

Finally, attribute 8 is set to the value in ATRB8 for later use in identifying the transaction. Figure 23 contains the flow diagram for user function UF(6). User function UF(7) is unnecessary and has been deleted from the program. To prevent a FORTRAN compile error the call statement remains in the code, but the function contains only a return statement.

User function UF(8) records the time of the equipment failure. To record the equipment failure time UF(8) sets NUM8 equal to the integer value of attribute 8 to index array AVAIL(I,J). Next UF(8) stores the current time, TNOW, in AVAIL(NUM8,3). Last, it returns the value of attribute 8 to satisfy a FORTRAN function requirement. A flow diagram of user function UF(8) is contained in Figure 24.

To record how long a spare LRU remains broken, user function UF(9) records the time a defective LRU is removed from the equipment and user function UF(10) records the time the LRU repair is completed. UF(9) works like UF(6), recording the LRU type in AVAIL(NUM8,4) and the removal time in AVAIL(NUM8,5); while UF(10) works like UF(8) recording the repaired time in AVAIL(NUM8,6). Figure 25 and 26, respectively, show flow diagrams of user functions UF(9) and UF(10).

User function UF(11) assigns the equipment repair time to equipment if the defective LRU is not available for replacement. To accomplish this UF(11) checks to see

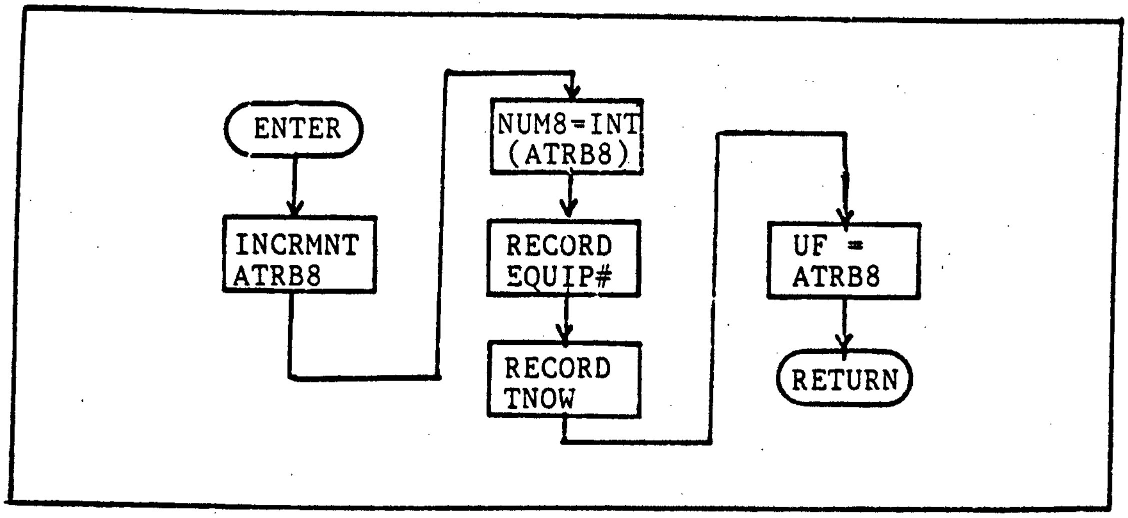

Figure 23. User Function UF(6) Flow Diagram.

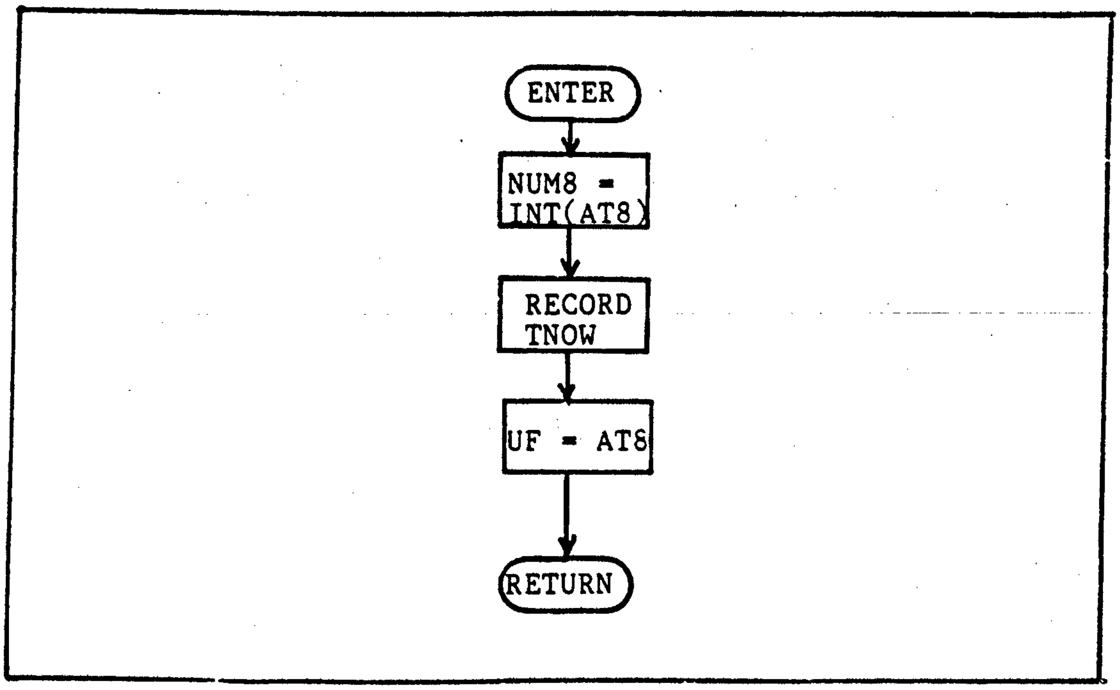

Figure 24. User Function UF(8) Flow Diagram.

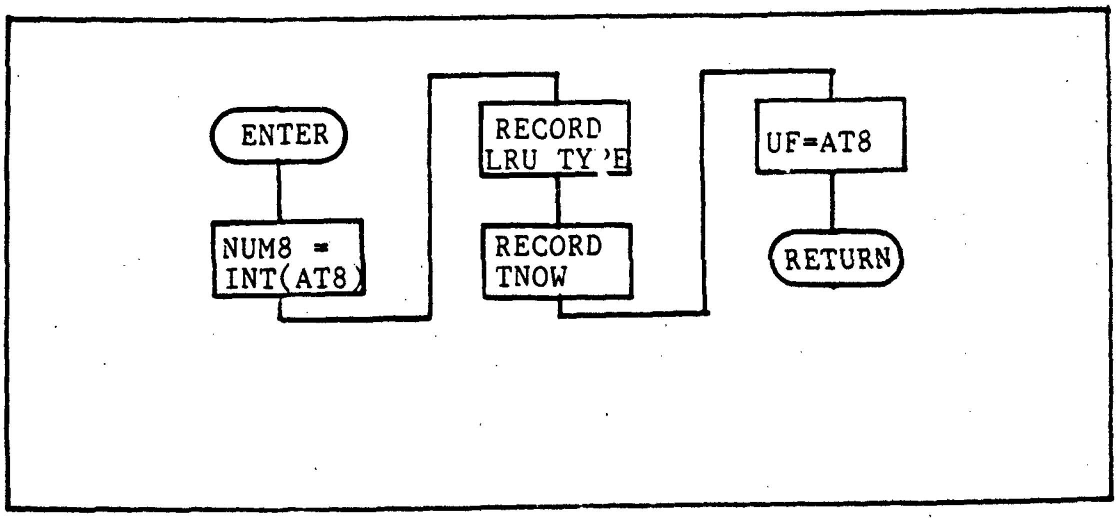

Figure 25. User Function UF(9) Flow Diagram.

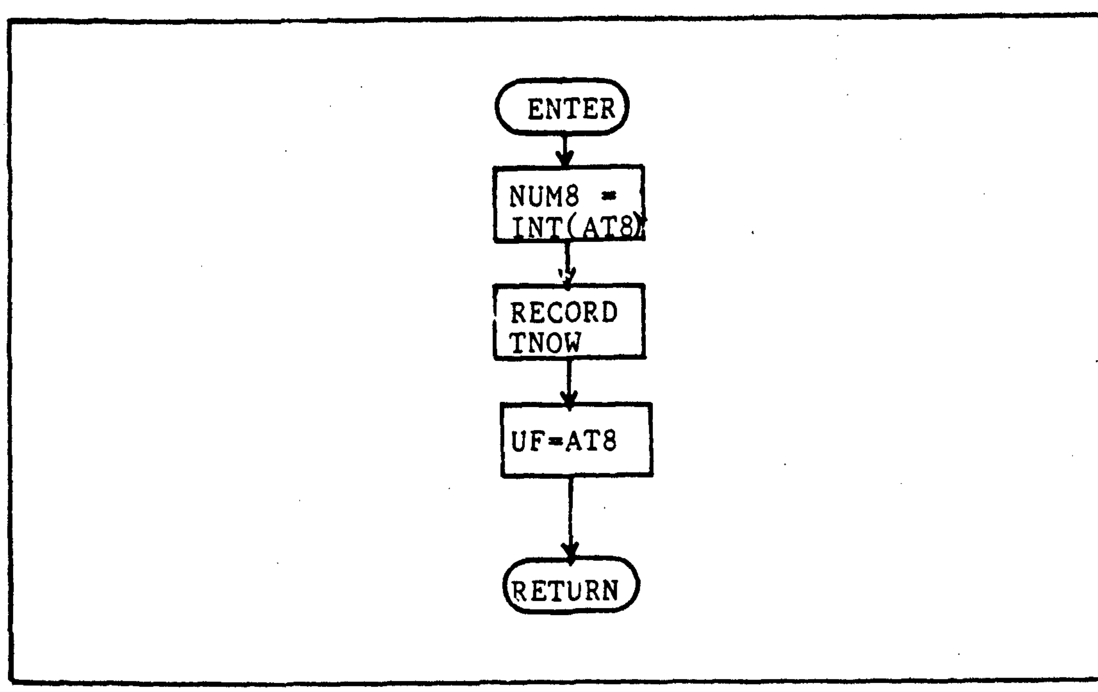

Figure 26. User Function UF(10) Flow Diagram.

if attribute 1 equals 10 or 12. If so, attribute 3 is set to the value of a sample taken from the lognormal distribution with a mean of 8 and a standard deviation of 4. Otherwise attribute 3 remains unchanged. Figure 27 contains a flow diagram of user function UF(11).

User function UF(12) records the time that the equipment returned to operation after a failure. UF(12) records the time in the same manner as UF(8) and UF(10). Figure 28 illustrates the flow diagram for user function UF(12).

User function UF(13) preempts repair of an LRU if the technicians are required to repair an equipment failure. User function UF(13) accomplishes the interrupt by checking to see if the number of technicians required for the repair are available. If there are not enough free technicians, UF(13) checks to see if any technicians are busy repairing broken LRUs. If the technicians are repairing LRUs, UF(13) calls STAGO, a Q-GERT subroutine, to interrupt the LRU repair and free the technicians. A flow diagram of user function UF(13) is contained in Figure 29.

To determine if a 3-level should be assigned to help with the repair user function UF(14) makes two checks. First, UF(14) uses Q-GERT function ICSRA(2) to determine if any 3-level technicians are available to help. Second, UF(14) checks to see if one or two technicians are required for the job. If the job requires only one technician and there are no available 3-levels, attribute 5 is set to 0 and

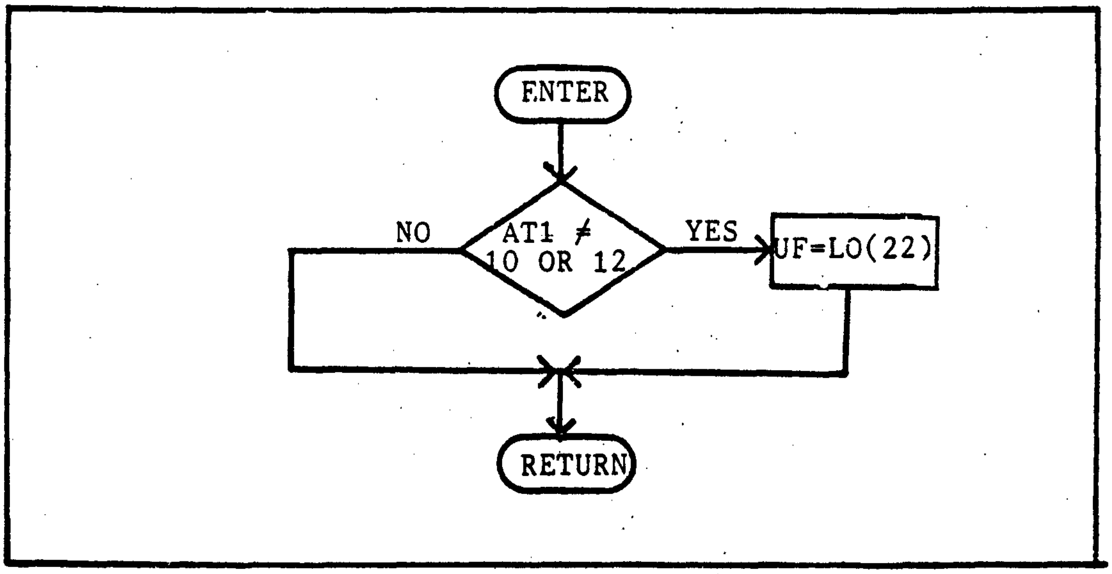

Figure 27. User Function UF(11) Flow Diagram.

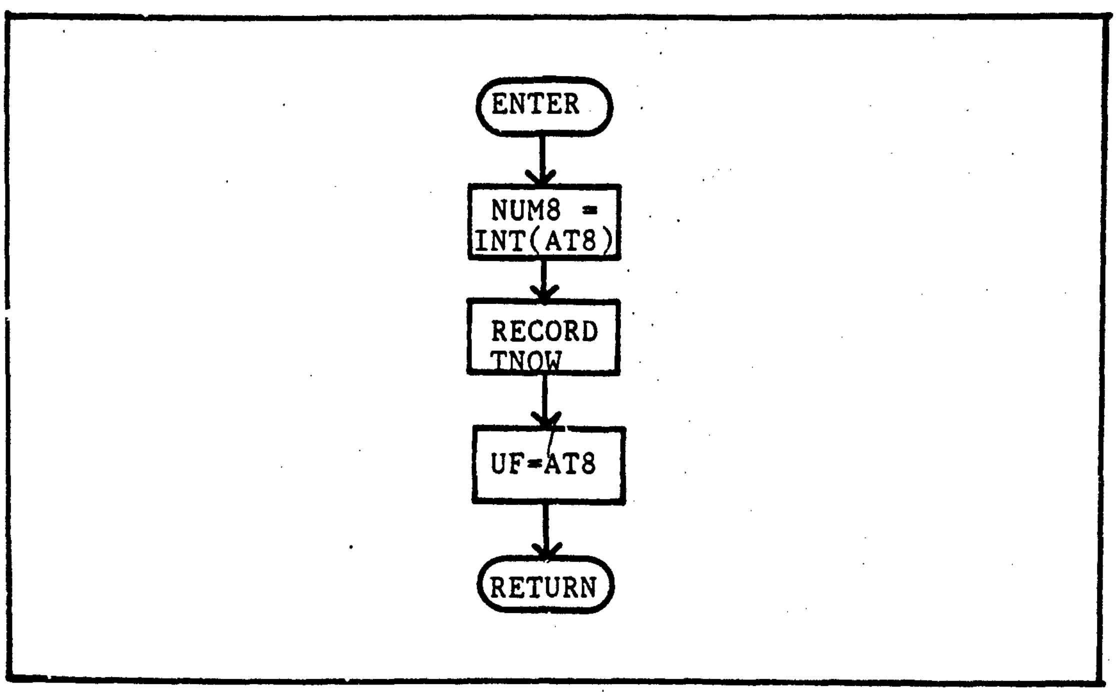

Figure 28. User Function UF(12) Flow Diagram.

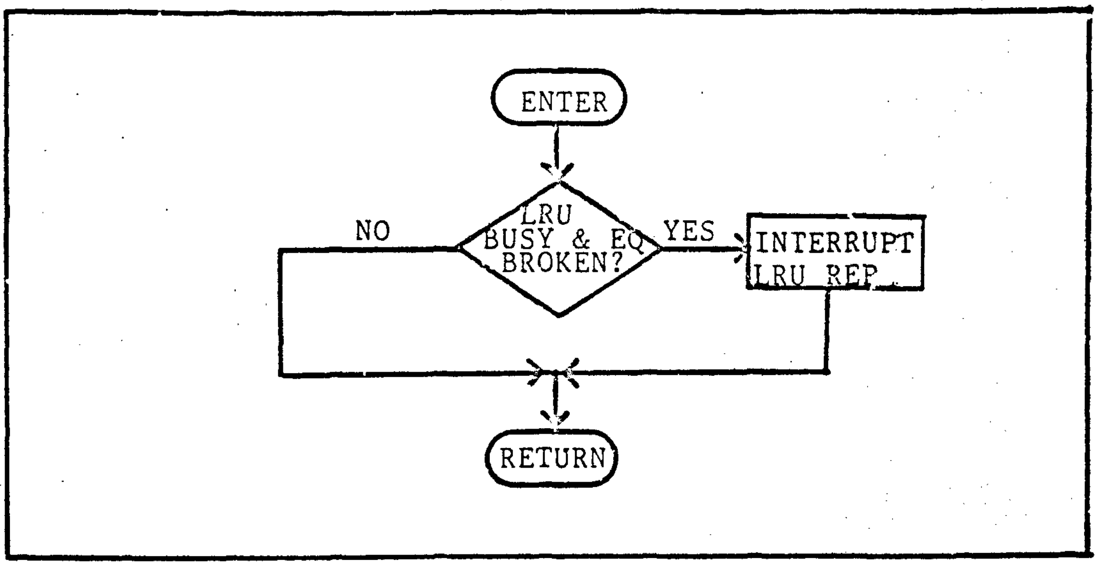

Figure 29. User Function UF(13) Flow Diagram.

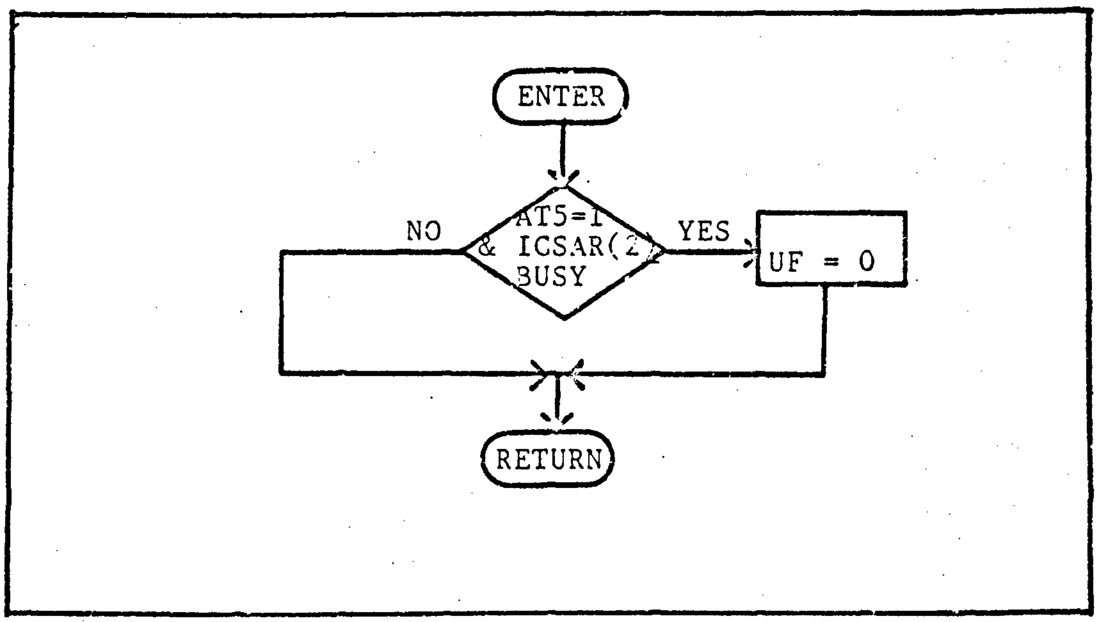

Figure 30. User Function UF(14) Flow Diagram.

no 3-level is assigned. Otherwise attribute 5 remains unchanged and a 3- level is assigned to assist a 5-level technician on the repair. Figure contains a flow diagram of user function UF(14).

User Subroutine UO. Q-GERT calls user subroutine UO at the end of each simulation run. At that time user subroutine UO performs several tasks. First, UO initializes array EQAV(I) to 0 so that it can be used to help calculate and store the equipment availabilities. Next, UO sorts the entries in array AVAIL(I,J) based on the failure times recorded in AVAIL(I,3). Then, UO prints a heading for the equipment history, it computes the equipment availability, it assigns names to the equipment numbers and LRU numbers, and prints the equipment history and availabilities. Figure 31 provides a flow diagram of the user subroutine UO and the FORTRAN code for UO as well as UI and UF is contained in appendix A.

Q-GERT Statements

Table III contains a list of all of the Q-GERT statements used in the model written for this thesis. Also included in the table is a brief explaination of the various fields associated with each statement. A more detailed explaination of the Q-GERT input statements is contained in the following paragraphs.

The first input statement in any Q-GERT program is the general (GEN) card. The GEN card is used to define the

Table III

Description of Q-GERT Input Statements.

1	2	3	4	5	6	7	8	9	10	11	12	13	14
GEN	Name [Blank*]	Project name or [Blank]	Month [1]	Day [1].	Year [2001]	Number of statistics nodes [0]	Number of sink nodes [0]	Number of sink nodes to end one run [value in 8]	Time to end one run of network [10^{20}]	Number of runs of network [1]	Output reports in addition to summary [First]	Time from which statistics are kept [0]	Maximum number of attributes [0]
REG or SOU	Node number/ ------- label	Initial number to release [1]	Subsequent number to release [∞]	Branching (D,P,F,A) [D]	Marking (M) [M if SOU, no M if REG]	Choice criterion (F,L,S,B) [L] ------- Attribute [M]							
QUE	Node number/ ------- label	Initial number in queue [0]	Capacity of Q-node [∞]	Branching (D,P,F,A) [D]	Ranking (F,L,S,B) [F]/ ------- Attribute [M]	Block or node number for balkers (B) [balkers destroyed]	Upper limit of first cell [N]	Width of histogram cell [N]	Following Allocate nodes				
VAS	Node number	Attribute number [1]	Distribution type [CO]	Parameter set [0]	(Repeats of Fields 3,4 and 5)								
PAR	Parameter set	Parameter 1 [0]	Parameter 2 [-10^{20}]	Parameter 3 [10^{20}]	Parameter 4 [0]	Stream number [10]							

* Default values are given in brackets[ ]. If no default value is indicated, data for the field is required. Options for a field are given in parenthesis (). A slash (/) indicates the field may contain two entries where the slash and second entry are optional.

Table III

Description of Q-GERT Input Statements (continued).

1	2	3	4	5	6	7	8	9	10	11	12	13	14
ACT	Start node	End node	Distribution or function type [CO]	Parameter set or constant [0.0]	Activity number/ ---------- label	Number of parallel servers [1]	Probability or attribute number or order [.5]	Condition code [Ni.R] i=start node					
RES	Resource number/ ---------- label	Number of units of this resource type available [1]	Allocate nodes to be polled when resource is freed [None]	(Repeats of Field 4)									
ALL	Node number	Queue selection rule [PCR]	Resource number [1]	Resource units required by waiting transaction [1]	Preceeding Q-node ---------- following node number [None]	(Repeats of Field 6)							
FRE	Node number	Output characteristics [D]	Resource number [1]	Resource units to be freed [1]	Allocate nodes in the order to be polled	(Repeats of Field 6							
FIN													

general project information. Information contained on the GEN card includes: the analyst's name, the project name, the date, the number of statistics nodes and sink nodes (not used in this thesis), number of sink node releases to end the simulation (not used in this thesis), the time to end one run of the network, the number of runs of the network, the number of output reports in addition to the summary report, the time from which statistics are kept, and the maximum number of attributes that can be assigned to any transaction. Additional fields can have values assigned, but are not used in this thesis. For additional information see Pritsker (Ref 16).

The fields associated with the regular (REG) and source (SOU) nodes are the same. Field 1 defines the node type, REG or SOU. The second field contains the node number and an optional node label separated by a slash(/). Fields three and four specify the number of arrivals needed to release the node for the first time and all subsequent times, respectively. The fifth field specifies the type of branching deterministic (D), probabilistic (P), conditional take first (F), or conditional take all (A). Field six is used to specify marking, marking is the default value for source nodes but not for the regular nodes. The last field specifies the choice criterion for holding attributes (not used in this thesis).

Q-node input cards use ten fields. The first field identifies the card as defining a Q-node (QUE). Field two identifies the node number and node label of the node defined by the card. Fields three and four identify the initial number of transactions in the queue and the capacity of the queue. Branching criterion is defined by field five and ranking of transactions in the queue by field six. Field seven describes the balking or balking associated with the node. Fields eight and nine describe the limits of any histogram to be drawn and is not used in this thesis. Field ten identifies any allocate nodes that follow the Q-node.

The value assignment (VAS) card is used to assign attributes to the transactions that pass through the node associated with the VAS card. Field one identifies the card as a VAS card. The second field identifies the associated with the VAS card. Field three identifies the attribute number and field four the distribution or function type. The fifth field identifies the parameter set defining the parameters of the distribution identified in field four. The remaining fields of the VAS card are repeats of fields 3, 4, and 5.

To define the parameters of a distribution a PAR card is used. The first field of the card identifies it as a PAR card and the second field identifies which parameter set it defines. The third, fourth, fifth, and sixth fields defines the parameters of the associated distribution. Since the various distributions use different parameter definitions fields three through six define different parameters for the different distributions. Table IV defines the use of fields three through six to define the distributions used in this thesis. Finally, field seven prescribes the random number stream to be used in generating samples from the distribution whose parameters are defines by the PAR card.

Activities are described by an ACT card. The activity card is defined by the ACT in field one. The second and third fields identify the starting and ending nodes of the activity, respectively. Field four describes the distribution type and field five the number of the parameter set for the distribution. The sixth field provides the activity number and label separated by a slash (/) and the seventh field the number of parallel servers. Field eight is used to describe the probability of choosing the activity or the attribute in which the probability is stored if the starting node has probabilistic branching, or the order of testing if the starting node has conditional take first branching. The last field used is field nine which provides the condition code for choosing the branch if the starting nose specifies conditional branching.

The resource node is identified by the RES in field one. Field two contains the resource number associated with the resource being modeled and a label for the resource, while field three specifies the number of resource units available when the simulation starts. The fourth through the thirteenth fields are used to specify the resource allocate nodes to be polled when the resources are freed.

Allocate nodes are used to allocate the resources defined by the resource card. Field one defines the allocate card by the letters ALL. The second field on an allocate card contains the node number of the allocate node. Field three contains the rule used to select the Q-node which holds the transaction that the resource will be allocated to. Field four is the resource number and field five the number of resources needed by the waiting transactions. The sixth through sixteenth fields list the preceeding Q-nodes in which the transactions are waiting and the nodes to which the transactions will be routed after the resources are allocated.

The free nodes free resources from transactions when the resources are no longer needed. The first field of a free card identifies it as a free (FRE) card and the second field assigns the node number. Field four identifies the resource nuber of the resource to be freed and field five identifies the number of units of the resource to be freed. Finally, fields six through fifteen identify the allocate nodes to be polled when the resources are freed.

The last node in a Q-GERT network must be either a begin or a finish card. Since begin cards are not used in this thesis only the finish card is described. The finish card contains only one field with the letters FIN.

Table IV

Code options for Q-GERT Specifications

Function and Distribution Types		Parameter Values*			
Code	Key	1	2	3	4
EX	Exponential	μ	a	b	-
IN	Incremental	-	-	-	-
LO	Lognormal	μ	a	b	σ
UF	User Function	-	-	-	-
UN	Uniform	-	a	b	-
		* - → not used; μ → mean; σ → standard deviation; a → minimum or optimistic time; b → maximum or pessimistic time.			

Q-GERT Code

The previous section defined the Q-GERT input statements used in this thesis. In this section the combination of statements that form the model developed for this thesis is explained. In addition to explaining the combination of Q-GERT input statements the reason for using that particular arrangement of statements is explained. The Q-GERT code for this thesis can be found in appendix A.

The first card in the Q-GERT code is the general (GEN) card. The word "DISPLAY" in the third field identifies this

Q-GERT program as a model of the ADP, LAN, and ILWSD systems. The zeros in fields seven, eight, and nine state that there are no sink or statistics nodes in this model and that the model is not terminated on the release of a sink node. Field 10 indicates that the network is to run for 20000 time units (hours in this model) and field 11 indicates that only one run of the network will be acconplished each time the Q-GERT program is run. The 12th field calls for an output report to be printed after the first run as well as for a summary report, and the 13th field indicates that the statistics will be kept from the time the network starts. Finally, the last field states that all eight attributes will be used in this simulation network.

The next 20 input cards identify the resources used in this network. The maintenance crew size can be adjusted by changing the value of field three on the resource 1 or resource 2 card. Similarly the spares level can be adjusted by changing the value of field 3 on any of the remaining resource cards.

The following card, the SOU card,identifies node 1 as a source node that releases the first time with no arrivals, and releases each subsequent time an arrival occurs. The VAS card associated with node 1 indicates that every time the node releases the value of attribute 1 is incremented. Conditional take all branching is indicated for node 1 by the "A" in the last field of the SOU card.

The next two cards are activity cards. The first of these activity cards routes a transaction from node 1 back to itself whenever the value of attribute 1 is less than 44. This causes exactly 44 transactions to be generated. The second activity routes the transaction from node 1 to node 2.

Node 2 is defined by the QUE card following the ACT card. This card indicated that the Q-node in labeled "operate" in the summary report, it has no transactions queued up at the start of the analysis run, and has a capacity of zero. In addition, the last two fields indicate that the node uses FIFO queueing and has deterministic output. As defined by the next card, values are assigned to seven attributes at node 2. The values assigned to attributes 2, 3, 4, 5, and 8 are determined by user functions 1, 2, 3, 4, and 6, and the value zero is assigned to attributes 6 and 7. The parameters defining the values assigned by the user functions are contained in the PAR cards immediately following the VAS card.

The ACT card that routes transactions from node 2 to node 11 simulates the equipment in operation. The duration of operation for each equipment is identified by the value of attribute 2, the activity is labeled "OPER-TIME", and the 44 servers represent the equipment in operation.

The next card identifies node 11 as a regular (REG) node which releases a transaction every time a transaction arrives. The VAS card associated with node 11 calls user functions UF 8 and UF 14, and the ACT card that follows routes the transaction from node 11 to node 5. Node 5 is defined by a QUE card which assigns the label "GET-5LVL" to the node in the output report. Node 5 is assigned an initial value of zero transactions at network start, has a capacity of 10 transactions, uses FIFO ordering of transactions within the queue, and routes the transaction through node 6, the following allocate node. The VAS card associated with node 5 assigns the value 1.0 to attribute 6 as the transactions are routed through the node.

The ALL card defines allocate node 6. Since only one Q-node preceeds ALL node 6, the Q-node selection rule chosen is priority based on the order listed in the last field on the card (POR). Fields four and five identify this node as allocating one unit of resource 1 to each transaction that passes through the node, and field six indicates that the transaction is routed from node 5 to node 11.

Immediately following the ALL card is a REG card that defines node 13. Fields three and four of node 13 indicate that it releases every time an entity arrives. The VAS card assiciated with node 11 is used to call user function UF(13) which places a value in attribute 5 that determines which activity the transaction will be routed down by the conditional take first branching defined by the "F" in the last field on the dard. The first of the two ACT cards defines the condition for the transaction to take the activity to node 3 (attribute 5 greater than zero), while the second ACT card defines the condition for routing the activity to node 7 (attribute 5 equal zero).

The next card in the program is a QUE card which has an initial quantity of transactions equal to zero and is capable of holding a maximum of one transaction in the queue. This card identifies Q-node 3 and labels it "GET-3LVL." The VAS card associated with Q-node 3 assigns the value 1 to attribute 7 as the transaction is routed through the node. The last field on the QUE card identifies node 4 as the following allocate node. The ALL card assigns one unit of resource 2 to each transaction that it routes from node 3 to node 7. Node 7 is defined by the REG card as a regular node that releases every time it gets an arrival. The ACT card that follows routes the transaction from node 7 to node 20.

Node 20 is also defined by a REG card. It also releases once for every arrival it gets. However, node 20 has conditional take first branching, as defined by the "F" in the last field of the card. Eighteen activities eminate from node 20, as illustrated by the 18 ACT cards that follow the REG card. Each activity card has a condition for taking the activity and the condition corresponds to the value in attribute 4 of the transaction passing through the node.

Each of the 18 activities terminates at a Q-node. The Q-nodes are used to store transactions that must await resources and each Q-node is followed by an allocate node. The allocate nodes are specified by ALL cards that follow immediately after the associated QUE cards. Each allocate card allocates one unit of the appropriate resource to each transaction that is routed through the node. All 18 allocate cards route the transactions that pass through them to node 65.

Node 65 is defined by a QUE card. It initially has no transactions queued and has a maximum capacity of 10 transactions. Ranking within the queue is FIFO and branching from the node is deternimistic. The ACT card that follows defines the activity from node 65 to node 66. The time it takes to get from node 65 to node 66 is defined by attribute 3.

A REG card defines node 66 which releases a transaction every time one arrives. The VAS card associated with node 66 calls user Function UF(9). The three activities eminating from node 66 are defined by the next three ACT cards. The first of the cards routes the transactions to node 12, the second routes transactions to node 8 and the third routes transactions to node 67.

Node 67, defined by a QUE card, has an no transactions initially in the queue and has a capacity of 10 transactions.

The VAS card associated with node 67 assigns the value 1.0 to attribute 6 and the value 0.0 to attribute 7. The last field of the QUE card indicates that node 67 routes all transactions through locate node 97. The allocate node is defined by the ALL card to allocate one unit of resource 1 to each transaction that it routes form node 67 to node 37.

Node 37 is a Q-node which the QUE card defines to have no capacity in the queue. All transactions that arrive at node 37 when the following allocate node has no available resources balks to node 95, as indicated by the 95 in field seven of the QUE card. The allocate node associated with node 37 is node 56. Node 56 allocates one unit of resource 2 to each transaction that it routes from node 37 to node 95.

Node 95 is defined by a QUE card to have no initial transactions in the queue and to have a capacity of 10. The VAS card associated with node 95 assigns a value from the lognormal distribution to attribute 3 of the current transaction. The activity from node 95 to node 14 is defined by the next ACT card. Fields four and five of the ACT card indicate that the duration of the activity is determined by the value of attribute 3 which was assigned in node 95. The sixth and seventh fields label the activity as "BENCH-CK" and indicate that there are 10 parallel servers.

The REG card that follows identifies node 14 which releases a transaction every time it has an arrival. The last field on the cars indicates that probabilistic branching is used in node 14. The next two cards are ACT cards that define the probabilistic branching from node 14. The first activity has a 90 percent probability of being chosen and routes transactions to node 96. The second activity has a 10 percent chance of being chosen and routes transactions to node 15.

Node 15 is defined by a REG card, it has deterministic branching. The first branch from node 15 routes transactions to node 8 and the second routes transactions to node 67 with a duration defined by the uniform distribution with parameter set 20. Node 96 is also defined by a REG card and also has deterministic branching. Two activities also eminate from node 96. The first activity is routed to node 8 and the second to node 69. Both activities have a duration of zero.

Node 69 is a regular node with conditional take first branching. The VAS card associated with node 69 calls user function 10. The twenty activities eminating from node 69 are defined by the next 20 ACT cards. Each ACT card defines the condition that must be met by attribute 4 to be selected. The activities route transactions to free node 76 through 94. Nodes 76 through 94 are defined by FRE cards and free one unit of the associated resource each time a transaction arrives. The last field of each FRE card lists the allocate nodes that the resources will poll after being freed.

The next node discussed is node 9, defined by a REG card. Transactions are routed to node 9 by a Q-GERT user function that interrupts service activity number 5. When a transaction arrives at node 9, transactions are routed on two activities. The first activity routes a transaction to node 67 and the second activity routes a transaction to node 8. Arrival of an activity at node 8 causes the node to route transactions on one or more of the three activities eminating from the node. The branching used is conditional take all. The activities eminating from node 8 compare the value of attribute 6 or 7, depending on the activity, to specified values. If the values are the same the activity is selected. The activities route the transactions to free nodes 17,18 and 19 where the appropriate number of units of resources 1 and 2 are freed to the corresponding allocate nodes.

Routing of activities to node 10 was discussed earlier in this section. For each transaction that arrives at node 10 the node releases. The VAS card associated with node 10 calls user functions UF(11) and UF(9). The activities eminating from node 10 routes transactions to node 12 with a duration determined by the value of attribute 3 and to node 8 with the same duration. Node 12 is defined by a REG card and the VAS card associated with node 12 calls user function UF(12). The activity eminating from node 12 routes transactions back to node 2 at the beginning of the network.

Q-GERT Program

Figure 31 contains a diagram of the Q-GERT network with the Q-GERT code inserted near the corresponding nodes and activities. With Figure 31 it becomes easier to visualize and relate the Q-GERT network with the corresponding code in the program. This section discussed the relationship between the Q-GERT code and the user functions using figure 31 to help explain the reasons for using the FORTRAN functions.

As transactions are generated in source node 1 the value of attribute 1 is incremented for two reasons. First, attribute 1 is used as a comparison value for the conditional branching that generates more transactions. Second, each transaction, or entity, generated by node 1 represents an equipment and the number in attribute 1 identifies the particular equipment the transaction represents.

Q-node 2 assigns values to the other seven attributes associated with the transactions generated in this program. The value assigned to attribute 2 is determined by user function UF(1) and represents the MTBF for the equipment represented by the entity. User function UF(2) generates the MTTR the equipment which is stored in attribute 2 and user function UF(3) generates the value for the MTTR for LRUs assigned to attribute 4. The value of attribute 5 is calculated in user function UF(4) and is determined by the value in attribute 1. Attributes 6 and 7 are constants assigned by the VAS card, and attribute 8 is determined by

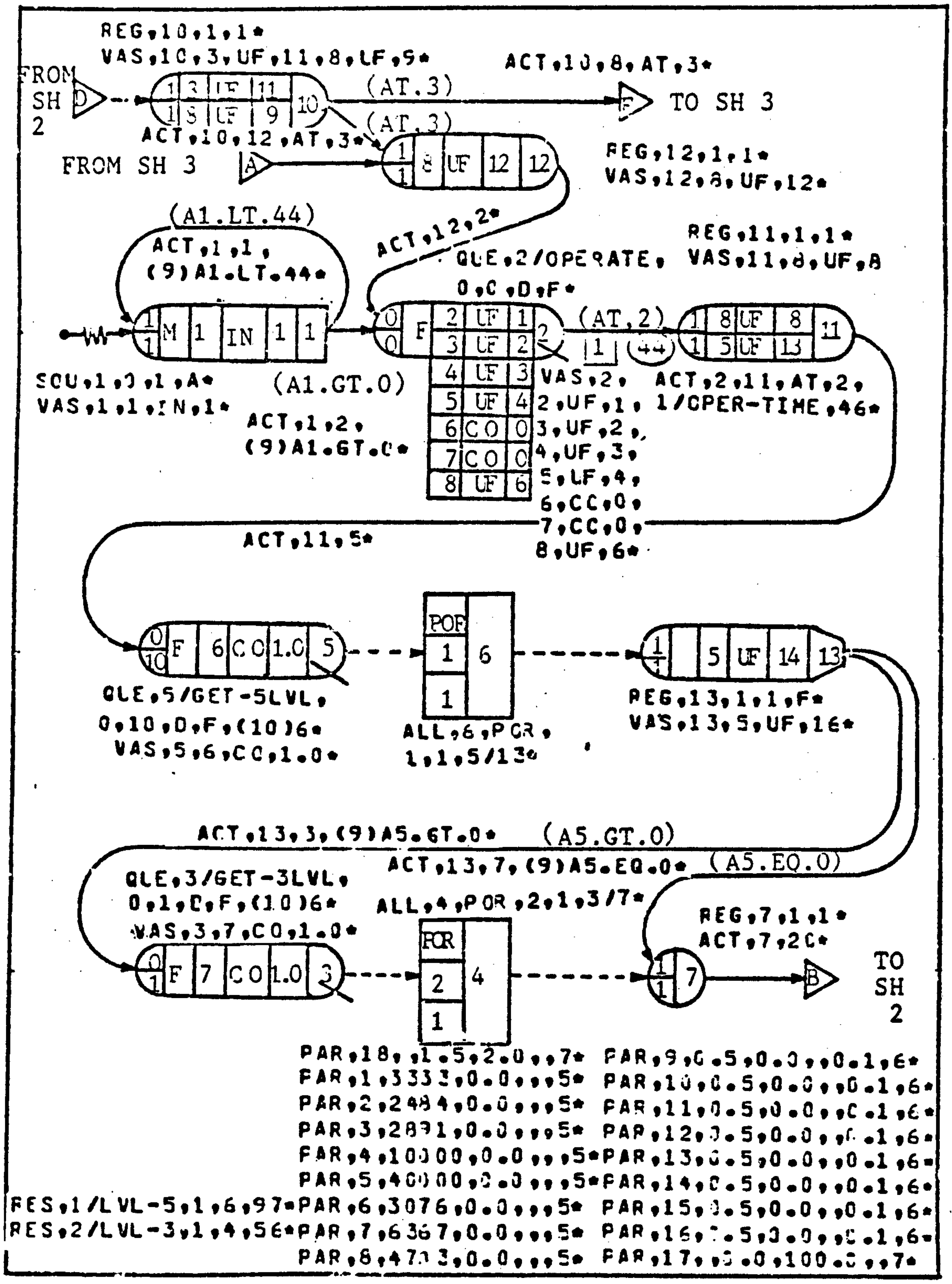

Figure 31 (Sheet 1). Q-GERT Diagram of Maintenance on the Upgraded SAC Command Post.

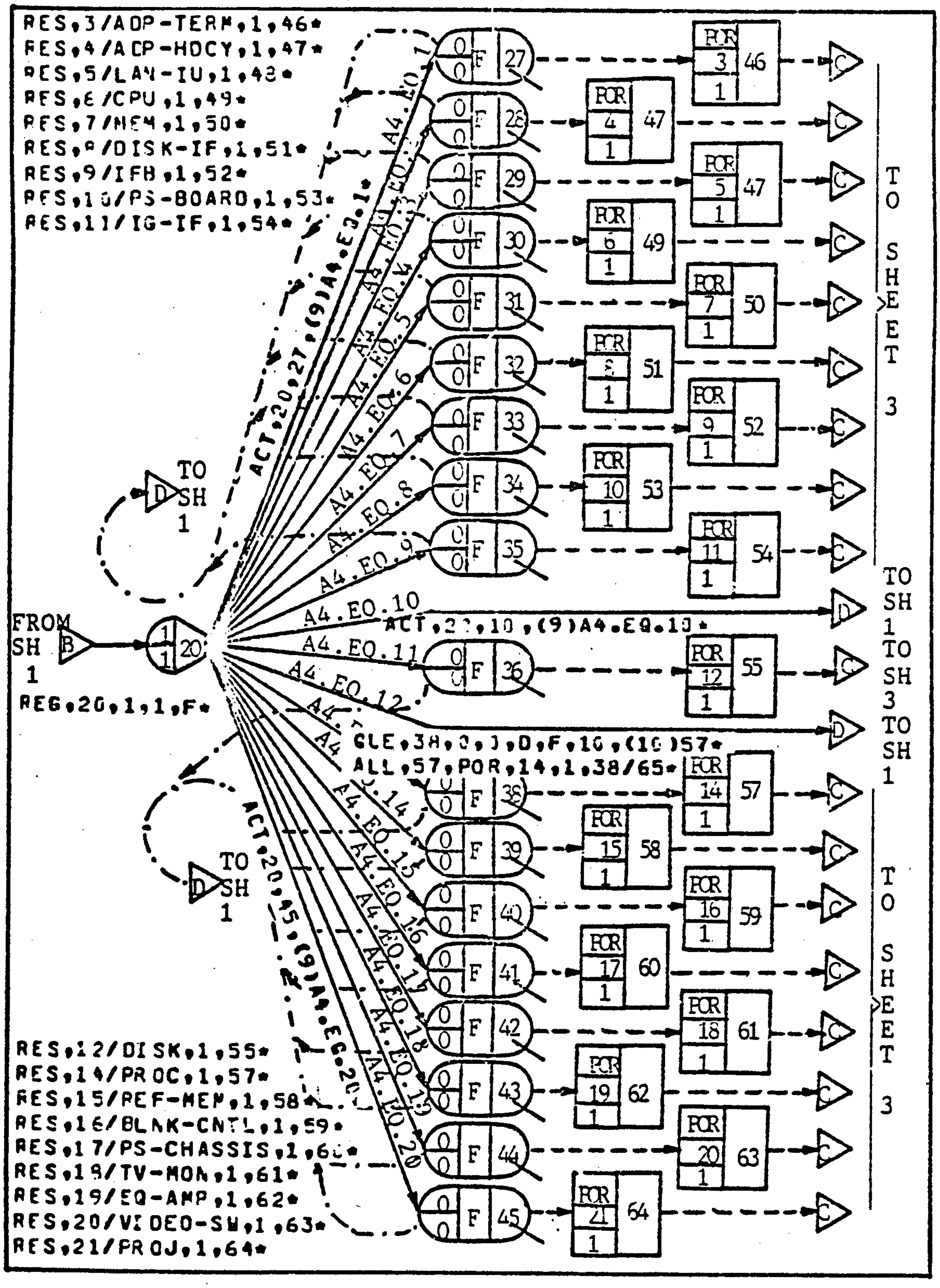

Figure 31 (Sheet 2). Q-GERT Diagram (Continued).

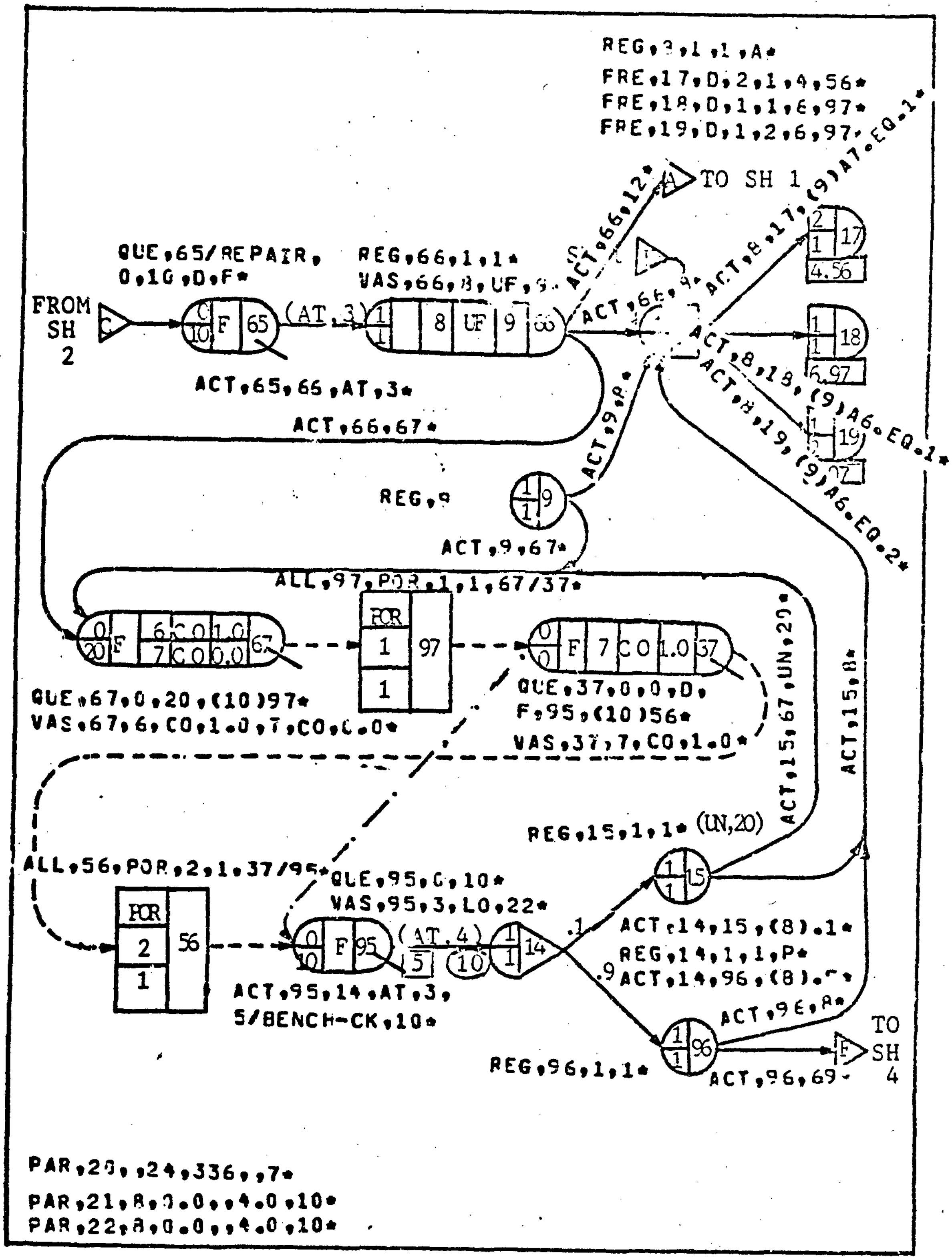

Figure 31 (Sheet 3). Q-GERT Diagram (Continued).

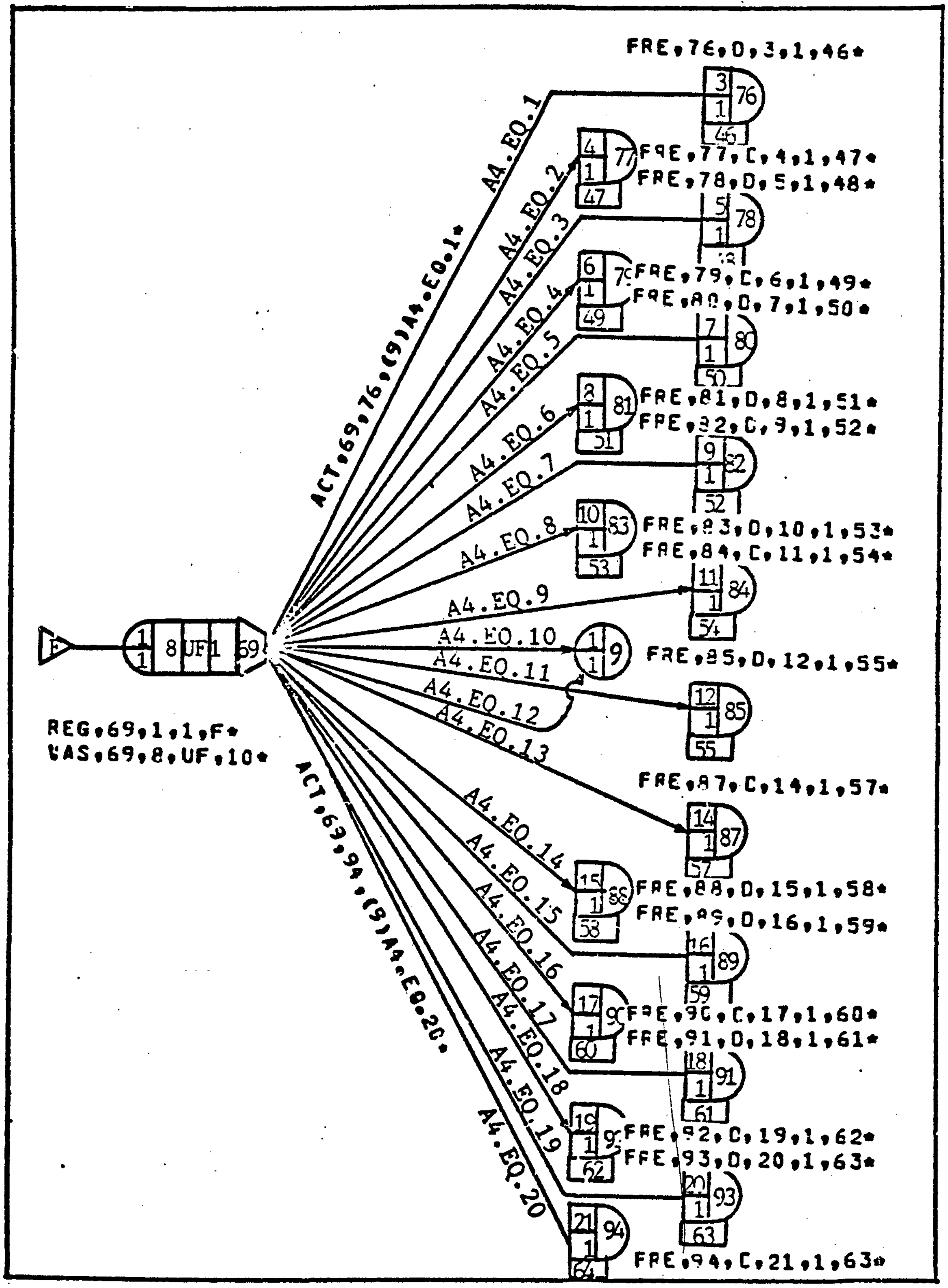

Figure 31 (Sheet 4). Q-GERT Diagram (Continued).

assigned by the VAS card, and attribute 8 is determined by user function UF(6). UF(6) assigns a value to attribute 8 that corresponds to the order that the equipment either initially started operation or returned to operation and is used to order the data to be printed in the equipment history. UF(6) also records the equipment start time.

The next node, node 11 uses two user functions. The first user function, UF(8) records the time that the equipment failed, and the second user function, UF(13), interrupts the service of any LRUs, if necessary, to free repairmen to fix broken equipment. Q-node 5 used a constant distribution to assign the value 1.0 to all transactions passing through it. User function 14 is called from node 13 to determine if a 3-level should be assigned to the repair activity. If a 3-level should be assigned, attribute 5 is not changed by UF(14), but if a 3-level should not be assigned, attribute 5 is set to zero. If the transaction is routed through node 3, attribute 7 is set to 1 to indicate that a 3-level is assigned to the task.

User functions are not called from the nodes listed on sheet 2 of the Q-GERT diagrams, but several user functions are called from the nodes drawn on sheet 3. Node 66 calls user function UF(9) to record the time that the LRU was removed from the equipment. In addition UF(9) records the number associated with the failed LRU. Nodes 67 and 37 use constant distributions to assign values corresponding to the number of 3- level and 5- level technicians assigned to the repair.

Node 69 on sheet 4 calls user function UF(10) to record the time that the repair of the LRU is completed. Back on sheet 1 three more user functions are called. Node 10 calls user functions UF(11) and UF(9). UF(11) is used to compute the time it takes to repair an equipment if the spare LRU is also broken, and UF(9) records the time that the repair of the equipment is started. The only user function left is UF(12) which is called by node 12. UF(12) is used to record the time that a system is returned to operation.

This chapter has explained the computerization of the parametric model developed in Chapter III. The next chapter will provide a validation and verification of the parametric and the computer models.

V VALIDATION AND VERIFICATION

Fishman and Kiviat (Ref 6) divide the evaluation of simulation projects into three categories: verification, validation, and problem analysis. Verification involves testing to insure that the model behaves the way the modeler intends; validation involves testing to see that the model is in agreement with the real system; and problem analysis involves drawing statistically significant inferences from the data generated by the simulation. This chapter examines the first two categories and Chapter VI presents the third category.

Validation

As stated in the previous paragraph, validation is testing to assure that the model is in agreement with the real system. Since the system being modeled for this thesis does not yet exist, testing for agreement between the model and the system is impossible. However, many tests can be performed to assure that the model does in fact provide information that would be consistant with the real system if it existed. For example, the availability data generated by this model could be compared with analytical availability data computed from the reliability and maintainability estimates used for this thesis or a history of the equipment operation and failures could be printed to determine if the model produced a realistic scenario of operation, failure, and repair of the equipment. The following subsections address the various methods used in this thesis to validate the model.

Availability. In Chapter II three questions were raised about the definition of reliability, which in turn affects the equipment availability. The questions concerned the determination of the operating environment, the determination of adequate performance and the probabilistic notion of equipment failure. The following paragraphs address these issues.

All of the equipment planned for the SAC Command Post upgrade is designed to operate in an air conditioned environment with controlled humidity. The environment at SAC Headquarters where the equipment will be operating meets these environmental criteria. Therefore, the predicted equipment reliabilities are appropriate for use in this thesis.

System performance is usually defined by operations personnel and is usually defined in three levels: satisfactory operation, impaired operation, and not operational. The determining factor on the adequate performance of the system is the amount of information that the system can provide to the users at any point in time. For simplicity, this thesis assumes two levels of operational availability, operational and not operational. The systems in this thesis are assumed to be operational if data can be provided to the users through half of the input and output devices associated with the system. Therefore the ILWSD system is considered operational as long as one of the disk drives, one of the display computers, three of the image generators, one of the video switch power supplies and four of the projectors are operational. The television monitors in the ILWSD system are convenience devices and for this thesis are not considered necessary for system operation. Similarly, the ADP system is considered operational as long as the command post computer and at least five ADP work stations are operational, and the CCTV system is considered operational as long as the RF modulator, six briefer stations, and ten television monitors are operating satisfactorily. The upgraded voice communications, on the other hand, consists of 54 individual units, and failure of half of any category of equipment would be considered a system failure for this thesis.

The probabilistic notion of equipment failure deals with the probability distribution and mean time between failure of the equipment being modeled. The exponential distribution was chosen to model the equipment reliability for several reasons. First, the exponential distribution has been shown to closely resemble the actual reliability of electronic equipment. In fact, the resemblence is sc close that MIL-HBBK-217B prescribes the use of the exponential distribution when modeling the reliability of electronic equipment. Another reason for using the exponential distribution is that the reliability data gathered for this thesis estimated equipment reliability using the exponential distribution. The final reason for using the exponential distribution is the memoryless property, which simplifies the FORTRAN programming and equipment reliability calculations.

The mean time between failures for the equipment was based on data obtained from several sources. The MTBFs for the display computer, command post computer, image generator, and video switches were obtained from the minutes of a critical design review for the Digital Television Element Backup, a system similar to the ILWSD system (Ref 13). Similarly, the MTBFs for the television monitor, disk drives, power supplies, and printers were obtained from articles and advertisements in trade magazines, and from vendor brochures. Finally, the MTBFs for the remaining equipment were estimated using information provided in telephone conversations with personnel working for MITRE Corporation (Washington D.C.) (Ref 20).

Table V contains a list of the reliability figures used to calculate the equipment reliabilities used in this thesis, and the source for the reliability figures. To calculate the equipment reliability the following formulas are used:

$$R(t) = e^{-(t/\theta)} \tag{4}$$

Table V

Reliability Data and Source

Equipment and LRUs	Failure Rate x 10^{-6} Hours	MTBF Hours	MTTR Hours	Source
Disk Drive	100.0	10000	.5	McLaughlin (Ref 15)
CPU Board	64.0	15625	.22	CDR Minutes (Ref 13)
MEM Board	80.0	12500	.22	CDR Minutes (Ref 13)
IF Board	34.8	28735	.22	CDR Minutes (Ref 13)
Pwr Sup Board	25.0	40000	.22	CDR Minutes (Ref 13)
IG IF Board	24.8	40322	.22	CDR Minutes (Ref 13)
Disk IF Board	20.0	50000	.22	CDR Minutes (Ref 13)
Blnk Cntl Board	20.8	48077	.22	CDR Minutes (Ref 13)
Proc Board	49.6	20157	.22	CDR Minutes (Ref 13)
Ref Mem Board	52.2	19157	.22	CDR Minutes (Ref 13)
Equalizer Amp	5.2	192308	.22	CDR Minutes (Ref 13)
LAN IU	100.0	10000	.5	MITRE (Ref 21)
Vid Sw Pwr Sup	25.0	40000	.5	CDR Minutes (Ref 13)
Computer Chassis	5.0	200000	.32	CDR Minutes (Ref 13)
IG Pwr Sup &Chas	20.0	40000	.43	CDR Minutes (Ref 13)
Video Switches	6.6	135135	.22	CDR Minutes (Ref 13)
ADP Terminal	100.0	10000	.5	MITER (Ref 20)
ADP Printer	100.0	10000	.5	Printek (Ref 22)
Projector	200.0	5000	.5	MITRE (Ref 20)
TV Monitors	146.9	6807	.4	CDR Minutes (Ref 13)
RF Modulator	50.0	20000	.5	MITRE (Ref 20)
TV Camera	25.0	40000	.5	MITRE (Ref 20)
Microphone	25.0	40000	.5	MITRE (Ref 20)

and

$$R_1(t)\cdots R_n(t) = \exp[-(t/\theta_1)]\cdots\exp[-(t/\theta_n)]$$
$$= \exp[-t(1/\theta_1 + \cdots + 1/\theta_n)] \quad (5)$$

Setting $1/\theta$ equal to λ produces the following equation:

$$R_1(t)\cdots R_n(t) = \exp[-t(\lambda_1 + \cdots + \lambda_n)] \quad (6)$$

In equations 4, 5, and 6, θ represents the MTBF t represents time and λ represents the failure rate. The equipment MTBFs were calculated using equation 6 and the failure rates provided in Table V. The failure rates for the upgraded voice communications system were omitted from the table because reliability estimates for the equipment could not be obtained, therefore conservative estimates were made.

The system availability for the ILW&D system can be calculated using the following formula: (Ref 9)

$$A_s = [1-(1-A_1)^2][1-(1-A_2)^2][1-(1-A_3)^2] \quad (7)$$
$$[\sum_{x=3}^{6}\binom{6}{x}A_4^x(1-A_4)^{6-x}][\sum_{x=4}^{8}\binom{8}{x}A_5^x(1-A_5)^{8-x}]$$

Where A_1 is the availability of the display computer, A_2 is the availability of the disk drive, A_3 is the availability of the video switch power supply, A_4 is the availability of an image generator, and A_5 is the availability of a projector. Similar formulas can be used to obtain the predicted availabilities for the other systems. Using the formulas, the following availabilities were predicted:

ILWSD system, .99999965; ADP system, .9997982; CCTV system, .9997; and upgraded voice communications, .99989975. These availabilities were predicted using the estimated mean time between failures and a mean time to repair of .5 hours.

Since the system availability predictions are so high it is very possible that a system failure would not occur during a reasonable length simulation run. Therefore, one measure of the reasonableness of the model could be the number of times a system failure occurs. Another measurement could be to compare the equipment availabilities generated by the simulation program with the availabilities predicted using analytical techniques.

History Report. Another approach to validating the computer model of the SAC Command Post upgrade equipment is to print a history of equipment failures and examine it to see if it reasonably approximates reality. Several things could be examined in the history, for instance, if the MTBF were cut in half it is reasonable to expect the number of failures to double if nothing else is changed. Similarly, if the MTTR LRU, is doubled it is reasonable to expect the average number of spares available to drop.

Conclusions on Validity. The model developed for this thesis does adequately represent the systems described in Chapter II. In 24 runs of the simulation program, a failure of the ILWSD system occurred only once and the availabilities of the equipment closely corresponded to the availabilities computed analytically under the same conditions. Furthermore the printed history of equipment operation,failure and repair bore a strong resemblence to equipment operation,failure and repair of real equipment. A sample history is included in appendix C.

<u>Verification</u>

As stated earlier in this chapter, verification is insuring that the model performs the way the modeler intends. A number of tests were accomplished it verify the model developed for this thesis. During the development of the Q-GERT code, traces were printed out after each run of the network. A trace is an option available in Q-GERT which allows the modeler to observe a printed record of the arrivals of transactions at nodes and the release of transactions from nodes. With a nodal trace the modeler can actually follow the simulation run through the network to see that it performs as intended.

To verify the FORTRAN code, each subroutine and function was developed separately and tested before and after it was included in the Q-GERT program. After the FORTRAN code was installed in the Q-GERT program,calls were made to see that the functions operated as expected with the other code and to see that if calls to more than one user function were made from the same node that the calls were in the proper order.

Experimental Design

As stated in Chapter I the purpose of this thesis is to develop, test and validate a model which can be used to determine the number and skill level mix of Air Force maintenance personnel required to maintain the equipment systems proposed for the upgraded SAC Command Post. Other objectives include testing the sensitivity of the maintenance crew size to variances in MTBF, MTTR, system size, and system availability; and test the sensitivity of system availability to variances in MTBF, MTTR, system size, spares level, and crew size. To accomplish these a 2^5 factorial experiment was set up.

A 2^5 factorial design consists of five factors of interest each factor set at two levels. The factors considered for this experiment are: crew size and skill level mix, spares level, mean time between failure, mean time to repair the system and mean time to repair the LRUs. To determine what levels to run for each factor two approaches were taken. For the crew size and skill level mix, and the spares level test runs of were made on the network with the resources level for both factors set to 10. The results of these runs indicated that the required level of maintenance personnel is either two or three, and the required level of spares is either one or two. Since one third to one half of each maintenance crew would be 3-level technicians it was decided to run the experiment with one 5-level and one 3-

level technician as the low level, and two 5-level and one 3-level technicians as the high level for the maintenance crew factor. From the test runs it was also determined that the low level for spares should be one and the high level should be two.

The levels for the other factors were determined in another manner. The MTBFs for the various equipment were determined from the sources listed in Table V and these MTBFs were used as the high levels for the experiment. To select a value for the low level the MTBFs were divided by two. Similarly the equipment MTTRs were derived from the data provided in Table V. From this data it was decided to use the value .5 hours for the high level and the value 2.0 for the low level. Data was not available to help determine the MTTR LRUs, therefore estimates of repair time were made of how long it would take to repair LRUs with and without automated test equipment. These estimates are 4 hours with automated test equipment and 16 hours without it. Therefore 4 hours was chosen to be the high level and 16 hours was chosen to be the low level. As can be seen by examining the choices for the high and low levels, the values chosen for high levels are those levels that would tend to produce a higher availibility and those chosen for the low level would tend to produce a lower availability.

To provide a reasonable estimate of the error associated with the observations, multiple runs of the network were made. In this case three runs were made for each factor level where observations were taken. Making three observations per factor level allows one degree of freedom to be used in estimating the value of the contrasts associated with each main effect and the interactions, and two degrees of freedom per cell to estimate error.

Finally, the duration of the simulation was determined. To determine the run time for the simulation program, the model was run at four times, 5000, 10000, 20000, and 40000 hours. At 5000 hours over one third of the equipment modeled did not experience failure, and at 10000 hours nearly 20 percent of the equipment did not experience failures. However, at 20000 and 40000 hours over 95 precent of the equipment failed, indicating that 20000 hours was a sufficient duration for the simulation.

Variance Reduction. Variance reduction techniques are used to reduce the total number of runs of the simulation network in order to get meaningful results. For this thesis, common random number streams were used for variance reductions.

When using common random number streams the modeler selects one stream and a seed for the stream and used the same number stream for all corresponding runs of the network. If multiple observations are taken per cell, the modeler selects a different number stream for those runs. In this experiment six random number streams were used on each run. One random number stream was used for the MTBFs, another for the MTTR equipment, another for the MTTR LRUs, and three random number streams for selecting samples from the uniform distribution. Each of these random number streams used the default seed and the streams were changed to obtain different observations for the same factor levels. None of the random streams chosen was the default stream, thereby further reducing the variance.

Replication Minimization. With a full factorial 2^5 experiment with three observations per cell 96, runs of the network would be required to gather the data necessary to determine which factors are significant. Furthermore, if the model had to be run for three different systems the number of runs would jump to 288 and the number of observations would be staggering. Therefore, preliminary analysis was performed to determine how to reduce the number of runs of the network and still obtain valid results.

The first analysis performed to minimize the number of replications required to obtain valid results involved examining the three systems being modeled. In all three systems a minimum of two repairmen were required to maintain each system. If no more than two repairmen were required to maintain the most complex and largest of these systems, then no more than two repairmen would be required to maintain the smaller, less complex systems. Furthermore if only one spare LRU is required to maintain the system with the lowest MTBF, then the other systems would also require only one spare LRU to support the same amount of equipment with a higher MTBF. One system, the ILWSD and ADP system has both a lower MTBF and a larger more complex system. Therefore, the ILWSD and ADP systems model was run to determine if any of the factors could be eliminated from the model of the other two models.

Even if all of the factors were found to be insignificant, and no runs were required for the two simpler models, the full 2^5 factorial experiment would require 96 simulation runs and would produce an extremely large amount of data for analysis. Therefore, each of the factors initially considered for this model was examined to see if it could be eliminated from the experiment. Maintenance technicians certainly could not be eliminated from the experiment because determination of the appropriate crew size is the main purpose of this model. Similarly spares level and reliability cannot be removed from the experiment. However, changing the MTTR for the equipment from .5 hours to 2.0 hours will have an extremely small impact on the equipment reliability. For example, changing the MTTR for the display computer the equipment with the lowest MTBF, from .5 to 2.0 reduces the availability of the equipment from .9998 to .9992. Finally, varying the MTTR LRUs appears to have a large effect on the amount of time that the maintenance technicians were busy. Therefore, equipment MTTR was eliminated from the experiment.

By eliminating one factor from the experiment the number of runs was reduced to 48 and the experiment became a full factorial 2^4 experiment. Further examination of the model indicated that spares level appeared to have little impact on the availability or the maintenance crew size. However, since one of the objectives of the thesis is to determine the impact of variance of spares levels it cannot be eliminated from the experiment. One way of including the spares level into the experimental design but still reduce the number of runs is a fractional factorial experiment.

The problem of performing a fractional factorial experiment in a 2^4 design is that the first order interactions are confounded with other first order interactions and the main effects are confounded with the second order interactions. Fortunately, if there is good reason to suspect that one of the main effects is insignificant, the first and second order interactions associated with that main effect are also insignificant. In fact, if the main effect were zero, the interactions containing that main effect also would be zero had the confounding would be insignificant.

For the reasons listed in the above paragraphs the experimental design for this thesis was reduced from a 2^5 full factorial experiment on three models to a $\frac{1}{2}\ 2^4$ fractional factorial design. The specific design used in this thesis was taken from Hicks (Ref 7:308,309). In this design, the full factorial 2^4 design was divided into two blocks in which all main effects were confounded with second order interactions and the first order interactions were confounded with other first order interactions which were considered to be zero. The resulting blocks are as follows

block I	(1)	ab	cd	abcd	ac	bc	ad	bd
block II	a	b	acd	bcd	c	abc	d	abd

After the blocks were created, block I was chosen at random and the corresponding experiments were run on the display and ADP systems model. The runs associated with design (1) had all of the factors set to the low level, design abcd had all of the factors set to the high level, design ab had factors a and b set to the high level and factors c and d set to the low level, and so forth. The results of the runs are contained in Appendix B.

Analysis of the Observations

The model developed for this thesis provided two types of observations of concern. The first set of observations are the equipment availabilities and the second set are the maintenance technician utilizations. Both equipment availability and technician utilization were analyzed using Yates technique (Ref 7:118,119). Tables VI and VII con-atin the analyses on one set of availability data and

Table VI

Yates Method applied to Availability Data

Trtmts	Response	(1)	(2)	(3)	(4)	SS	MS	F Ratio
(1)	2.9845	2.9845	5.9828	11.9822	23.9783			
a		2.9983	5.9994	11.9961	.0139	.000008	.000008	32.14
b		2.9997	5.9970	.0138	.0143	.000009	.000009	35.71
ab	2.9983	2.9997	5.9991	.0001	-.0145	.000009	.000009	35.71
c		2.9984	.0138	.0138	.0187	.000014	.000014	50.00
ac	2.9997	2.9986	.0000	.0005	-.0133	.000007	.000007	25.00
bc	2.9997	2.9994	-.0002	-.0166	-.0139	.000008	.000008	32.14
abc		2.9997	.0003	.0021	.0139	.000008	.000008	32.14
d		-2.9845	.0138	.0166	.0139			
ad	2.9984	2.9983	.0000	.0021	-.0139			
bd	2.9986	2.9997	.0002	-.0138	.0133			
abd		-2.9986	.0003	.0005	.0187			
cd	2.9994	2.9984	5.9828	-.0138	-.0145			
acd		-2.9986	-5.9994	.0001	.0143			
bcd		-2.9994	-5.9970	-11.9822	.0139			
abcd	2.9997	2.9997	5.9991	11.9961	23.9983			
					error	.00000450	.00000028	

Table VII

Yates Method Applied To Utilization Data

Trtmnt	Response	(1)	(2)	(3)	(4)	SS	MS	F Ratio
(1)	1.111	1.111	1.602	2.358	3.605			
a		.501	.756	1.247	-1.505	.0528	.0528	117.85
b		.192	.838	-.984	-.057	.0001	.0001	.22
ab	.501	.564	.409	-.521	.417	.0068	.0068	15.18
c		.244	-.610	-.236	-1.275	.0682	.0682	152.23
ac	.192	.594	-.374	.179	.415	.0072	.0072	16.08
bc	.564	.290	-.350	.846	.461	.0088	.0088	19.64
abc		.119	-.171	-.429	-1.111	.0514	.0514	114.73
d		-1.111	-.610	-.846	-1.111			
ad	.244	.501	.374	-.429	.461			
bd	.594	.192	.350	.236	.415			
abd		-.564	-.171	.179	-1.275			
cd	.290	.244	1.602	.984	.417			
acd		-.594	-.756	-.521	-.057			
bcd		-.290	-.838	-2.358	-1.505			
abcd	.119	.119	.409	1.247	3.605			
					error	.0072	.000448	

on the technician utilization data.

Hicks describes Yates method as a procedure that reduces the analysis to a simple adding and subtracting of numbers. To perform Yates method of analysis the analyst lists the treatment combinations in the first column as shown in Tables VI and VII. In the second column the analyst records the total response to each of the treatment combinations. When a fractional factorial design is used those responses corresponding to treatment combinations not tested are left blank. The third column is labeled (1) and the values entered in the first eight positions are the pair wise sums of the responses listed in the second column. For example, in Table VI the first entry is the sum of 2.9845 and zero, and the second entry is the sum of zero and 2.9983. The final eight entries in the third column is the pair wise difference of the entries in the second column. For example, in Table VI the ninth entry is -2.9845, the difference between zero and 2.9845.

The entries in the fourth column, labeled (2),are obtained by pair wise addition and subtraction of the third column. The entries for the fifth and sixth columns, labeled (3) and (4), are obtained in the same manner. The values contained in the sixth column are the contrasts.

The seventh column contains the sum of the squares of the contrasts. To obtain the sum of the squares of the contrasts, the analyst must square the entries in the column labeled (4) and divide the resulting number by $3 \cdot 2^3$, where

3 is the number of observations per cell and 2^3 is the full factorial equivalent of the $\frac{1}{2}2^4$ factorial experiment.

The sum of the squares error and sum of the squares total must be calculated in another way, however. The sum of the squares total is computed by squaring each of the original observations and adding the results. In Table VI the sum of the squares total is: $(.9999)^2+(.9999)^2+(.9998)^2+(.9999)^2+(.9997)^2+(.9998)^2+(.9995)^2+(.9999)^2+(.9992)^2+(.9977)^2+(.9998)^2+(.9998)^2+(.9997)^2+(.9993)^2+(.9994)^2+(.9999)^2+(.9999)^2+(.9998)^2+(.9995)^2+(.9991)^2+(.9997)^2+(.9949)^2+(.9945)^2+(.9951)^2 = 23.9514$. The sum of the squares error is computed by summing the squares of the differences between the observation ond mean value of each cell. The sum of the squares error for Table VI is .00000371.

The mean square are computed by dividing the sum of the squares by the degrees of freedom. In this case the mean squares for the first and second order interactions is the same as the sum of the squares, and the mean square error is $.00000371/16 = .00000023$.

To compute the F significants of the contrasts the sum of the squares of the contrast is divided by the sum of the squates error and compared to the F statistic with one degree of freedom in the numerator and 16 degrees of freedom in the denominator. The F statistic for Tables VI and VII are 3.05 for a .10 confidence level and 4.49 for a .05 confidence level. All of the F ratios in Table VI exdeed the F statistics, therefore all of the contrasts and interactions are significant at the .05 level.

The Yates method was also applied to the maintenance technician utilization data and the results are in Table VII. From Table VII it can be seen that only contrast b is insignificant. Contrast b corresponds to the spares level.

Appendix B contains the equipment availability and repairman utilization data generates by the simulation runs. From the data in Appendix B it can be seen that the data analyzed in Table VI is representative of the availabilities of all of the equipment in the ILWSD and the ADP systems. The conclusions that can be drawn from the the results of this simulation program are contained in Chapter VI.

VI CONCLUSIONS AND RECOMMENDATIONS

The final part of the evaluation of a simulation project is the problem analysis. In this step the results of the simulation are evaluated to see if statistically significant inferences can be made. The following section identifies the inferences that can be drawn from this thesis effort, and the last section identifies additional areas of research that could be performed on this problem.

Conclusions

As stated in Chapter I the primary objective of this thesis is to develop, test, and validate a model which can be used to determine the number and skill level mix of Air Force maintenance personnel necessary to maintain the electronic equipment in the upgraded SAC Command Post. The simulation model developed, tested and validated for this thesis satisfies this objective. Although the reliabilities used in this model may not be the same as the reliabilities of the equipment which will eventually be installed at the SAC Command Post and the equipment may vary somewhat from the configuration used in this thesis, the model can be easily modified to accomodate any differences. Furthermore, the model shows that not more than two technicians, one 5- level and one 3-level, per crew are are required to maintain the equipment planned for the upgraded SAC Command Post.

This thesis also has two subobjectives. The first subobjective is to determine the sensitivity of the maintenance crew size to variance in equipment reliability and maintainability, system size and complexity, spares level, and system availability. The second subobjective is to determine the sensitivity of system availability to variance in equipment reliability and maintainability, system size and complexity, spares level, and crew size. The following subsections address these subobjectives.

<u>Crew Size</u>. The data in Table VI, Chapter V, illustrates the analysis of the data gathered from the simulation runs on repairman utilization. Four factors were analyzed in this Table: crew size, represented by factor a; spares level, represented by factor b; equipment reliability (MTBF), represonted by factor c; and LRU repair time, represented by factor d. The first conclusion that can be drawn from Table VII is that the spares level has no significant impact on maintanance personnel utilization for the levels of equipment reliability, crew size and LRU repair rates chosen. This is apparent because the F ratio for factor b is 0.22 and the .10 significance level for the F test is 3.05. Since the spares level is so insignificant, the first order interactions associated with the spares level will also be insignificant, probably very close to zero. Therefore, the first order interactions that are confounded with the first order interactions containing factor b will not be significantly

affected by the confounding.

All other main effects and first order interactions are significant, even at the .01 level. This indicates that changes in equipment reliability, LRU repair time and crew size do affect the amount of time each maintenance technician works. The significance of equipment reliability and LRU repair time is obvious since doubling the number of failures will double the amount of work and quadrupling the LRU repair time will increase the amount of time spent on each job. Similarly, it is obvious that increasing the number of maintenance personnel will decrease the amount of work each repairman must perform.

From the data gathered in the simulation runs (see Appendix B) it can be seen that two maintenance technicians would be able to maintain the electronic systems described in this thesis at an availability greater than .99. In addition, the policy in 1ACOMGP is to have three shifts performing maintenance: Day Shift, working from 0730 to 1630; Swing Shift, working from 1630 to 2400; and Mid Shift, working from 2400 to 0730. With these constraints three technicians would be required on each shift to provide seven day a week coverage, and a fourth technician would be required to cover for leaves. This results in twelve technicians to cover three shifts. If however a rotating shift schedule were used the number of technicians required to maintain the equipment would be reduced to 10, five crews containing two technicians each. In addition to the technicians on crew, the maintenance shop will require one technician to be the shop superintendent. Since the CCTV and the upgraded voice systems are smaller and have higher equipment reliabilities than the ILWSD and ADP systems, two maintenance technicians per crew would also be able to maintain the equipment in each of those systems.

Since the exponential distribution was used to model the eqipment reliabilities, doubling the equipment failure rates is essentially the same as doubling the size of the system. Therefore the following conclusions can be drawn from the data in Appendix B:

1. Increasing the number of technicians per crew reduces the amount of time each technician works, but two technicians per crew in each maintenance shop can maintain the equipment at a greater than 99 percent availability.
2. Doubling the failure rate, or equivalently doubling the system size, has a significant effect on the amount of time each technician works, but with the system modeled for this thesis two technicians would be capable of maintaining a system with double the failures and still maintain an availability greater than 99 percent.
3. Quadrupling the repair time for the LRUs significantly affects the amount of time each technician

spends working, but two technicians are still capable of maintaining an equipment availability greater than 99 percent.

Availability. The sensitivity of equipment availability to variance in crew size, spares level, equipment reliability, and LRU repair time was analyzed in Table VI. From Table VI it can be seen that even though the equipment availability never dropped below 99 percent, all factors analyzed in this thesis were significant, even at the .01 level. This implies that large enough changes in the equipment reliability, system size, spares level, or LRU MTTR could significantly reduce the equipment availability. Furthremore, all of the first order interactions were significant. This implies that changes in the more than one factor would produce an even greater change in the system availability.

Although all of the factors analyzed have a significant effect on the equipment availability, the modeled systems would still have an availability greater than 99 percent even if the system size were doubled. This implies that at the reliabilities used in this model, there is a great deal of variance that can occur before the equipment availability is seriously affected.

Recommendations

The analysis performed for this thesis was accomplished using estimates of the system design, equipment reliabilities and maintainabilities, and the LRU repair time. When the final system design for the upgraded SAC Command Post is determined, the model developed for this thesis should be modified to reflect any defferences and run to determine if the crew size estimated in this thesis is still valid.

In this thesis the systems were modeled to determine how many maintenance technicians are required to maintain the equipment modeled. At SAC Headquaretrs, however, there are many existing maintenance shops. A study should be performed to determine if the existing maintenance shops could maintain the new equipment with little or no increase in manpower requirements. Possible maintenance shops to evaluate for this study incluse the Digital Television Element (DTVE) maintenance, the SACDIN maintenance, and the future CCPDS maintenance shops.

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APPENDIX A

COMPUTER PROGRAMS

```
      SUBROUTINE UI
*****************************************************************
*                                                               *
*     THIS USER SUBROUTINE INITIALIZES ARRAY AVAIL(I,J)         *
*          AND VARIABLE ATRB8                                   *
*                                                               *
*****************************************************************
      COMMON /QVAR/ NDE,NFTBU(100),NREL(100),NRELP(100),NRUNS,
     +NREL2(100),NRUN,NTC(100),PARAM(100,4),TBEG,TNOW
      COMMON /HAL/ AVAIL(500,7),ATRB8
      X = .0
      DO 10 J=1,7
        DO 20 I=1,500
          AVAIL(I,J) = X
 20     CONTINUE
        X = 20000.0
 10   CONTINUE
      ATRB8 = 0.0
      CALL CPLO(9)
      CALL CPLO(10)
      CALL CPLO(11)
      CALL CPLO(12)
      CALL CPLO(13)
      CALL CPLO(14)
      CALL CPLO(15)
      CALL CPLO(16)
      CALL CPLO(21)
      RETURN
      END
```

```
      FUNCTION UF(IFN)
C************************************************************************
C     [illegible]                                                       *
C                                                                       *
C     THE USER FUNCTIONS (UF) IN THIS Q-GERT PROGRAM PERFORM            *
C     THE FOLLOWING FUNCTIONS:                                          *
C                                                                       *
C     UF1 COMPUTES THE MEAN TIME BETWEEN FAILURES FOR EACH              *
C         ELECTRINIC SYSTEM IN THE COMMAND POST                         *
C                                                                       *
C     UF2 COMPUTES THE TIME REQUIRED TO TROUBLESHOOT, AND               *
C         REMOVE AND REPLACE A FAILED LINE REPLACABLE UNIT (LRU)        *
C                                                                       *
C     UF3 COMPUTES WHICH LRU FAILED CAUSING THE SYSTEM FAILURE          *
C                                                                       *
C     UF4 COMPUTES THE NUMBER OF REPAIRMEN REQUIRED TO REPAIR           *
C         THE FAILED SYSTEM                                             *
C                                                                       *
C     UF5 COMPUTES THE TIME REQUIRED TO TROUBLESHOOT, AND               *
C         REPAIR A FAILED SYSTEM IF ONE OF THE REPAIRMEN IS             *
C         A 3-LEVEL MAINTENANCE TECHNICIAN                              *
C                                                                       *
C     UF6 COMPUTES THE TIME THAT A SYSTEM STARTED OPERATION             *
C         OR RETURNED TO OPERATION AFTER A FAILURE                      *
C                                                                       *
C     UF8 RECORDS THE TIME THAT EACH SYSTEM FAILED                      *
C                                                                       *
C     UF9 RECORDS THE TIME THAT REPAIR WORK STARTED ON EACH LRU         *
C                                                                       *
C     UF10 RECORDS THE TIME THAT EACH LRU REPAIR WAS COMPLETED          *
C                                                                       *
C     UF11 COMPUTES THE SYSTEM REPAIR TIME IF THE SPARE LRU             *
C          NOT AVAILABLE                                                *
C     UF12 RECORDS THE TIME THAT SYSTEM REPAIR WAS COMPLETED            *
C                                                                       *
C     UF13 INTERUPTS REPAIR OF A BROKEN LRU IF A SYSTEM FAILS           *
C          OCCURS AND THERE ARE NO IDLE TECHNICIANS                     *
C                                                                       *
C     UF14 DETERMINES IF A 3-LEVEL SHOULD BE ASSIGNED                   *
C                                                                       *
C************************************************************************
      COMMON /QVAR/ NDE,NFTBU(100),NREL(100),NRELP(100),NRUNS,
     +NREL2(100),NRUN,NTC(100),PARAM(100,4),TBEG,TNOW
      COMMON /HAL/ AVAIL(800,7),ATRIB
      REAL LO
      GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14) IFN
```

```
*****************************************************************
*                                                               *
*     COMPUTE THE MTBF FOR EACH SYSTEM                          *
*                                                               *
*****************************************************************
  1 IF (GATRB(1).LE.10) THEN
       LF = EX(1)
*      COMMAND POST ADF WORK STATION
    ELSEIF (GATRB(1).LE.12) THEN
       LF = EX(2)
*      DISPLAY COMPUTER SYSTEM
    ELSEIF (GATRB(1).LE.13) THEN
       LF = EX(3)
*      COMMAND POST ADF COMPUTER
    ELSEIF (GATRB(1).LE.16) THEN
       LF = EX(4)
*      DISK DRIVES FOR THE COMPUTERS
    ELSEIF (GATRB(1).LE.1[illegible]) THEN
       LF = EX(5)
*      VIDEO SWITCH POWER SUPPLY
    ELSEIF (GATRB(1).LE.24) THEN
       LF = EX(6)
*      IMAGE GENERATORS\
    ELSEIF (GATRB(1).LE.36) THEN
       LF = EX(7)
*      TELEVISION MONITOR STRING
    ELSE
       LF = EX(8)
*      LARGE SCREEN PROJECTOR STRING
    ENDIF
    RETURN
```

```
*************************************************************************
*                                                                       *
*     COMPUTE THE TIME REQUIRED TO REPAIR A FAILED SYSTEM               *
*                                                                       *
*************************************************************************
    2 IF (GATRB(1).LE.10) THEN
        LF = .1+LC(9)
*       COMMAND POST ADP WORK STATION
      ELSEIF (GATRB(1).LE.12) THEN
        LF = .1+LC(10)
*       DISPLAY COMPUTER SYSTEM
      ELSEIF (GATRB(1).LE.13) THEN
        LF = .1+LC(11)
*       COMMAND POST ADP COMPUTER
      ELSEIF (GATRB(1).LE.16) THEN
        LF = .1+LC(12)
*       DISK DRIVES
      ELSEIF (GATRB(1).LE.18) THEN
        LF = .1+LC(13)
*       VIDEO SWITCH POWER SUPPLY
      ELSEIF (GATRB(1).LE.24) THEN
        LF = .1+LC(14)
*       IMAGE GENERATORS
      ELSEIF (GATRB(1).LE.36) THEN
        LF = .1+LC(15)
*       TELEVISION MONITOR STRING
      ELSE
        LF = .1+LC(16)
*       LARGE SCREEN PROJECTOR STRING
      ENDIF
      RETURN
```

```
*     *****************************************************************
*                                                                     *
*     DETERMINE WHICH LRU FAILED CAUSING THE SYSTEM FAILURE           *
*                                                                     *
*     *****************************************************************
    3 PROB = UN(17)
      IF (GATRB(1).LE.10) THEN
*       COMMAND POST ADF WORK STATIONS
        IF (PROB.LE.33) THEN
          LF = 1.0
*         ADF TERMINAL
        ELSEIF (PROB.LE.66) THEN
          LF = 2.0
*         HARDCOPY PRINTER
        ELSE
          LF = 3.0
*         LAN INTERFACE UNIT
        ENDIF
      ELSEIF (GATRB(1).LE.12) THEN
*       DISPLAY COMPUTER SYSTEM
        IF (PROB.LE.6) THEN
          LF = 3.0
*         LAN INTERFACE UNIT
        ELSEIF (PROB.LE.22) THEN
          LF = 4.0
*         CPU BOARD
        ELSEIF (PROB.LE.42) THEN
          LF = 5.0
*         MEMORY BOARD
        ELSEIF (PROB.LE.47) THEN
          LF = 6.0
*         DISK INTERFACE BOARD
        ELSEIF (PROB.LE.56) THEN
          LF = 7.0
*         COMPUTER INTERFACE BOARD
        ELSEIF (PROB.LE.62) THEN
          LF = 8.0
*         POWER SUPPLY BOARD
        ELSEIF (PROB.LE.99) THEN
          LF = 9.0
*         IMAGE GENERATOR INTERFACE BOARD
        ELSE
          LF = 10.0
*         COMPUTER CHASSIS PARTS
        ENDIF
      ELSEIF (GATRB(1).LE.13) THEN
*       COMMAND POST ADF COMPUTER
        IF (PROB.LE.8) THEN
          LF = 3.0
*         LAN INTERFACE UNIT
```

```
          ELSEIF (PROB.LE.34) THEN
            LF = 4.
*           CPU BOARD
          ELSEIF (PROB.LE.66) THEN
            LF = 5.
*           MEMORY BOARD
          ELSEIF (PROB.LE.74) THEN
            LF = 6.0
*           DISK INTERFACE BOARD
          ELSEIF (PROB.LE.88) THEN
            LF = 7.0
*           COMPUTER INTERFACE BOARD
          ELSEIF (PROB.LE.99) THEN
            LF = 8.0
*           POWER SUPPLY BOARD
          ELSE
            LF = 10.
*           COMPUTER CHASSIS PARTS
          ENDIF
        ELSEIF (GATRB(1).LE.16) THEN
          LF = 11.0
*         DISK DRIVE
        ELSEIF (GATRB(1).LE.18) THEN
          LF = 12.0
*         VIDEO POWER SUPPLY
        ELSEIF (GATRB(1).LE.24) THEN
*         IMAGE GENERATORS
          IF (PROB.LE.15) THEN
            LF = 13.0
*           IMAGE GENERATOR PROCESSOR BOARD
          ELSEIF (PROB.LE.79) THEN
            LF = 14.0
*           REFRESH MEMORY BOARD
          ELSEIF (PROB.LE.92) THEN
            LF = 15.0
*           BLINK AND OUTPUT CONTROL CARD
          ELSE
            LF = 16.0
*           POWER SUPPLY AND CHASSIS
          ENDIF
        ELSEIF (GATRB(1).LE.36) THEN
*         TELEVISION MONITOR STRING
          IF (PROB.LE.92) THEN
            LF = 17.0
*         TELEVISION MONITOR
```

```
        ELSEIF (P[illegible].LE.[illegible]) THEN
          UF = 1[illegible].
*         EQUALIZER AMPLIFIER
        ELSE
          UF = 19.
*         VIDEO SWITCH
        ENDIF
      ELSE
*       LARGE SCREEN PROJECTOR STRING
        IF (PROB.LE.93) THEN
          UF = 2
*         PROJECTOR
        ELSEIF (PROB.LE.95) THEN
          UF = 1[illegible]
*         EQUALIZER AMPLIFIER
        ELSE
          UF = 19
*         VIDEO SWITCH
        ENDIF

      ENDIF
      RETURN
******************************************************************
*                                                                *
*     COMPUTE THE NUMBER OF REPAIRMEN REQUIRED TO FIX THE SYSTEM *
*                                                                *
******************************************************************
    4 IF (GATRB(3).EQ.17.OR.GATRB(3).EQ.2J) THEN
        UF = 2.0
*       TV MONITOR OR PROJECTOR
      ELSE
        UF = 1.0
*       ALL OTHER SYSTEMS
      ENDIF
      RETURN
******************************************************************
*                                                                *
*     COMPUTE REPAIR TIME IF 3-LEVEL ASSISTS IN REPAIR           *
*                                                                *
******************************************************************
    5 UF = GATRB(3)*UN(14)
      RETURN
```

```
*************************************************************************
*                                                                       *
*     RECORD THE TIME THAT THE SYSTEM STARTED OPERATION                 *
*                                                                       *
*************************************************************************
   6 ATRB(3) = ATRB(3) + 1.0
     NUMB = INT(ATRB(3))
     AVAIL(NUMB,1) = GATRB(1)
     AVAIL(NUMB,2) = TNOW
     LF = ATRB(4)
     RETURN
*************************************************************************
*                                                                       *
*     DETERMINE THE SKILL LEVEL OF THE NEXT REPAIRMAN ASSIGNED          *
*                                                                       *
*************************************************************************
   7 IF (GATRB(9).GE.1.0.AND.GATRB(7)+GATRB(6).GE.GATRB(5)) THEN
       LF = 6.0
     ELSE
       LF = GATRB(5)
     ENDIF
     RETURN
*************************************************************************
*                                                                       *
*     RECORD THE TIME OF EACH SYSTEM FAILURE                            *
*                                                                       *
*************************************************************************
   8 NUMB = INT(GATRB(8))
     AVAIL(NUMB,3) = TNOW
     LF = GATRB(3)
     RETURN
*************************************************************************
*                                                                       *
*     RECORD THE TIME THAT REPAIR OF EACH LRU STARTED                   *
*                                                                       *
*************************************************************************
   9 NUMB = INT(GATRB(8))
     AVAIL(NUMB,4) = GATRB(4)
     AVAIL(NUMB,5) = TNOW
     LF = GATRB(3)
     RETURN
*************************************************************************
*                                                                       *
*     RECORD THE TIME THAT EACH LRU REPAIR WAS COMPLETED                *
*                                                                       *
*************************************************************************
  10 NUMB = INT(GATRB(8))
     AVAIL(NUMB,6) = TNOW
     LF = GATRB(9)
     RETURN
```

```
*     ... ..... ............................................................
*                                                                          *
*      COMPLETE SYSTEM REPAIR TIME WITH NO SPARE LRU                      *
*                                                                          *
****************************************************************************
   11 IF (GATRB(1).NE.10.OR.GATRB(1).NE.12) THEN
        LF = LC(22)
      ENDIF
      RETURN
****************************************************************************
*                                                                          *
*      RECORD TIME SYSTEM WAS RETURNED TO OPERATION                        *
*                                                                          *
****************************************************************************
   12 NUMB = INT(GATRB(8))
      AVAIL(NUMB,7) = TNOW
      AVAIL(NUMB,6) = TNOW
      LF = GATRB(5)
      RETURN
****************************************************************************
*                                                                          *
*      PREEMPT REPAIR OF SPARE FOR FAILED SYSTEM                           *
*                                                                          *
****************************************************************************
   13 IF(ISTUS(35,5).GT.0.AND.ICSPA(1)+ICSPA(2).LT.GATRB(5)) THEN
        CALL STAGC(5,9,0.1,0,ATT)
         PRINT*,'NO SERVERS AVAILABLE'
      ENDIF
      LF = GATRB(5)
      RETURN
****************************************************************************
*                                                                          *
*      DETERMINE IF A 3-LEVEL SHOULD BE ASSIGNED                           *
*                                                                          *
****************************************************************************
   14 IF(ICSRA(2).EQ.0.AND.GATRB(5).EQ.1) LF = 0
      RETURN
      END
```

```
      SUBROUTINE LT
*************************************************************************
*                                                                       *
*     THIS USER SUBROUTINE SORTS THE DATA GATHERED DURING THE          *
*     RUNS AND PRINTS A HISTORY OF THE SYSTEM OPERATION                 *
*     FAILURES, AND REPAIR ACTIVITIES, THEN COMPUTES AND PRINTS        *
*     THE AVAILABILITY OF EACH SYSTEM                                   *
*                                                                       *
*************************************************************************
      COMMON /HAL/ AVAIL(500,7),ATRBS
      CHARACTER*8 EQUIP,LRU
      REAL EGAV(44)
*************************************************************************
*                                                                       *
*     SET ARRAY EGAV EQUAL TO 0.0                                       *
*                                                                       *
*************************************************************************
      DO 100 I=1,44
        EGAV(I) = 0.0
100   CONTINUE
*************************************************************************
*                                                                       *
*     SORT THE DATA BASED ON THE FAILURE TIME OF THE SYSTEM             *
*                                                                       *
*************************************************************************
      DO 500 I=1,ATRBS
        DO 600 J=I,ATRBS
          IF (AVAIL(I,3).GT.AVAIL(J,3)) THEN
            AVAIL1 = AVAIL(I,1)
            AVAIL2 = AVAIL(I,2)
            AVAIL3 = AVAIL(I,3)
            AVAIL4 = AVAIL(I,4)
            AVAIL5 = AVAIL(I,5)
            AVAIL6 = AVAIL(I,6)
            AVAIL7 = AVAIL(I,7)
            AVAIL(I,1) = AVAIL(J,1)
            AVAIL(I,2) = AVAIL(J,2)
            AVAIL(I,3) = AVAIL(J,3)
            AVAIL(I,4) = AVAIL(J,4)
            AVAIL(I,5) = AVAIL(J,5)
            AVAIL(I,6) = AVAIL(J,6)
            AVAIL(I,7) = AVAIL(J,7)
            AVAIL(J,1) = AVAIL1
            AVAIL(J,2) = AVAIL2
            AVAIL(J,3) = AVAIL3
            AVAIL(J,4) = AVAIL4
            AVAIL(J,5) = AVAIL5
            AVAIL(J,6) = AVAIL6
            AVAIL(J,7) = AVAIL7
          ENDIF
600     CONTINUE
500   CONTINUE
```

```
*******************************************************************
*                                                                 *
*     PRINT THE HEADINGS FOR THE HISTORY                          *
*                                                                 *
*******************************************************************
      PRINT'(1X,''OPERATING TIME'',26X,''LRU REPAIR TIME'')'
      PRINT'('' EQUIPMENT'',7X,''START'',8X,''FAILURE'',7X,
     +''REPLACED'',7X,''START'',7X,''FINISH'')'
      PRINT'(''   NAME'',8X,''DAY   TIME   DAY   TIME'',7X,
     +''LRU'',8X,''DAY   TIME   DAY   TIME'')'
      DO 100 I=1,ATRB8
        NUM1 = INT(AVAIL(I,1))
        NUM4 = INT(AVAIL(I,4))
*******************************************************************
*                                                                 *
*     COMPUTE THE SYSTEM AVAILABILITIES                           *
*                                                                 *
*******************************************************************
         IF (NUM1.EQ.1) EQAV(1) = EQAV(1) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.2) EQAV(2) = EQAV(2) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.3) EQAV(3) = EQAV(3) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.4) EQAV(4) = EQAV(4) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.5) EQAV(5) = EQAV(5) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.6) EQAV(6) = EQAV(6) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.7) EQAV(7) = EQAV(7) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.8) EQAV(8) = EQAV(8) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.9) EQAV(9) = EQAV(9) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.10) EQAV(10) = EQAV(10) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.11) EQAV(11) = EQAV(11) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.12) EQAV(12) = EQAV(12) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.13) EQAV(13) = EQAV(13) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.14) EQAV(14) = EQAV(14) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.15) EQAV(15) = EQAV(15) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.16) EQAV(16) = EQAV(16) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.17) EQAV(17) = EQAV(17) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.18) EQAV(18) = EQAV(18) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.19) EQAV(19) = EQAV(19) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.20) EQAV(20) = EQAV(20) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.21) EQAV(21) = EQAV(21) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.22) EQAV(22) = EQAV(22) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.23) EQAV(23) = EQAV(23) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.24) EQAV(24) = EQAV(24) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.25) EQAV(25) = EQAV(25) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.26) EQAV(26) = EQAV(26) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.27) EQAV(27) = EQAV(27) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.28) EQAV(28) = EQAV(28) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.29) EQAV(29) = EQAV(29) + (AVAIL(I,3)-AVAIL(I,2))
         IF (NUM1.EQ.30) EQAV(30) = EQAV(30) + (AVAIL(I,3)-AVAIL(I,2))
```

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      IF (NUM1.EQ.31) EQAV(31) = EQAV(31) + (AVAIL(I,3)-AVAIL(I,2))
      IF (NUM1.EQ.32) EQAV(32) = EQAV(32) + (AVAIL(I,3)-AVAIL(I,2))
      IF (NUM1.EQ.33) EQAV(33) = EQAV(33) + (AVAIL(I,3)-AVAIL(I,2))
      IF (NUM1.EQ.34) EQAV(34) = EQAV(34) + (AVAIL(I,3)-AVAIL(I,2))
      IF (NUM1.EQ.35) EQAV(35) = EQAV(35) + (AVAIL(I,3)-AVAIL(I,2))
      IF (NUM1.EQ.36) EQAV(36) = EQAV(36) + (AVAIL(I,3)-AVAIL(I,2))
      IF (NUM1.EQ.37) EQAV(37) = EQAV(37) + (AVAIL(I,3)-AVAIL(I,2))
      IF (NUM1.EQ.38) EQAV(38) = EQAV(38) + (AVAIL(I,3)-AVAIL(I,2))
      IF (NUM1.EQ.39) EQAV(39) = EQAV(39) + (AVAIL(I,3)-AVAIL(I,2))
      IF (NUM1.EQ.40) EQAV(40) = EQAV(40) + (AVAIL(I,3)-AVAIL(I,2))
      IF (NUM1.EQ.41) EQAV(41) = EQAV(41) + (AVAIL(I,3)-AVAIL(I,2))
      IF (NUM1.EQ.42) EQAV(42) = EQAV(42) + (AVAIL(I,3)-AVAIL(I,2))
      IF (NUM1.EQ.43) EQAV(43) = EQAV(43) + (AVAIL(I,3)-AVAIL(I,2))
      IF (NUM1.EQ.44) EQAV(44) = EQAV(44) + (AVAIL(I,3)-AVAIL(I,2))
**********************************************************************
*                                                                    *
*     DETERMINE THE NAME OF THE FAILED SYSTEM                        *
*                                                                    *
**********************************************************************
      IF (NUM1.EQ.1) EQUIP = 'ADP  1'
      IF (NUM1.EQ.2) EQUIP = 'ADP  2'
      IF (NUM1.EQ.3) EQUIP = 'ADP  3'
      IF (NUM1.EQ.4) EQUIP = 'ADP  4'
      IF (NUM1.EQ.5) EQUIP = 'ADP  5'
      IF (NUM1.EQ.6) EQUIP = 'ADP  6'
      IF (NUM1.EQ.7) EQUIP = 'ADP  7'
      IF (NUM1.EQ.8) EQUIP = 'ADP  8'
      IF (NUM1.EQ.9) EQUIP = 'ADP  9'
      IF (NUM1.EQ.10) EQUIP = 'ADP 10'
      IF (NUM1.EQ.11) EQUIP = 'D COMP 1'
      IF (NUM1.EQ.12) EQUIP = 'D COMP 2'
      IF (NUM1.EQ.13) EQUIP = 'CP COMP'
      IF (NUM1.EQ.14) EQUIP = 'D DISK 1'
      IF (NUM1.EQ.15) EQUIP = 'D DISK 2'
      IF (NUM1.EQ.16) EQUIP = 'CP DISK'
      IF (NUM1.EQ.17) EQUIP = 'VID PS 1'
      IF (NUM1.EQ.18) EQUIP = 'VID PS 2'
      IF (NUM1.EQ.19) EQUIP = 'IM GEN 1'
      IF (NUM1.EQ.20) EQUIP = 'IM GEN 2'
      IF (NUM1.EQ.21) EQUIP = 'IM GEN 3'
      IF (NUM1.EQ.22) EQUIP = 'IM GEN 4'
      IF (NUM1.EQ.23) EQUIP = 'IM GEN 5'
      IF (NUM1.EQ.24) EQUIP = 'IM GEN 6'
      IF (NUM1.EQ.25) EQUIP = 'TV MON 1'
      IF (NUM1.EQ.26) EQUIP = 'TV MON 2'
      IF (NUM1.EQ.27) EQUIP = 'TV MON 3'
      IF (NUM1.EQ.28) EQUIP = 'TV MON 4'
      IF (NUM1.EQ.29) EQUIP = 'TV MON 5'
      IF (NUM1.EQ.30) EQUIP = 'TV MON 6'
```

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      IF (NUM1.EQ.31) EQUIP = 'TV MON 7'
      IF (NUM1.EQ.32) EQUIP = 'TV MON 8'
      IF (NUM1.EQ.33) EQUIP = 'TV MON 9'
      IF (NUM1.EQ.34) EQUIP = 'TV MON10'
      IF (NUM1.EQ.35) EQUIP = 'TV MON11'
      IF (NUM1.EQ.36) EQUIP = 'TV MON12'
      IF (NUM1.EQ.37) EQUIP = 'PROJ 1'
      IF (NUM1.EQ.38) EQUIP = 'PROJ 2'
      IF (NUM1.EQ.39) EQUIP = 'PROJ 3'
      IF (NUM1.EQ.40) EQUIP = 'PROJ 4'
      IF (NUM1.EQ.41) EQUIP = 'PROJ 5'
      IF (NUM1.EQ.42) EQUIP = 'PROJ 6'
      IF (NUM1.EQ.43) EQUIP = 'PROJ 7'
      IF (NUM1.EQ.44) EQUIP = 'PROJ 8'
************************************************************************
*                                                                      *
*      DETERMINE THE NAME OF THE FAILED LRU                            *
*                                                                      *
************************************************************************
      IF (NUM4.EQ.1) LRU = 'TERM'
      IF (NUM4.EQ.2) LRU = 'HDCY'
      IF (NUM4.EQ.3) LRU = 'LAN IU'
      IF (NUM4.EQ.4) LRU = 'CPU'
      IF (NUM4.EQ.5) LRU = 'MEM'
      IF (NUM4.EQ.6) LRU = 'DISK IF'
      IF (NUM4.EQ.7) LRU = 'IFB'
      IF (NUM4.EQ.8) LRU = 'PS BOARD'
      IF (NUM4.EQ.9) LRU = 'IG   IF'
      IF (NUM4.EQ.10) LRU = 'CHASSIS'
      IF (NUM4.EQ.11) LRU = 'DISK'
      IF (NUM4.EQ.12) LRU = 'VIDEO PS'
      IF (NUM4.EQ.13) LRU = 'PROC'
      IF (NUM4.EQ.14) LRU = 'REF MEM'
      IF (NUM4.EQ.15) LRU = 'BLNK CTL'
      IF (NUM4.EQ.16) LRU = 'PS CHAS'
      IF (NUM4.EQ.17) LRU = 'TV MON'
      IF (NUM4.EQ.18) LRU = 'EQ AMP'
      IF (NUM4.EQ.19) LRU = 'VIDEO SW'
      IF (NUM4.EQ.20) LRU = 'PROJ'
************************************************************************
*                                                                      *
*     CONVERT RUN TIME INTO DAY, HOUR, AND MINUTE                      *
*                                                                      *
************************************************************************
```

```
      DAY1 = AVAIL(I,2)/24
      NDAY1 = INT(DAY1)
      TIM1 = (DAY1-NDAY1)*24
      NTIM1 = INT(TIM1)
      XMIN1 = (TIM1-NTIM1)*60
      MIN1 = INT(XMIN1)
      DAY2 = AVAIL(I,3)/24
      NDAY2 = INT(DAY2)
      TIM2 = (DAY2-NDAY2)*24
      NTIM2 = INT(TIM2)
      XMIN2 = (TIM2-NTIM2)*60
      MIN2 = INT(XMIN2)
      DAY3 = AVAIL(I,5)/24
      NDAY3 = INT(DAY3)
      TIM3 = (DAY3-NDAY3)*24
      NTIM3 = INT(TIM3)
      XMIN3 = (TIM3-NTIM3)*60
      MIN3 = INT (XMIN3)
      DAY4 = AVAIL(I,6)/24
      NDAY4 = INT (DAY4)
      TIM4 = (DAY4-NDAY4)*24
      NTIM4 = INT(TIM4)
      XMIN4 = (TIM4-NTIM4)*60
      MIN4 = INT(XMIN4)
      DAY5 = AVAIL(I,7)/24
      NDAY5 = INT(DAY5)
      TIM5 = (DAY5-NDAY5)*24
      NTIM5 = INT(TIM5)
      XMIN5 = (TIM5-NTIM5)*60
      MIN5 = INT(XMIN5)
*****************************************************************
*                                                               *
*      PRINT HISTORY                                            *
*                                                               *
*****************************************************************
      PRINT 200,EQUIP,NDAY1,NTIM1,MIN1,NDAY2,NTIM2,MIN2,
     +LBL,NDAY3,NTIM3,MIN3,NDAY4,NTIM4,MIN4,NDAY5,NTIM5,MIN5
 200  FORMAT(' ',A8,5X,I4,2X,I2,':',I2,3X,I4,2X,I2,':',I2,
     +5X,A8,4X,I4,2X,I2,':',I2,3X,I4,2X,I2,':',I2
     +,3X,I4,2X,I2,':',I2)
 100  CONTINUE
      DO 123 I=1,ATRB3-1
       J=I+1
        IF (AVAIL(I,7).GE.AVAIL(J,3)) THEN
         PRINT*,AVAIL(I,1),' ',AVAIL(I,7),' REPAIRED'
         PRINT*,AVAIL(J,1),' ',AVAIL(J,3),' BROKEN'
        ENDIF
 123  CONTINUE
      DO 700 I=1,44
        PRINT*,' SEED 1 A C ',I,' ',EQAV(I)/20000
 700  CONTINUE
      RETURN
      END
```

*** INPUT CARDS ***

```
GEN,ACNEW,DISPLAY,[illegible],1,[illegible],[illegible],2[illegible],[illegible],F,[illegible]
RES,1/LVL-[illegible],[illegible],[illegible],[illegible]7*        2-LEVEL
RES,2/LVL-3,1,4,56*        3-LEVEL
RES,3/ADP-TERM,1,46*       ADP TERMINAL
RES,4/ADP-HDCY,1,47*       HARDCOPY PRINTER
RES,5/LAN-IU,1,48*         LAN INTERFACE UNIT
RES,6/CPU,1,49*            CPU BOARD
RES,7/MEM,1,50*            MEMORY BOARD
RES,8/DISK-IF,1,51*        DISK INTERFACE BOARD
RES,9/IFB,1,52*            COMPUTER INTERFACE BOARD
RES,10/PS-BOARD,1,53*      POWER SUPPLY BOARD
RES,11/IG-IF,1,54*         IMAGE GEN BOARD
RES,12/DISK,1,55*          DISK DRIVE
RES,14/PROC,1,57*          PROCESSOR BOARD
RES,15/REF-MEM,1,58*       REFRESH MEMORY BOARD
RES,16/BLNK-CNTL,1,5[illegible]*     BLINK AND OUTPUT CONTROL BOARD
RES,17/PS-CHASSIS,1,[illegible]*     POWER SUPPLY AND CHASSIS
RES,18/TV-MON,1,61*        TELEVIVION
RES,19/EQ-AMP,1,62*        EQUALIZER AMP
RES,20/VIDEO-SW,1,63*      VIDEO SWITCH
RES,21/PROJ,1,64*          PROJECTOR
SOU,1,[illegible],1,A*     GENERATE SYSTEMS
VAS,1,1,[illegible],1*     INCREMENT ATTRIBUTE 1 (SYSTEM)
ACT,1,1,(9)A1.LT.44*       GENERATE 44 SYSTEMS
ACT,1,2,(7)A1.GT.[illegible]*    PUT EQUIP INTO SYSTEM
QUE,2/OPERATE,[illegible],[illegible],D,F*    OPERATE QUEUE
VAS,2,2,UF,1,3,UF,2,4,UF,3,5,UF,4,6,CO,[illegible],7,CO,[illegible],8,UF,6*
PAR,1,33[illegible],[illegible],[illegible],,,1*       MTBF FOR ADP WORK STATIONS
PAR,2,24[illegible],[illegible],[illegible],,,1*       MTBF FOR DISPLAY COMPUTER
PAR,3,23[illegible],[illegible],[illegible],,,1*       MTBF FOR COMMAND POST COMPUTER
PAR,4,1[illegible],[illegible],[illegible],,,1*        MTBF FOR DISK DRIVES
PAR,5,4[illegible],[illegible],[illegible],,,1*        MTBF FOR POWER SUPPLIES
PAR,6,30[illegible],[illegible],[illegible],,,1*       MTBF FOR IMAGE GENERATOR
PAR,7,635[illegible],[illegible],[illegible],,,1*      MTBF FOR TELEVISION MONITOR STRING
PAR,[illegible],47[illegible],[illegible],[illegible],,,1*     MTBF FOR PROJECTOR STRING
PAR,9,0.5,0.[illegible],,0.1,2*    MTTR WORK STATIONS
PAR,10,[illegible].5,[illegible].[illegible],,[illegible].1,2*    MTTR DISPLAY COMPUTER
PAR,11,[illegible].5,[illegible].[illegible],,[illegible].1,2*    MTTR COMMAND POST COMPUTER
PAR,12,[illegible].5,0.[illegible],,[illegible].1,2*    MTTR DISK DRIVE
PAR,13,0.5,0.[illegible],,[illegible].1,2*    MTTR VIDEO POWER SUPPLY
PAR,14,[illegible].5,0.[illegible],,[illegible].1,2*    MTTR IMAGE GENERATOR
PAR,15,0.5,0.[illegible],,[illegible].1,2*    MTTR TELEVISION MONITOR
PAR,16,[illegible].5,[illegible].[illegible],,[illegible].1,2*    MTTR PROJECTOR
PAR,17,,0.0,100.[illegible],,3*    UNIFORM [illegible] - 100
PAR,18,,1.5,2.0,,3*        UNIFORM 1.5 - 2.0
PAR,20,,24,336,,3*
ACT,2,11,AT,2,1/OPER-TIME,44* SYSTEM OPERATION
REG,11,1,1*                RECORD TIME
VAS,11,[illegible],UF,[illegible],5,UF,14*     OF SYSTEM FAILURE
```

```
ACT,1 ,7*                          GET A 3-LEVEL
GUE,?/GET-3LVL, ,1 ,D,F,(1 )6*
VAS,5,5,C ,1, *
ALL,6,P  ,1,1,5/17*               ALLOCATE 3-LEVEL
REG,13,1, ,F*                      DETERMINE IF 3-LEVEL IS NEEDED
VAS,17,5,UF,1+*                    CRITERIA FOR NEEDING A 3-LEVEL
ACT,13,3,(9)A5.GT.0*               GET A 3-LEVEL
ACT,13,7,(9)A5.EQ. *               GET A SPARE LRU
GUE,3/GET-3LVL, ,1,D,F,(1 )4*
VAS,3,7,CC,1.3*
ALL,4,PCR,2,1,3/7*                 ALLOCATE A 3-LEVEL
REG,7,1,1*                         START TROUBLESHOOTING
ACT,7,2 *                          GET A SPARE LRU
REG,2 ,1,1,F*                      CHOOSE THE LRU
ACT,2 ,27,(9)A4.EG.1*              ADP TERMINAL
ACT,2 ,2 ,(9)A4.EQ.2*              HOCY PRINTER
ACT,2 ,29,(9)A4.EQ.3*              LAN INTERFACE UNIT
ACT,2 ,3 ,(9)A4.EG.4*              CPU BOARD
ACT,2 ,31,(9)A4.EG.5*              MEMORY BOARD
ACT,2 ,32,(9)A4.EQ.6*              DISK IF BOARD
ACT,2 ,33,(9)A4.EG.7*              INTERFACE BOARD
ACT,2 ,34,(9)A4.EG.8*              POWER SUPPLY BOARD
ACT,2 ,35,(9)A4.EQ.9*              IMAGE GEN IF BOARD
ACT,2 ,1 ,(9)A4.EG.10*             CHASSIS PARTS
ACT,2 ,36,(9)A4.EG.11*             DISK DRIVE
ACT,2 ,1 ,(9)A4.EQ.12*             VIDEO POWER SUPPLY
ACT,2 ,3 ,(9)A4.EG.13*             PROCESSOR BOARD
ACT,2 ,3 ,(9)A4.EG.14*             REFRESH MEMORY BOARD
ACT,2 ,4 ,(9)A4.EQ.15*             BLINK AND OUTPUT CONTROL BOARD
ACT,2 ,41,(9)A4.EG.16*             POWER SUPPLY AND CHASSIS
ACT,2 ,42,(9)A4.EG.17*             TELEVISION MONITOR
ACT,2 ,43,(9)A4.EQ.1 *             EQUALIZER AMPLIFIER
ACT,2 ,44,(9)A4.EG.19*             VIDEO SWITCH
ACT,2 ,45,(9)A4.EG.2 *             PROJECTOR
GUE,27, , ,D,F,1 ,(1 )46*          WAIT FOR TERMINAL
ALL,46,P  ,3,1,27/65*              ALLOCATE TERMINAL
GUE,2 , , ,D,F,1 ,(1 )47*          WAIT FOR PRINTER
ALL,47,P  ,4,1,2 /65*              ALLOCATE PRINTER
GUE,2 , , ,D,F,1 ,(1 )4 *          WAIT FOR LAN IF
ALL,4 ,P  ,5,1,2 /65*              ALLOCATE LAN IF
GUE,3 , , ,D,F,1 ,(1 )4 *          WAIT FOR CPU BOARD
ALL,49,P  ,6,1,3 /65*              ALLOCATE CPU BOARD
GUE,31, , ,D,F,1 ,(1 )5 *          WAIT FOR MEMORY BOARD
ALL,5 ,P  ,7,1,31/65*              ALLOCATE MEMORY BOARD
GUE,32, , ,D,F,1 ,(1 )51*          WAIT FOR DISK IF BOARD
ALL,51,P  , ,1,32/65*              ALLOCATE DISK IF BOARD
GUE,33, , ,D,F,1 ,(1 )52*          WAIT FOR COMPUTER BOARD
ALL,52,P  ,9,1,33/65*              ALLOCATE COMPUTER IF BOARD
GUE,34, , ,D,F,1 ,(1 )53*          WAIT FOR POWER SUPPLY BOARD
ALL,53,P  ,1 ,1,34/65*             ALLOCATE POWER SUPPLY BOARD
GUE,3 , , ,D,F,1 ,(1 )54*          WAIT FOR IMAGE GEN IF BOARD
ALL,54,P  ,1 ,1,3 /65              ALLOCATE IMAGE GEN IF BOARD
```

```
GUE,3?, , ,D,F,1 ,(1 )?? WAIT FO DISK DRIVE
ALL,55,P? ,12,1, ?/65     ALLOCATE DISK DRIVE
GUE,3?,?, ,D,F,1 ,(1 )57* WAIT FOR PROCESSOR BOARD
ALL,57,P?,14,1,3 /65*     ALLOCATE PROCESSOR BOARD
GUE,3?,?, ,D,F,1?,(1 )58* WAIT FOR REFRESH MEMORY BOARD
ALL,5?,P??,15,1,3?/65*    ALLOCATE REFRESH MEMORY BOARD
GUE,4?,?,?,D,F,1?,(1 )59* WAIT FOR BLNK & OUTPUT CNTL BOARD
ALL,59,P?,16,1,4?/65*     ALLOCATE BLNK & OUTPUT CNTL BOARD
GUE,41,?, ,D,F,1?,(1?)6?* WAIT FOR POWER SUPPLY & CHASSIS
ALL,6?,P??,1?,1,41/65*    ALLOCATE POWER SUPPLY & CHASSIS
GUE,42, ,?,D,F,1 ,(1 )61* WAIT FOR TELEVISION MONITOR
ALL,61,P??,1?,1,42/65*    ALLOCATE TELEVISION MONITOR
GUE,43,?,?,D,F,1?,(1?)62* WAIT FOR EQUALIZER AMPLIFIER
ALL,62,P??,1?,1,43/65*    ALLOCATE EQUALIZER AMPLIFIER
GUE,44,?,?,D,F,1?,(1?)63* WAIT FOR VIDEO SWITCH
ALL,63,P??,2?,1,44/65*    ALLOCATE VIDEO SWITCH
GUE,4?,?, ,D,F,1 ,(1 )64* WAIT FOR PROJECTOR
ALL,64,P??,21,1,4?/65*    ALLOCATE PROJECTOR
GUE,65/REPAIR,?,1 ,D,F*
ACT,65,66,AT,3*           REPAIR SYSTEM
REG,66,1,1*               RECORD TIME THAT
VAS,66,-,UF,?*            REPAIR WAS COMPLETED
ACT,66,12*                RETURN SYSTEM TO ON-LINE
ACT,66,3*                 RETURN REPAIRMEN
ACT,66,67*                PUT LRU IN REPAIR QUEUE
GUE,67,?,2?,(1?)?7*       WAIT FOR 5-LEVEL
VAS,67,6,CO,1,?,7,CO,?,?* RECORD 5-LEVEL ASSIGNED
ALL,?7,P??,1,1,67/37*     ALLOCATE 5-LEVEL
GUE,37, , ,D,F,?5,(1?)56* WAIT FOR 3-LEVEL (IF AVAILABLE)
VAS,37,7,CO,1,?*          RECORD 3-
ALL,56,P?R,2,1,37/95*     ALLOCATE 3-LEVEL
PAR,21,?,?,?,?,?,?*       REPAIR TIME W/O LRU
PAR,22,?,?,?,?,?,?*       LRU REPAIR TIME
GUE,95,?,??*              START LRU REPAIR
VAS,95,3,LO,22*           ASSIGN LRU REPAIR TIME
ACT,95,14,AT,3,5/BENCH-CK,1?* REPAIR LRU
REG,14,1,1,?*
ACT,14,95,(?),?*
ACT,14,15,(?),1*
REG,15,1,1*
ACT,15,?*
ACT,15,67,UN,2?*
REG,96,1,1*               COMPLETE LRU REPAIR
ACT,96,3*                 RETURN REPAIRMEN
ACT,96,69*                RETURN LRU TO SPARE
REG,69,1,1,F*             RECORD LRU REPAIR COMPLETE
VAS,69,?,UF,1?*
ACT,69,76,(?)A4.EQ.1*     RETURN TERMINAL
ACT,69,77,(?)A4.EQ.2*     RETURN PRINTER
ACT,69,7?,(?)A4.EQ.3*     RETURN CAN IF ON
```

```
ACT,6[illegible],7[illegible],(9)A4.EQ.[illegible]*       RETURN CPU BOARD
ACT,6[illegible],[illegible],(9)A4.EQ.[illegible]*        RETURN MEMORY BOARD
ACT,6[illegible],[illegible],(9)A4.EQ.6*                  RETURN DISK IF BOARD
ACT,64,[illegible],(9)A4.EQ.7*                            RETURN COMPUTER IF BOARD
ACT,6[illegible],[illegible],(9)A4.EQ.[illegible]*        RETURN POWER SUPPLY BOARD
ACT,6[illegible],[illegible],(9)A4.EQ.[illegible]*        RETURN IMAGE GEN IF BOARD
ACT,6[illegible],[illegible],(9)A4.EQ.1[illegible]*       CHASSIS PARTS
ACT,6[illegible],[illegible],(9)A4.EQ.11*                 RETURN DISK DRIVE
ACT,69,9[illegible],(9)A4.EQ.12*                          VIDEO POWER SUPPLY
ACT,69,87,(9)A4.EQ.13*                                    RETURN PROCESSOR BOARD
ACT,69,[illegible],(9)A4.EQ.14*                           RETURN REFRESH MEMORY BOARD
ACT,69,89,(9)A4.EQ.15*                                    RETURN BLNK & OUTPUT CNTL BOARD
ACT,69,[illegible],(9)A4.EQ.1[illegible]*                 RETURN POWER SUPPLY & CHASSIS
ACT,69,91,(9)A4.EQ.17*                                    RETURN TELEVISION
ACT,69,92,(9)A4.EQ.18*                                    RETURN EQUALIZER AMPLIFIER
ACT,69,93,(9)A4.EQ.19*                                    RETURN VIDEO SWITCH
ACT,6[illegible],94,(9)A4.EQ.2[illegible]*                RETURN PROJECTOR
REG,[illegible],1,1*                                          PREEMPTED LRU REPAIR
ACT,[illegible],67*                                       RETURN LRU TO REPAIR QUEUE
ACT,9,8*                                                  RETURN REPAIRMEN
REG,1[illegible],1,1*                                     RECORD TIME THAT SYSTEM REPAIR
VAS,1[illegible],3,LF,11,8,LF,9*                          WAS COMPLETED
ACT,1[illegible],12,AT,3*
REG,12,1,1*                                               RECORD TIME SYSTEM ON LINE
VAS,12,[illegible],LF,12*
ACT,12,2*
ACT,1[illegible],[illegible],AT,3*                        RETURN REPAIRMEN
REG,[illegible],1,1,A*                                    SELECT RETURNED REPAIRMEN
ACT,3,17,(3)A7.EQ.1*                                      ONE 3-LEVEL
ACT,3,1[illegible],(3)A6.EQ.1*                            ONE 5-LEVEL
ACT,3,1[illegible],(3)A6.EQ.2*
FRE,17,C,2,1,4,36*                                        FREE ONE 3-LEVEL
FRE,1[illegible],D,1,1,6,37*                              FREE ONE 5-LEVEL
FRE,1[illegible],C,1,2,[illegible],37*                    FREE TWO 5-LEVELS
FRE,76,C,3,1,46*                                          FREE ONE TERMINAL
FRE,77,D,4,1,47*                                          FREE ONE PRINTER
FRE,7[illegible],C,[illegible],1,43*                      FREE ONE LAN IF UNIT
FRE,7[illegible],D,[illegible],1,4[illegible]*            FREE ONE CPU BOARD
FRE,[illegible],C,7,1,[illegible]*                        FREE ONE MEMORY BOARD
FRE,81,D,[illegible],1,51*                                FREE ONE DISK IF BOARD
FRE,82,C,9,1,52*                                          FREE ONE COMPUTER IF BOARD
FRE,83,D,10,1,53*                                         FREE ONE POWER SUPPLY BOARD
FRE,84,D,11,1,54*                                         FREE ONE IMAGE GEN IF BOARD
FRE,85,C,12,1,55*                                         FREE ONE DISK DRIVE
FRE,87,D,14,1,57*                                         FREE ONE PROCESSOR BOARD
FRE,8[illegible],C,15,1,58*                               FREE ONE REFRESH MEMORY BOARD
FRE,89,C,16,1,59*                                         FREE ONE BLINK & OUTPUT CNTL BOARD
FRE,9[illegible],D,17,1,60*                               FREE ONE BLNK & OUTPUT AND CHASSIS
FRE,91,D,18,1,61*                                         FREE ONE TELEVISION MONITOR
FRE,92,C,19,1,62*                                         FREE ONE EQUALIZER AMPLIFIER
FRE,93,C,2[illegible],1,63*                               FREE ONE VIDEO SWITCH
FRE,94,D,21,1,63*                                         FREE ONE PROJECTOR
FIN*
```

APPENDIX B

Results of 24 Simulation Runs

SEED	1	(1)	1	.996225726861
SEED	1	(1)	2	.996989419905-
SEED	1	(1)	3	.995600074247
SEED	1	(1)	4	.994354018832
SEED	1	(1)	5	.997222421872-
SEED	1	(1)	6	.996818115971
SEED	1	(1)	7	.993254667366
SEED	1	(1)	8	.996719473382 5
SEED	1	(1)	9	.9977149923321
SEED	1	(1)	10	.994987237727
SEED	1	(1)	11	.9943687653449
SEED	1	(1)	12	.9949245225078
SEED	1	(1)	13	.998148261728
SEED	1	(1)	14	.9967724962135
SEED	1	(1)	15	.9985843117308
SEED	1	(1)	16	.9975728158379
SEED	1	(1)	17	1.
SEED	1	(1)	18	.9965776752932
SEED	1	(1)	19	.9951802771223
SEED	1	(1)	20	.9966306032298
SEED	1	(1)	21	.9971193533235
SEED	1	(1)	22	.9938218909957
SEED	1	(1)	23	.9979949134636
SEED	1	(1)	24	.9934176114468
SEED	1	(1)	25	.9979703968586
SEED	1	(1)	26	.9916030929881
SEED	1	(1)	27	.9963383251963
SEED	1	(1)	28	.9973926348673
SEED	1	(1)	29	.9975367085511
SEED	1	(1)	30	.9952883011613
SEED	1	(1)	31	.99841046163 3
SEED	1	(1)	32	.9974487216394
SEED	1	(1)	33	.9951472629791
SEED	1	(1)	34	.9979862321261
SEED	1	(1)	35	.9990671975293
SEED	1	(1)	36	.9947399294991
SEED	1	(1)	37	.9993669823819
SEED	1	(1)	38	.994168557133
SEED	1	(1)	39	.9993674485104
SEED	1	(1)	40	.9987940229749
SEED	1	(1)	41	.9973203681564
SEED	1	(1)	42	.9973470329532
SEED	1	(1)	43	.9983839421025
SEED	1	(1)	44	.997512143102-

** ESOURCE UTILIZATION**

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	1	.406	1	0	.594	1
2	LVL-3	1	[illegible]	1	0	.595	1
3	ADP-TERM	1	.100	1	0	.9 0	1
4	ADP-HDCY	0	.056	1	1	.944	1
5	LAN-IU	0	.083	1	1	.917	1
6	CPU	0	.007	1	1	.993	1
7	MEM	0	.005	1	1	.995	1
8	DISK-IF	0	.036	1	1	.964	1
9	IFB	1	.016	1	0	.984	1
10	PS-BOARD	0	.017	1	1	.983	1
11	IG-IF	0	.024	1	1	.976	1
12	DISK	0	.040	1	1	.960	1
14	PROC	0	.036	1	1	.964	1
15	REF-MEM	1	.091	1	0	.919	1
16	BLNK-CNT	0	.017	1	1	.983	1
17	PS-CHASS	0	.066	1	1	.934	1
13	TV-MON	0	.145	1	1	.855	1
19	EQ-AMP	[illegible]	[illegible]	1	1	.995	1
20	VIDEO-SW	[illegible]	.013	1	1	.987	1
21	PROJ	0	.093	1	1	.907	1

SEED	2	(1)	1	.9942323023257
SEED	2	(1)	2	.9966173560152
SEED	2	(1)	3	.9945013824251
SEED	2	(1)	4	.9983827700617
SEED	2	(1)	5	.9973003238746
SEED	2	(1)	6	.9979665367657
SEED	2	(1)	7	.9969079433399
SEED	2	(1)	8	.993669955747
SEED	2	(1)	9	.9961219684846
SEED	2	(1)	10	.9994857915601
SEED	2	(1)	11	.993843962792
SEED	2	(1)	12	.9936424818951
SEED	2	(1)	13	.9984652572841
SEED	2	(1)	14	.9998469901069
SEED	2	(1)	15	.9989883047301
SEED	2	(1)	16	.9978333021914
SEED	2	(1)	17	.9990108311701
SEED	2	(1)	18	.9997725619357
SEED	2	(1)	19	.9995179857605
SEED	2	(1)	20	.9986934231385
SEED	2	(1)	21	.9963267980561
SEED	2	(1)	22	.9982313980619
SEED	2	(1)	23	.9957046417248
SEED	2	(1)	24	.9978934546865
SEED	2	(1)	25	.9989041015051
SEED	2	(1)	26	.9985646661815
SEED	2	(1)	27	.9988375962441
SEED	2	(1)	28	.9992513015887
SEED	2	(1)	29	.9998465194165
SEED	2	(1)	30	.9991423463894
SEED	2	(1)	31	.999307966041
SEED	2	(1)	32	.9981373340534
SEED	2	(1)	33	.9995165136105
SEED	2	(1)	34	.9978408486836
SEED	2	(1)	35	.998308125892
SEED	2	(1)	36	.9993600366661
SEED	2	(1)	37	.9985573588685
SEED	2	(1)	38	.9997738639675
SEED	2	(1)	39	.9967919537045
SEED	2	(1)	40	.9945334173033
SEED	2	(1)	41	.9981337691045
SEED	2	(1)	42	.9993974660341
SEED	2	(1)	43	.9990774058598
SEED	2	(1)	44	.9980421148495

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	1	.351	1	0	.649	1
2	LVL-3	1	.349	1	0	.651	1
3	ADP-TERM	0	.091	1	1	.909	1
4	ADP-HDCY	0	.078	1	1	.922	1
5	LAN-IU	1	.069	1	0	.931	1
6	CPU	0	.013	1	1	.987	1
7	MEM	0	.045	1	1	.955	1
8	DISK-IF	0	.001	1	1	.999	1
9	IFB	0	.004	1	1	.996	1
10	PS-BOARD	0	.010	1	1	.990	1
11	IG-IF	0	.025	1	1	.975	1
12	DISK	0	.014	1	1	.986	1
14	PROC	0	.031	1	1	.969	1
15	REF-MEM	0	.079	1	1	.921	1
16	BLNK-CNT	0	.009	1	1	.991	1
17	PS-CHASS	0	.007	1	1	.993	1
18	TV-MON	0	.104	1	1	.896	1
19	EQ-AMP	0	.002	1	1	.998	1
20	VIDEO-SW	0	.005	1	1	.995	1
21	PROJ	0	.152	1	1	.848	1

SEED	3	(1)	1	.9995035475135
SEED	3	(1)	2	.9985063268822
SEED	3	(1)	3	.994855110686
SEED	3	(1)	4	.9994509421733
SEED	3	(1)	5	.9940072364381
SEED	3	(1)	6	.9968549484547
SEED	3	(1)	7	.9962964633207
SEED	3	(1)	8	.9958570759199
SEED	3	(1)	9	.9973336063005
SEED	3	(1)	10	.9964482197448
SEED	3	(1)	11	.994655519411
SEED	3	(1)	12	.9950794913861
SEED	3	(1)	13	.9987624521675
SEED	3	(1)	14	.9996667973893
SEED	3	(1)	15	.9995131894068
SEED	3	(1)	16	.9988015434498
SEED	3	(1)	17	.9973106617664
SEED	3	(1)	18	.998459385336
SEED	3	(1)	19	.998253790556
SEED	3	(1)	20	.9951015117931
SEED	3	(1)	21	.9960516552893
SEED	3	(1)	22	.9981136121787
SEED	3	(1)	23	.9975234946654
SEED	3	(1)	24	.9948481048579
SEED	3	(1)	25	.9976765219958
SEED	3	(1)	26	.9985845921451
SEED	3	(1)	27	.9945252103377
SEED	3	(1)	28	.99445096128
SEED	3	(1)	29	.9965440079601
SEED	3	(1)	30	.9993395723928
SEED	3	(1)	31	.9997988226697
SEED	3	(1)	32	.999941552868
SEED	3	(1)	33	.9998927189019
SEED	3	(1)	34	.9983355829977
SEED	3	(1)	35	.9987578705909
SEED	3	(1)	36	.9994515944314
SEED	3	(1)	37	.994912546285
SEED	3	(1)	38	.9973692354041
SEED	3	(1)	39	.999712104559
SEED	3	(1)	40	.996287769985
SEED	3	(1)	41	.9965018724154
SEED	3	(1)	42	.9987125906054
SEED	3	(1)	43	.9979818847375
SEED	3	(1)	44	.9981864741283

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.358	1	1	.642	1
2	LVL-3	0	.357	1	1	.643	1
3	ADP-TERM	0	.042	1	1	.958	1
4	ADP-HDCY	0	.080	1	1	.920	1
5	LAN-IU	0	.088	1	1	.912	1
6	CPU	0	.008	1	1	.992	1
7	MEM	0	.016	1	1	.984	1
8	DISK-IF	0	.002	1	1	.998	1
9	IFB	0	.005	1	1	.995	1
10	PS-BOARD	0	0.000	0	1	1.000	1
11	IG-IF	0	.034	1	1	.966	1
12	DISK	0	.024	1	1	.976	1
14	PROC	0	.010	1	1	.990	1
15	REF-MEM	0	.084	1	1	.916	1
16	BLNK-CNT	0	.020	1	1	.980	1
17	PS-CHASS	0	.018	1	1	.982	1
18	TV-MON	0	.105	1	1	.895	1
19	EQ-AMP	0	.001	1	1	.999	1
20	VIDEO-SW	0	.045	1	1	.955	1
21	PROJ	0	.152	1	1	.848	1

SEED	1	A	B	1	.9996151111766
SEED	1	A	B	2	.999714236186
SEED	1	A	B	3	.999717564434
SEED	1	A	B	4	.999539389565
SEED	1	A	B	5	.999457061236
SEED	1	A	B	6	.9996108986892
SEED	1	A	B	7	.9967475042686
SEED	1	A	B	8	.999471684649
SEED	1	A	B	9	.999546857783
SEED	1	A	B	10	.9996073482897
SEED	1	A	B	11	.99987849697871
SEED	1	A	B	12	.99976266706155
SEED	1	A	B	13	.9993214753984
SEED	1	A	B	14	.99981988276569
SEED	1	A	B	15	.9994596350413
SEED	1	A	B	16	.9999359511253
SEED	1	A	B	17	1.
SEED	1	A	B	18	.9995529211294
SEED	1	A	B	19	.999296111365
SEED	1	A	B	20	.999500056378
SEED	1	A	B	21	.9992507168127
SEED	1	A	B	22	.9982548093215
SEED	1	A	B	23	.9967461563334
SEED	1	A	B	24	.9987521235297
SEED	1	A	B	25	.9998018015767
SEED	1	A	B	26	.9997651591062
SEED	1	A	B	27	.9997264604138
SEED	1	A	B	28	.9997836449827
SEED	1	A	B	29	.9998096723418
SEED	1	A	B	30	.9997555084799
SEED	1	A	B	31	.9998543465259
SEED	1	A	B	32	.9989677114725
SEED	1	A	B	33	.9997776900312
SEED	1	A	B	34	.9985145911589
SEED	1	A	B	35	.999811397384
SEED	1	A	B	36	.997128641957
SEED	1	A	B	37	.9990563616398
SEED	1	A	B	38	.9998416123458
SEED	1	A	B	39	.9997635347423
SEED	1	A	B	40	.9990190213865
SEED	1	A	B	41	.9998425351019
SEED	1	A	B	42	.9998744489602
SEED	1	A	B	43	.9998065360398
SEED	1	A	B	44	.9996774917197

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.416	2	2	1.584	2
2	LVL-3	0	.133	1	1	.867	1
3	ADP-TERM	[illegible]	.079	2	2	1.921	2
4	ADP-HDCY	[illegible]	.049	1	2	1.951	2
5	LAN-IU	0	.078	2	2	1.922	2
6	CPU	[illegible]	.032	1	2	1.968	2
7	MEM	0	.006	1	2	1.994	2
8	DISK-IF	[illegible]	.008	1	2	1.992	2
9	IFB	0	.013	1	2	1.987	2
10	PS-BOARD	0	.004	1	2	1.996	2
11	IG-_F	0	.021	1	2	1.979	2
12	DISK	[illegible]	.02[illegible]	2	2	1.980	2
14	PROC	0	.027	1	2	1.973	2
15	REF-MEM	0	.179	2	2	1.821	2
16	BLNK-CNT	[illegible]	.016	1	2	1.984	2
17	PS-CHASS	[illegible]	.012	1	2	1.988	2
18	TV-MON	[illegible]	.128	2	2	1.872	2
19	EQ-AMP	0	.005	1	2	1.995	2
20	VIDEO-SW	[illegible]	.015	1	2	1.985	2
21	PROJ	0	.112	2	2	1.888	2

SEED 2 A B 1 .9997623246067
SEED 2 A B 2 .9996300469236
SEED 2 A B 3 .9990570249435
SEED 2 A B 4 .9996597673145
SEED 2 A B 5 .9995699257378
SEED 2 A B 6 .9984714514497
SEED 2 A B 7 .9995529175802
SEED 2 A B 8 .9972623565748
SEED 2 A B 9 .9930746715017
SEED 2 A B 10 .9988334235597
SEED 2 A B 11 .9986331571565
SEED 2 A B 12 .9995253238785
SEED 2 A B 13 .997973103117
SEED 2 A B 14 .9993321388679
SEED 2 A B 15 .999803322406
SEED 2 A B 16 .9999523539624
SEED 2 A B 17 .9992672733663
SEED 2 A B 18 .9990564814283
SEED 2 A B 19 .9982734206454
SEED 2 A B 20 .9996479454786
SEED 2 A B 21 .9993892836428
SEED 2 A B 22 .9996723986931
SEED 2 A B 23 .9971161038668
SEED 2 A B 24 .9996511823105
SEED 2 A B 25 .9998574515267
SEED 2 A B 26 .9997669700557
SEED 2 A B 27 .9998790229564
SEED 2 A B 28 .9996393358985
SEED 2 A B 29 .9997541518777
SEED 2 A B 30 .9999199880654
SEED 2 A B 31 .9980814823481
SEED 2 A B 32 .9997371911251
SEED 2 A B 33 .999012973401
SEED 2 A B 34 .9996842474266
SEED 2 A B 35 .9987952356411
SEED 2 A B 36 .9997639722652
SEED 2 A B 37 .9994966184351
SEED 2 A B 38 .9995667397678
SEED 2 A B 39 .999612306822
SEED 2 A B 40 .9998512959992
SEED 2 A B 41 .9993495941043
SEED 2 A B 42 .9999361293831
SEED 2 A B 43 .9998851986538
SEED 2 A B 44 .9998258446126

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	1	.357	2	1	1.643	2
2	LVL-3	0	.105	1	1	.695	1
3	ADP-TERM	1	.108	2	1	1.892	2
4	ADP-HDCY	0	.060	2	2	1.940	2
5	LAN-IU	0	.124	2	2	1.876	2
6	CPU	0	.014	1	2	1.986	2
7	MEM	0	.023	1	2	1.977	2
8	DISK-IF	0	.038	1	2	1.962	2
9	IFB	0	.000	1	2	2.000	2
10	PS-BOARD	0	.002	1	2	1.998	2
11	IG-IF	0	.047	1	2	1.953	2
12	DISK	0	.032	1	2	1.968	2
14	PROC	0	.029	1	2	1.971	2
15	REF-MEM	0	.088	2	2	1.912	2
16	BLNK-CNT	0	.005	1	2	1.995	2
17	PS-CHASS	1	.003	1	1	1.997	2
18	TV-MON	0	.090	2	2	1.910	2
19	EQ-AMP	0	.001	1	2	1.999	2
20	VIDEO-SW	0	.011	1	2	1.989	2
21	PROJ	0	.062	2	2	1.938	2

SEED 3 A B 1 .9934276445143
SEED 3 A B 2 .9989781801713
SEED 3 A B 3 .9994937069 734
SEED 3 A B 4 .9997424113444
SEED 3 A B 5 .99305752735
SEED 3 A B 6 .9998002614916
SEED 3 A B 7 .9979822058295
SEED 3 A B 8 .9997034491448
SEED 3 A B 9 .9997231976195
SEED 3 A B 10 .999500233353
SEED 3 A B 11 .9983517 625 9
SEED 3 A B 12 .9957013286839
SEED 3 A B 13 .9991630534664
SEED 3 A B 14 .9998104481578
SEED 3 A B 15 .9998506556382
SEED 3 A B 16 .9999083423134
SEED 3 A B 17 .9985366995115
SEED 3 A B 18 .9995626663198
SEED 3 A B 19 .9981638339651
SEED 3 A B 20 .9993771558794
SEED 3 A B 21 .9966896853743
SEED 3 A B 22 .9996509838378
SEED 3 A B 23 .9987439649545
SEED 3 A B 24 .9974460739268
SEED 3 A B 25 .9991556246555
SEED 3 A B 26 .999872895316
SEED 3 A B 27 .9999054679273
SEED 3 A B 28 .9997375885264
SEED 3 A B 29 .9998769453833
SEED 3 A B 30 .99987685632
SEED 3 A B 31 .9997825428314
SEED 3 A B 32 .9996219898706
SEED 3 A B 33 .9998262234474
SEED 3 A B 34 .9989969525133
SEED 3 A B 35 .9983208096449
SEED 3 A B 36 .99897424931
SEED 3 A B 37 .9995512149276
SEED 3 A B 38 .9981054871831
SEED 3 A B 39 .9998454292395
SEED 3 A B 40 .9997682093155
SEED 3 A B 41 .9999118062527
SEED 3 A B 42 .9997531123716
SEED 3 A B 43 .9998545276613
SEED 3 A B 44 .9997788883651

** ESOURCE UTILIZATION**

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.370	2	2	1.630	2
2	LVL-3	0	.122	1	1	.878	1
3	ADP-TERM	0	.102	2	2	1.898	2
4	ADP-HDCY	[illegible]	.023	1	2	1.977	2
5	LAN-IU	0	.052	2	2	1.948	2
6	CPU	0	.023	1	2	1.977	2
7	MEM	0	.011	1	2	1.989	2
8	DISK-IF	0	.001	1	2	1.999	2
9	IFB	0	.030	1	2	1.970	2
10	PS-BOARD	0	.005	1	2	1.995	2
11	IG-IF	0	.026	2	2	1.974	2
12	DISK	[illegible]	.031	2	2	1.969	2
14	PROC	[illegible]	.037	1	2	1.963	2
15	REF-MEM	[illegible]	.118	2	2	1.882	2
16	BLNK-CNT	0	.006	1	2	1.994	2
17	PS-CHASS	0	.005	1	2	1.995	2
18	TV-MON	0	.151	2	2	1.849	2
19	EQ-AMP	[illegible]	.003	1	2	1.997	2
20	VIDEO-SW	[illegible]	.017	1	2	1.983	2
21	PROJ	[illegible]	.104	2	2	1.896	2

SEED	1	A	C	1	.[illegible]
SEED	1	A	C	2	.[illegible]
SEED	1	A	C	3	.[illegible]
SEED	1	A	C	4	.9999426632[illegible]22
SEED	1	A	C	5	.9998734822154
SEED	1	A	C	6	.9996454564152
SEED	1	A	C	7	.999612176[illegible]4
SEED	1	A	C	8	.99984735383[illegible]51
SEED	1	A	C	9	.9998397996333
SEED	1	A	C	10	.9998829[illegible]17432
SEED	1	A	C	11	.99987[illegible]7112627
SEED	1	A	C	12	.9994329933[illegible]51
SEED	1	A	C	13	.9997553531[illegible]522
SEED	1	A	C	14	.99991[illegible]6[illegible]9[illegible]1
SEED	1	A	C	15	.99967637[illegible]4744
SEED	1	A	C	16	.[illegible]9996[illegible]1414[illegible]463
SEED	1	A	C	17	1.
SEED	1	A	C	18	.99963466[illegible]74731
SEED	1	A	C	19	.99966245777[illegible]
SEED	1	A	C	20	.9996147544227
SEED	1	A	C	21	.9999[illegible]3262617
SEED	1	A	C	22	.99961964[illegible]9767
SEED	1	A	C	23	.999[illegible]17675617
SEED	1	A	C	24	.99986[illegible]6534654[illegible]
SEED	1	A	C	25	.9999691433935
SEED	1	A	C	26	.99966652[illegible]6944
SEED	1	A	C	27	.9999[illegible]5641[illegible]77[illegible]
SEED	1	A	C	28	.99963[illegible]50[illegible]1375
SEED	1	A	C	29	.9999[illegible]4347263
SEED	1	A	C	30	.9998112271[illegible]54
SEED	1	A	C	31	.9996222[illegible]53237
SEED	1	A	C	32	.9999379599953
SEED	1	A	C	33	.9999435167[illegible]23
SEED	1	A	C	34	.99991401[illegible]3[illegible]313
SEED	1	A	C	35	.999372[illegible]388856
SEED	1	A	C	36	.999457[illegible]299926
SEED	1	A	C	37	.99988724[illegible]366
SEED	1	A	C	38	.99997[illegible]5997345
SEED	1	A	C	39	.99992427[illegible]6126
SEED	1	A	C	40	.9998861353[illegible]00
SEED	1	A	C	41	.9998496071593
SEED	1	A	C	42	.999962901633
SEED	1	A	C	43	.99996[illegible]91[illegible]73[illegible]7
SEED	1	A	C	44	.9997916221529

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.0[illegible]1	2	2	1.909	2
2	LVL-3	0	.02[illegible]	1	1	.980	1
3	ADP-TERM	0	.037	1	1	.963	1
4	ADP-HDCY	0	.019	1	1	.981	1
5	LAN-IL	0	.021	1	1	.979	1
6	CPU	0	.002	1	1	.998	1
7	FEM	0	.[illegible]	1	1	1.000	1
8	DISK-IF	0	.002	1	1	.998	1
9	IFB	0	.004	1	1	.996	1
10	PC-BCARD	0	.013	1	1	.987	1
11	IG-IF	0	.0[illegible]	1	1	.992	1
12	DISK	0	.012	1	1	.988	1
13	PCCC	0	.034	1	1	.966	1
14	REF-MEM	0	.047	1	1	.953	1
15	BLNK-CNT	0	.001	1	1	.999	1
16	FS-CHASS	0	.001	1	1	.999	1
17	TV-MON	0	.037	1	1	.963	1
18	EG-AMP	0	.[illegible]	1	1	1.000	1
19	VIDEO-SW	0	.0[illegible]2	1	1	.958	1
20	[illegible] CJ	0	.052	1	1	.949	1

SEED	2	A	C	1	[illegible]
SEED	2	A	C	2	[illegible]
SEED	2	A	C	3	[illegible]
SEED	2	A	C	4	[illegible]
SEED	2	A	C	5	[illegible]
SEED	2	A	C	6	[illegible]
SEED	2	A	C	7	[illegible]
SEED	2	A	C	8	[illegible]
SEED	2	A	C	9	[illegible]
SEED	2	A	C	10	[illegible]
SEED	2	A	C	11	[illegible]
SEED	2	A	C	12	[illegible]
SEED	2	A	C	13	[illegible]
SEED	2	A	C	14	[illegible]
SEED	2	A	C	15	[illegible]
SEED	2	A	C	16	[illegible]
SEED	2	A	C	17	[illegible]
SEED	2	A	C	18	1.
SEED	2	A	C	19	[illegible]
SEED	2	A	C	20	[illegible]
SEED	2	A	C	21	[illegible]
SEED	2	A	C	22	[illegible]
SEED	2	A	C	23	[illegible]
SEED	2	A	C	24	[illegible]
SEED	2	A	C	25	[illegible]
SEED	2	A	C	26	[illegible]
SEED	2	A	C	27	[illegible]
SEED	2	A	C	28	[illegible]
SEED	2	A	C	29	[illegible]
SEED	2	A	C	30	[illegible]
SEED	2	A	C	31	[illegible]
SEED	2	A	C	32	[illegible]
SEED	2	A	C	33	[illegible]
SEED	2	A	C	34	[illegible]
SEED	2	A	C	35	[illegible]
SEED	2	A	C	36	[illegible]
SEED	2	A	C	37	[illegible]
SEED	2	A	C	38	[illegible]
SEED	2	A	C	39	[illegible]
SEED	2	A	C	40	[illegible]
SEED	2	A	C	41	[illegible]
SEED	2	A	C	42	1.
SEED	2	A	C	43	[illegible]
SEED	2	A	C	44	[illegible]

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.179	2	2	1.821	2
2	LVL-3	0	.049	1	1	.951	1
3	ADP-TERM	0	.026	1	1	.974	1
4	ADP-HDCY	0	.040	1	1	.960	1
5	LAN-IU	0	.055	1	1	.945	1
6	CPU	0	.005	1	1	.995	1
7	MEM	0	.044	1	1	.956	1
8	DISK-IF	0	.025	1	1	.975	1
9	IFB	0	.001	1	1	.999	1
10	PS-BOARD	0	.002	1	1	.998	1
11	IG-IF	0	.002	1	1	.998	1
12	DISK	0	.021	1	1	.979	1
14	PROC	0	.003	1	1	.997	1
15	REF-MEM	0	.028	1	1	.972	1
16	BLNK-CNT	0	.009	1	1	.991	1
17	PS-CHASS	0	.001	1	1	.999	1
18	TV-MON	0	.070	1	1	.930	1
19	SG-AMP	0	.001	1	1	.999	1
20	VIDEO-SW	0	.032	1	1	.968	1
21	PROJ	0	.043	1	1	.957	1

SEED	3	A	C	1	[illegible]
SEED	3	A	C	2	.99972[illegible]3552[illegible]67
SEED	3	A	C	3	.999[illegible]64[illegible]132116
SEED	3	A	C	4	.9996816687957
SEED	3	A	C	5	.9998612[illegible]527717
SEED	3	A	C	6	.9999066403314
SEED	3	A	C	7	.9975812615321
SEED	3	A	C	8	.9998442957164
SEED	3	A	C	9	.9998444354[illegible]13
SEED	3	A	C	10	.9998919815465
SEED	3	A	C	11	.997632474925
SEED	3	A	C	12	.9996471569354
SEED	3	A	C	13	.9997981737361
SEED	3	A	C	14	.9995644811944
SEED	3	A	C	15	.99991[illegible]3336[illegible]
SEED	3	A	C	16	.9999[illegible]340[illegible]134
SEED	3	A	C	17	.99[illegible]466995115
SEED	3	A	C	18	.9995926613[illegible]
SEED	3	A	C	19	.9998111074957
SEED	3	A	C	20	.9998320023341
SEED	3	A	C	21	.99988[illegible]741531[illegible]
SEED	3	A	C	22	.9998217921964
SEED	3	A	C	23	.9998427810557
SEED	3	A	C	24	.9996369242234
SEED	3	A	C	25	.9997[illegible]361426
SEED	3	A	C	26	.9999653886143
SEED	3	A	C	27	.9999618511207
SEED	3	A	C	28	.9997978497716
SEED	3	A	C	29	.9998541842041
SEED	3	A	C	30	.9998850791752
SEED	3	A	C	31	.9998020141721
SEED	3	A	C	32	1.
SEED	3	A	C	33	.9999244427627
SEED	3	A	C	34	.9984610784531
SEED	3	A	C	35	.9998460531179
SEED	3	A	C	36	.9999736431321
SEED	3	A	C	37	.9997222475995
SEED	3	A	C	38	.9996836375324
SEED	3	A	C	39	.9996574492[illegible]25
SEED	3	A	C	40	.9998460872571
SEED	3	A	C	41	.9999338859021
SEED	3	A	C	42	.9998799512384
SEED	3	A	C	43	.999934055166
SEED	3	A	C	44	.9998999328342

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	1	.191	2	1	1.809	2
2	LVL-3	1	.047	1	0	.953	1
3	ADP-TERM	0	.013	1	1	.987	1
4	ADP-HDCY	0	.027	1	1	.973	1
5	LAN-IL	0	.035	1	1	.965	1
6	CPU	0	.006	1	1	.994	1
7	MEM	0	.005	1	1	.995	1
8	DISK-IF	0	0.000	0	1	1.000	1
9	IFB	0	.011	1	1	.989	1
10	PS-BOARD	0	.002	1	1	.998	1
11	IG-IF	0	.028	1	1	.972	1
12	DISK	0	.017	1	1	.983	1
14	PROC	0	.004	1	1	.996	1
15	REF-MEM	0	.053	1	1	.947	1
16	BLNK-CNT	1	.004	1	0	.996	1
17	PS-CHASS	0	.016	1	1	.984	1
18	TV-MON	1	.077	1	0	.923	1
19	EQ-AMP	0	.001	1	1	.999	1
20	VIDEO-SW	0	.010	1	1	.990	1
21	PROJ	0	.052	1	1	.948	1

SEED	1	A	D 1	.9993[illegible]4279469[illegible]
SEED	1	A	D 2	.9997594962167
SEED	1	A	D 3	.9994106998274
SEED	1	A	D 4	.9997238227[illegible]38
SEED	1	A	D 5	.9995096854414
SEED	1	A	D 6	.9987418509635
SEED	1	A	D 7	.9995206922455
SEED	1	A	D 8	.9986760444981
SEED	1	A	D 9	.9985341730976
SEED	1	A	D 10	.9996560229553
SEED	1	A	D 11	.9984880786727
SEED	1	A	D 12	.99879125550[illegible]4
SEED	1	A	D 13	.9988334257857
SEED	1	A	D 14	.999659742[illegible]39
SEED	1	A	D 15	.9998946451445
SEED	1	A	D 16	.9993148326794
SEED	1	A	D 17	1.
SEED	1	A	D 18	.9997223853818
SEED	1	A	D 19	.9996324577719
SEED	1	A	D 20	.99812996459
SEED	1	A	D 21	.9987058973852
SEED	1	A	D 22	.999449860[illegible]281
SEED	1	A	D 23	.9992153691284
SEED	1	A	D 24	.9994982213867
SEED	1	A	D 25	.9998281153338
SEED	1	A	D 26	.999669331608
SEED	1	A	D 27	.9991803175318
SEED	1	A	D 28	.999[illegible]93845[illegible]9[illegible]5
SEED	1	A	D 29	.9996942103324
SEED	1	A	D 30	.9999071621213
SEED	1	A	D 31	.9997589688617
SEED	1	A	D 32	.9998709219369
SEED	1	A	D 33	.9998546309736
SEED	1	A	D 34	.9998429596965
SEED	1	A	D 35	.9998102714293
SEED	1	A	D 36	.9991978346673
SEED	1	A	D 37	.9996815480085
SEED	1	A	D 38	.9994633007498
SEED	1	A	D 39	.9997656116539
SEED	1	A	D 40	.9998349217083
SEED	1	A	D 41	.9997406741727
SEED	1	A	D 42	.9999365290559
SEED	1	A	D 43	.9986165885562
SEED	1	A	D 44	.9996808991894

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.205	2	2	1.795	2
2	LVL-3	0	.059	1	1	.941	1
3	ADP-TERM	0	.037	1	1	.963	1
4	ADP-HDCY	0	.091	1	1	.909	1
5	LAN-IU	0	.064	1	1	.936	1
6	CPU	0	.005	1	1	.995	1
7	MEM	0	.003	1	1	.997	1
8	DISK-IF	0	.014	1	1	.986	1
9	IFB	0	.002	1	1	.998	1
10	PS-BOARD	0	.003	1	1	.997	1
11	IG-IF	0	.046	1	1	.954	1
12	DISK	0	.020	1	1	.980	1
14	PROC	0	.023	1	1	.977	1
15	REF-MEM	0	.072	1	1	.928	1
16	BLNK-CNT	0	.020	1	1	.980	1
17	PS-CHASS	0	.018	1	1	.982	1
18	TV-MON	0	.066	1	1	.934	1
19	EQ-AMP	0	.008	1	1	.992	1
20	VIDEO-SW	0	.005	1	1	.995	1
21	PROJ	0	.006	1	1	.994	1

SEED	2	A	D	1	.9996830674?11
SEED	2	A	D	2	.9949171957216
SEED	2	A	D	3	.999349141476
SEED	2	A	D	4	.9996233457491
SEED	2	A	D	5	.9997573039359
SEED	2	A	D	6	.9995705128368
SEED	2	A	D	7	.9997051002252
SEED	2	A	D	8	.9995345291747
SEED	2	A	D	9	.9997576483949
SEED	2	A	D	10	.9993730974571
SEED	2	A	D	11	.9980852224461
SEED	2	A	D	12	.998986404543
SEED	2	A	D	13	.9990682835466
SEED	2	A	D	14	.9998835151981
SEED	2	A	D	15	.9998430693827
SEED	2	A	D	16	.9993647336822
SEED	2	A	D	17	.99831.3981452
SEED	2	A	D	18	.9996783972324
SEED	2	A	D	19	.9995992623946
SEED	2	A	D	20	.9992556386227
SEED	2	A	D	21	.9968147477644
SEED	2	A	D	22	.9996931092846
SEED	2	A	D	23	.99871486883.6
SEED	2	A	D	24	.9987435153794
SEED	2	A	D	25	.999772128262
SEED	2	A	D	26	.9993749517193
SEED	2	A	D	27	.999824720365
SEED	2	A	D	28	.9997371406312
SEED	2	A	D	29	.99980604098.9
SEED	2	A	D	30	.99985273133
SEED	2	A	D	31	.99987521503 43
SEED	2	A	D	32	.9999944383531
SEED	2	A	D	33	.99981564416-5
SEED	2	A	D	34	.99981279211 9
SEED	2	A	D	35	.9999665653158
SEED	2	A	D	36	.9994513303952
SEED	2	A	D	37	.9995582069694
SEED	2	A	D	38	.999631525 70
SEED	2	A	D	39	.9997915363726
SEED	2	A	D	40	.9998224493432
SEED	2	A	D	41	.9995260993097
SEED	2	A	D	42	.9999361293831
SEED	2	A	D	43	.9995806471655
SEED	2	A	D	44	.9996817562234

** ESOURCE UTILIZATION**

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.182	2	2	1.818	2
2	LVL-3	0	.051	1	1	.949	1
3	ADP-TERM	0	.032	1	1	.968	1
4	ADP-HDCY	0	.075	1	1	.925	1
5	LAN-IU	0	.039	1	1	.961	1
6	CPU	0	.006	1	1	.994	1
7	MEM	0	.031	1	1	.969	1
8	DISK-IF	0	.01[illegible]	1	1	.983	1
9	IFB	0	.002	1	1	.998	1
10	PS-BOARD	0	.002	1	1	.998	1
11	IG-IF	0	.003	1	1	.997	1
12	DISK	0	.036	1	1	.964	1
14	PROC	0	.018	1	1	.982	1
15	REF-MEM	1	.087	1	0	.913	1
16	BLNK-CNT	0	.008	1	1	.992	1
17	PS-CHASS	0	.011	1	1	.989	1
18	TV-MON	0	.065	1	1	.935	1
19	EQ-AMP	0	.001	1	1	.999	1
20	VIDEO-SW	0	.022	1	1	.978	1
21	PROJ	0	.088	1	1	.912	1

SEED	3	A	C	1	.999595671016
SEED	3	A	C	2	.9995069069524
SEED	3	A	C	3	.9996912781082
SEED	3	A	C	4	.9994814331134
SEED	3	A	C	5	.9996508520379
SEED	3	A	C	6	.9987647276546
SEED	3	A	C	7	.9992362470789
SEED	3	A	C	8	.9995106553224
SEED	3	A	C	9	.9997736650225
SEED	3	A	C	10	.9998838932029
SEED	3	A	C	11	.9984145436238
SEED	3	A	C	12	.999531248168
SEED	3	A	C	13	.9997537689553
SEED	3	A	C	14	.9994677650895
SEED	3	A	C	15	.999913033698
SEED	3	A	C	16	.9999003428134
SEED	3	A	C	17	.9994741698035
SEED	3	A	C	18	.9997266791076
SEED	3	A	C	19	.9986055088655
SEED	3	A	C	20	.9990390011286
SEED	3	A	C	21	.999335517104
SEED	3	A	C	22	.9992877290232
SEED	3	A	C	23	.999461752368
SEED	3	A	D	24	.9986864038908
SEED	3	A	C	25	.9996384062546
SEED	3	A	C	26	.999580704992
SEED	3	A	D	27	.9999050309436
SEED	3	A	C	28	.9997378487716
SEED	3	A	C	29	.9999288449843
SEED	3	A	C	30	.9996359808627
SEED	3	A	C	31	.9997313229842
SEED	3	A	C	32	.9998818272595
SEED	3	A	D	33	.9998174116952
SEED	3	A	C	34	.99948329623
SEED	3	A	C	35	.9998169758176
SEED	3	A	C	36	.9998330560851
SEED	3	A	C	37	.999008524828
SEED	3	A	C	38	.9995982583673
SEED	3	A	C	39	.9985231730383
SEED	3	A	C	40	.9994051414983
SEED	3	A	D	41	.9999118062557
SEED	3	A	C	42	.999776400863
SEED	3	A	C	43	.9994571972407
SEED	3	A	C	44	.999804512364

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.182	2	2	1.818	2
2	LVL-3	0	.053	1	1	.947	1
3	ADP-TERM	0	.020	1	1	.980	1
4	ADP-HDCY	0	.049	1	1	.951	1
5	LAN-IU	0	.059	1	1	.941	1
6	CPU	0	.006	1	1	.994	1
7	MEM	0	.037	1	1	.933	1
8	DISK-IF	0	0.000	0	1	1.000	1
9	IFB	0	.003	1	1	.997	1
10	PS-BOARD	0	.001	1	1	.999	1
11	IG-IF	0	.007	1	1	.993	1
12	DISK	0	.057	1	1	.943	1
14	PROC	0	.010	1	1	.990	1
15	REF-MEM	0	.104	1	1	.896	1
16	BLNK-CNT	0	.013	1	1	.987	1
17	PS-CHASS	0	.001	1	1	.999	1
18	TV-MON	0	.076	1	1	.924	1
19	EQ-AMP	0	.006	1	1	.994	1
20	VIDEO-SW	0	.006	1	1	.994	1
21	PROJ	0	.088	1	1	.912	1

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SEED 1 B C 1 .99[illegible]6742933147
SEED 1 B C 2 .9996656776157
SEED 1 B C 3 .9978068645462
SEED 1 B C 4 .999645[illegible]335536
SEED 1 B C 5 .9996124881172
SEED 1 B C 6 .99325990[illegible]3623
SEED 1 B C 7 .99975675[illegible]3634
SEED 1 B C 8 .99[illegible]597[illegible]133635
SEED 1 B C 9 .9979164975598
SEED 1 B C 10 .99936[illegible]7[illegible]333
SEED 1 B C 11 .9967240[illegible]5[illegible]324
SEED 1 B C 12 .[illegible]137 797
SEED 1 B C 13 .[illegible]457[illegible]2[illegible]744
SEED 1 B C 14 .[illegible]41721[illegible]65
SEED 1 B C 15 .999971454453
SEED 1 B C 16 .99946[illegible]14[illegible]453
SEED 1 B C 17 1.
SEED 1 B C 18 .999552921[illegible]294
SEED 1 B C 19 .99744[illegible]6[illegible]57332
SEED 1 B C 20 .9999114139[illegible]33
SEED 1 B C 21 .9997754484046
SEED 1 B C 22 .9993632695432
SEED 1 B C 23 .9972511764562
SEED 1 B C 24 .99941356[illegible]5[illegible]92
SEED 1 B C 25 .9999601439935
SEED 1 B C 26 .99986652[illegible]6944
SEED 1 B C 27 .9998612384934
SEED 1 B C 28 .99991[illegible]111
SEED 1 B C 29 .9994926313042
SEED 1 B C 30 .9998810957127
SEED 1 B C 31 .999916276983
SEED 1 B C 32 .99993799[illegible]53
SEED 1 B C 33 .9999435167029
SEED 1 B C 34 .9999140036613
SEED 1 B C 35 .9999454826118
SEED 1 B C 36 .99754[illegible]67[illegible]6[illegible]
SEED 1 B C 37 .9997631061432
SEED 1 B C 38 .99997[illegible]5997349
SEED 1 B C 39 .999942739942
SEED 1 B C 40 .999698135[illegible]
SEED 1 B C 41 .9998869747247
SEED 1 B C 42 .99992[illegible]092[illegible]612
SEED 1 B C 43 .999968911[illegible]73[illegible]7
SEED 1 B C 44 .9997[illegible]6221529
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RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.198	1	1	.802	1
2	LVL-3	0	.198	1	1	.802	1
3	ADP-TERM	0	.054	2	2	1.946	2
4	ADP-HCCY	0	.032	1	2	1.968	2
5	LAN-IU	0	.031	1	2	1.969	2
6	CPU	0	.002	1	2	1.998	2
7	MEM	0	.002	1	2	1.998	2
8	DISK-IF	0	.008	1	2	1.992	2
9	IFB	0	.004	1	2	1.996	2
10	PS-BOARD	0	.001	1	2	1.999	2
11	IO-IF	0	.020	1	2	1.980	2
12	DISK	0	.015	1	2	1.985	2
14	PROC	0	.011	1	2	1.989	2
15	REF-MEM	0	.123	2	2	1.877	2
16	BLNK-CNT	0	.004	1	2	1.996	2
17	PS-CHASS	0	.003	1	2	1.997	2
18	TV-MON	0	.046	2	2	1.954	2
19	EQ-AMP	0	.001	1	2	1.999	2
20	VIDEO-SW	0	.003	1	2	1.997	2
21	PROJ	0	.046	2	2	1.954	2

SEED	2	B	C	1	[illegible]
SEED	2	B	C	2	[illegible]
SEED	2	B	C	3	.9996399332163
SEED	2	B	C	4	.9999391626399
SEED	2	B	C	5	.9994225627194
SEED	2	B	C	6	.99929555504128
SEED	2	B	C	7	.9997765985393
SEED	2	B	C	8	.9992971047765
SEED	2	B	C	9	.9995162413115
SEED	2	B	C	10	.9985622098495
SEED	2	B	C	11	.9969096473911
SEED	2	B	C	12	.9993586437956
SEED	2	B	C	13	.9969195422049
SEED	2	B	C	14	.99993770 432
SEED	2	B	C	15	.9993439813195
SEED	2	B	C	16	.9999784444073
SEED	2	B	C	17	.9992672733663
SEED	2	B	C	18	1.
SEED	2	B	C	19	.9991386234802
SEED	2	B	C	20	.9978717739731
SEED	2	B	C	21	.9992383159399
SEED	2	B	C	22	.9984126292959
SEED	2	B	C	23	.9996977722551
SEED	2	B	C	24	.9998367771149
SEED	2	B	C	25	.99950 2927389
SEED	2	B	C	26	.9998768761956
SEED	2	B	C	27	.9999137639978
SEED	2	B	C	28	.99956-2876963
SEED	2	B	C	29	.998677831 136
SEED	2	B	C	30	.9999412527596
SEED	2	B	C	31	.9983725642962
SEED	2	B	C	32	.99983441579
SEED	2	B	C	33	.9999 22927583
SEED	2	B	C	34	.9994477349132
SEED	2	B	C	35	.996846931 7235
SEED	2	B	C	36	.9989941217512
SEED	2	B	C	37	.99973 4254149
SEED	2	B	C	38	.9998421262827
SEED	2	B	C	39	.9998413768295
SEED	2	B	C	40	.9995854449963
SEED	2	B	C	41	.99957 8568376
SEED	2	B	C	42	1.
SEED	2	B	C	43	.999574937 891
SEED	2	B	C	44	.99993 7837662

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.175	1	1	.825	1
2	LVL-3	0	.175	1	1	.825	1
3	ADP-TERM	0	.054	2	2	1.946	2
4	ADP-HDCY	0	.029	1	2	1.971	2
5	LAN-IL	0	.053	1	2	1.947	2
6	CPU	0	.006	1	2	1.994	2
7	MEM	0	.015	1	2	1.985	2
8	DISK-IF	0	[illegible]	1	2	1.982	2
9	IFB	0	[illegible]	1	2	2.00[illegible]	2
10	F[illegible]-BOARD	0	[illegible]1	1	2	1.999	2
11	IG-IF	0	.015	1	2	1.985	2
12	DISK	0	.021	1	2	1.979	2
14	PROC	0	.017	1	2	1.983	2
15	REF-MEM	0	.041	1	2	1.959	2
16	BLNK-CNT	0	[illegible]3	1	2	1.997	2
17	PS-CHASS	0	[illegible]2	1	2	1.998	2
18	TV-MON	0	.048	1	2	1.952	2
19	EG-AMP	0	[illegible]	[illegible]	2	2.00[illegible]	2
20	VIDEO-SW	0	[illegible]2	1	2	1.998	2
21	PROJ	0	.033	1	2	1.967	2

SEED	3	B	C	1	.[illegible]
SEED	3	B	C	2	.[illegible]
SEED	3	B	C	3	.9976526414[illegible]
SEED	3	B	C	4	.9990733858073
SEED	3	B	C	5	.999801360[illegible]13
SEED	3	B	C	6	.9999194642512
SEED	3	B	C	7	.9998566806757
SEED	3	B	C	8	.99791132710[illegible]
SEED	3	B	C	9	.999663611665[illegible]
SEED	3	B	C	10	.9998161383244
SEED	3	B	C	11	.9997058251473[illegible]
SEED	3	B	C	12	.9986664550853
SEED	3	B	C	13	.9989626471597
SEED	3	B	C	14	.999914223147
SEED	3	B	C	15	.9999405678324
SEED	3	B	C	16	.9989091281184
SEED	3	B	C	17	.9977527103441
SEED	3	B	C	18	.9993855244093
SEED	3	B	C	19	.999717876721[illegible]
SEED	3	B	C	20	.9992189710793
SEED	3	B	C	21	.9998523906494
SEED	3	B	C	22	.9970535479525
SEED	3	B	C	23	.9994165965467
SEED	3	B	C	24	.9984149128383
SEED	3	B	C	25	.9998975562956
SEED	3	B	C	26	.9999653886143
SEED	3	B	C	27	.9994806494074
SEED	3	B	C	28	.9988968396373
SEED	3	B	C	29	.999845693991
SEED	3	B	C	30	.9999087844333
SEED	3	B	C	31	.9998268599356
SEED	3	B	C	32	1.
SEED	3	B	C	33	.9996671837238
SEED	3	B	C	34	.9996308180377
SEED	3	B	C	35	.9990655043229
SEED	3	B	C	36	.9995562451517
SEED	3	B	C	37	.9997464754896
SEED	3	B	C	38	.9996906603825
SEED	3	B	C	39	.999866723[illegible]382
SEED	3	B	C	40	.9986714997311
SEED	3	B	C	41	.9999156339293
SEED	3	B	C	42	.9998759512384
SEED	3	B	C	43	.9999414929022
SEED	3	B	C	44	.9997106703887

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	1	.191	1	0	.809	1
2	LVL-3	1	.191	1	0	.809	1
3	ADP-TERM	0	.023	1	2	1.977	2
4	ADP-HDCY	0	.021	1	2	1.979	2
5	LAN-IU	0	.054	1	2	1.946	2
6	CPU	0	.005	1	2	1.995	2
7	MEM	0	.043	1	2	1.957	2
8	DISK-IF	0	0.000	0	2	2.000	2
9	IFB	0	.015	1	2	1.985	2
10	PS-BOARD	0	.002	1	2	1.998	2
11	IG-IF	0	.006	1	2	1.994	2
12	DISK	0	.017	2	2	1.983	2
14	PROC	0	.018	1	2	1.982	2
15	REF-MEM	0	.052	2	2	1.948	2
16	BLNK-CNT	1	.012	1	1	1.988	2
17	PS-CHASS	0	.005	1	2	1.995	2
18	TV-MON	1	.072	1	1	1.928	2
19	EG-AMP	0	.001	1	2	1.999	2
20	VIDEC-SW	0	.008	1	2	1.992	2
21	PROJ	0	.075	2	2	1.925	2

SEED	1	B	D	1	.99[illegible]61[illegible]5[illegible]179
SEED	1	B	D	2	.994277630[illegible]217
SEED	1	B	D	3	.99920[illegible]165255
SEED	1	B	D	4	.9997055525521
SEED	1	B	D	5	.999512[illegible]207269
SEED	1	B	D	6	.9968479015151
SEED	1	B	D	7	.99951[illegible]2285125
SEED	1	B	D	8	.9969414365728
SEED	1	B	D	9	.99828[illegible]236488
SEED	1	B	D	10	.999069551713
SEED	1	B	D	11	.9994[illegible]0228634[illegible]
SEED	1	B	D	12	.9978109433899
SEED	1	B	D	13	.9992977327315
SEED	1	B	D	14	.9989369621474
SEED	1	B	D	15	.9976436[illegible]32323
SEED	1	B	D	16	.99983224[illegible]725
SEED	1	B	D	17	1.
SEED	1	B	D	18	.9997223863918
SEED	1	B	D	19	.99919[illegible]95[illegible]5539
SEED	1	B	D	20	.9996365556579
SEED	1	B	D	21	.9984514916652
SEED	1	B	D	22	.9987254363522
SEED	1	B	D	23	.9976544397543
SEED	1	B	D	24	.996385609322
SEED	1	B	D	25	.9994152229685
SEED	1	B	D	26	.9998438152464
SEED	1	B	D	27	.9993664844471
SEED	1	B	D	28	.999790357299
SEED	1	B	D	29	.9999197500918
SEED	1	B	D	30	.999751361[illegible]23
SEED	1	B	D	31	.9995786877276
SEED	1	B	D	32	.9998769638219
SEED	1	B	D	33	.9998562724563
SEED	1	B	D	34	.9995486427717
SEED	1	B	D	35	.99583[illegible]869[illegible]486
SEED	1	B	D	36	.9965885094153
SEED	1	B	D	37	.9992333664613
SEED	1	B	D	38	.9998121453792
SEED	1	B	D	39	.998521503534[illegible]
SEED	1	B	D	40	.999643295898
SEED	1	B	D	41	.9995016621267
SEED	1	B	D	42	.9996100892457
SEED	1	B	D	43	.9999395863462
SEED	1	B	D	44	.999737032[illegible]146

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.203	1	1	.792	1
2	LVL-3	0	.207	1	1	.793	1
3	ADP-TERM	0	.108	2	2	1.892	2
4	ADP-HDCY	0	.043	2	2	1.957	2
5	LAN-IU	0	.060	1	2	1.940	2
6	CPU	0	.005	1	2	1.995	2
7	MEM	0	.002	1	2	1.998	2
8	DISK-IF	0	.006	1	2	1.994	2
9	IFB	0	.003	1	2	1.997	2
10	PS-BOARD	0	.002	1	2	1.998	2
11	IG-IF	0	.012	1	2	1.988	2
12	DISK	0	.008	1	2	1.992	2
14	PROC	0	.012	1	2	1.988	2
15	REF-MEM	0	.161	2	2	1.839	2
16	BLNK-CNT	0	.007	1	2	1.993	2
17	PS-CHASS	0	.004	1	2	1.996	2
18	TV-MON	0	.082	2	2	1.918	2
19	EG-AMP	0	.001	1	2	1.999	2
20	VIDEO-SW	0	.003	1	2	1.997	2
21	PROJ	0	.086	2	2	1.914	2

SEED	2	B	D	1	.9[illegible]746[illegible]7[illegible]
SEED	2	B	D	2	.9[illegible]79[illegible]1675155
SEED	2	B	D	3	.99764[illegible]3665858
SEED	2	B	D	4	.9999349061641
SEED	2	B	D	5	.9994306811759
SEED	2	B	D	6	.9976995111174
SEED	2	B	D	7	.9991509909234
SEED	2	B	D	8	.9994146699517
SEED	2	B	D	9	.9997810713962
SEED	2	B	D	10	.999034197[illegible]279
SEED	2	B	D	11	.9968307727322
SEED	2	B	D	12	.9[illegible]9741643[illegible]1
SEED	2	B	D	13	.9995033373535
SEED	2	B	D	14	.99991 29[illegible]3114
SEED	2	B	D	15	.9999194472964
SEED	2	B	D	16	.9997146982[illegible]4
SEED	2	B	D	17	.998752814953
SEED	2	B	D	18	.9991602611363
SEED	2	B	D	19	.9993475523527
SEED	2	B	D	20	.999517719326
SEED	2	B	D	21	.9994044764836
SEED	2	B	D	22	.999512675371
SEED	2	B	D	23	.999049601[illegible]2354
SEED	2	B	D	24	.9996381211324
SEED	2	B	D	25	.9993373633234
SEED	2	B	D	26	.9996220011716
SEED	2	B	D	27	.9990314109354
SEED	2	B	D	28	.99959120541[illegible]
SEED	2	B	D	29	.9993036729587
SEED	2	B	D	30	.999153834 416
SEED	2	B	D	31	.999769252[illegible]855
SEED	2	B	D	32	.9996348647149
SEED	2	B	D	33	.999042688195
SEED	2	B	D	34	.999243738825[illegible]
SEED	2	B	D	35	.9998121666666
SEED	2	B	D	36	.9999341217532
SEED	2	B	D	37	.9998561501284
SEED	2	B	D	38	.99979970[illegible]439
SEED	2	B	D	39	.9994779923381
SEED	2	B	D	40	.999745617395[illegible]
SEED	2	B	D	41	.9996922952841
SEED	2	B	D	42	.9996252911415
SEED	2	B	D	43	.999894125[illegible]79
SEED	2	B	D	44	.9990660911751

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.184	1	1	.816	1
2	LVL-3	0	.184	1	1	.816	1
3	ADP-TERM	0	.067	1	2	1.933	2
4	ADP-HDCY	0	.043	2	2	1.957	2
5	LAN-IU	0	.043	2	2	1.957	2
6	CPU	0	.003	1	2	1.997	2
7	MEM	0	.038	2	2	1.962	2
8	DISK-IF	0	.017	1	2	1.983	2
9	IFB	0	.000	1	2	2.000	2
10	PS-BOARD	0	.001	1	2	1.999	2
11	IG-IF	0	.006	1	2	1.994	2
12	DISK	0	.003	1	2	1.997	2
14	PFCC	0	.008	1	2	1.992	2
15	REF-MEM	1	.116	2	1	1.884	2
16	BLNK-CNT	0	.003	1	2	1.997	2
17	FS-CHASS	0	.002	1	2	1.998	2
18	TV-MCN	0	.092	2	2	1.908	2
19	EG-AMP	0	.014	1	2	1.986	2
20	VIDEO-SW	0	.019	1	2	1.981	2
21	P-OJ	0	.095	2	2	1.905	2

SEED	3	B	D	1	.9[illegible]73[illegible]2[illegible]773
SEED	3	B	D	2	.99[illegible]6521114[illegible]24
SEED	3	B	D	3	.9[illegible]5413381144
SEED	3	B	D	4	.9[illegible]92[illegible]3[illegible]754[illegible]31
SEED	3	B	D	5	.9986935952184
SEED	3	B	D	6	.9997891539244
SEED	3	B	D	7	.9997976993618
SEED	3	B	D	8	.99928[illegible]272[illegible]65
SEED	3	B	D	9	.999031595 4[illegible]15
SEED	3	B	D	10	.99929[illegible]2402971
SEED	3	B	D	11	.9982610875942
SEED	3	B	D	12	.99824[illegible]016[illegible]2[illegible]2
SEED	3	B	D	13	.999247314[illegible]329
SEED	3	B	D	14	.9[illegible]98225171476
SEED	3	B	D	15	.9999131834068
SEED	3	B	D	16	.9[illegible]92219934[illegible]55
SEED	3	B	D	17	.9990165933[illegible]63
SEED	3	B	D	18	.9991791534999
SEED	3	B	D	19	.9995747566411
SEED	3	B	D	20	.9926764645[illegible]06
SEED	3	B	D	21	.9997304220683
SEED	3	B	D	22	.9990777281514
SEED	3	B	D	23	.9990955681215
SEED	3	B	D	24	.9991093917182
SEED	3	B	D	25	.9998636997393
SEED	3	B	D	26	.9996036256436
SEED	3	B	D	27	.9995569741152
SEED	3	B	D	28	.9992420236275
SEED	3	B	D	29	.999877526255
SEED	3	B	D	30	.99979562[illegible]4362
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SEED	3	B	D	34	.9996512632144
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SEED	3	B	D	36	.99982727541
SEED	3	B	D	37	.9995679131269
SEED	3	B	D	38	.99989166[illegible]3[illegible]25
SEED	3	B	D	39	.999263027793
SEED	3	B	D	40	.9997942313353
SEED	3	B	D	41	.9994409412879
SEED	3	B	D	42	.9996473637279
SEED	3	B	D	43	.9998957017977
SEED	3	B	D	44	.9[illegible]95[illegible]523[illegible]1056

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	1	.183	1	0	.817	1
2	LVL-3	1	.183	1	0	.817	1
3	ADP-TERM	0	.040	2	2	1.960	2
4	ADP-HCCY	0	.022	1	2	1.978	2
5	LAN-IU	0	.131	2	2	1.869	2
6	CPU	0	.003	1	2	1.997	2
7	MEM	1	.007	1	1	1.993	2
8	DISK-IF	0	.000	0	2	2.000	2
9	IFB	0	.033	1	2	1.967	2
10	PS-BOARD	0	.001	1	2	1.999	2
11	IG-IF	0	.016	1	2	1.984	2
12	DISK	0	.017	2	2	1.983	2
14	FACC	0	.028	1	2	1.972	2
15	REF-MEM	0	.043	2	2	1.957	2
16	BLNK-CNT	0	.005	1	2	1.995	2
17	PS-CHASS	0	.005	1	2	1.995	2
18	TV-MON	0	.107	2	2	1.893	2
19	EG-AMP	0	.000	1	2	2.000	2
20	VIDEO-SW	0	.031	1	2	1.969	2
21	PROJ	0	.111	2	2	1.889	2

SEED	2	C	D	1	.[illegible]479
SEED	2	C	D	2	.999761367[illegible]465
SEED	2	C	D	3	.999727[illegible]385436
SEED	2	C	D	4	.999655[illegible]833[illegible]5
SEED	2	C	D	5	.9998686923128
SEED	2	C	D	6	.9992131914929
SEED	2	C	D	7	.9994036711569
SEED	2	C	D	8	.9995925774679
SEED	2	C	D	9	.9996944456646
SEED	2	C	D	10	.99953[illegible]149[illegible]591
SEED	2	C	D	11	.9963868842319
SEED	2	C	D	12	.9996129042[illegible]25
SEED	2	C	D	13	.9996351751316
SEED	2	C	D	14	.99993778[illegible]432
SEED	2	C	D	15	.9999423856445
SEED	2	C	D	16	.9999764864[illegible]73
SEED	2	C	D	17	.9997328173273
SEED	2	C	D	18	1.
SEED	2	C	D	19	.999798469[illegible]156
SEED	2	C	D	20	.9998[illegible]6933[illegible]29
SEED	2	C	D	21	.9994306707593
SEED	2	C	D	22	.99912566[illegible]1298
SEED	2	C	D	23	.99968[illegible]5077[illegible]3
SEED	2	C	D	24	.9997343159618
SEED	2	C	D	25	.9999422811291
SEED	2	C	D	26	.9998768761856
SEED	2	C	D	27	.999854065[illegible]33
SEED	2	C	D	28	.9999462629353
SEED	2	C	D	29	.9999138273053
SEED	2	C	D	30	.9997464905634
SEED	2	C	D	31	.9998402208166
SEED	2	C	D	32	.999907671[illegible]641
SEED	2	C	D	33	.9996284355513
SEED	2	C	D	34	.9998486591578
SEED	2	C	D	35	.99994[illegible]60[illegible]2[illegible]74
SEED	2	C	D	36	.9998941217502
SEED	2	C	D	37	.9996706621364
SEED	2	C	D	38	.9998840579742
SEED	2	C	D	39	.9998595755841
SEED	2	C	D	40	.9999624796147
SEED	2	C	D	41	.9998501022112
SEED	2	C	D	42	1.
SEED	2	C	D	43	.999974937[illegible]891
SEED	2	C	D	44	.9999307807662

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.099	1	1	.901	1
2	LVL-3	0	.099	1	1	.901	1
3	ACP-TERM	0	.032	1	1	.968	1
4	ACP-HDCY	0	.018	1	1	.982	1
5	LAN-IU	0	.026	1	1	.974	1
6	CPU	0	.002	1	1	.998	1
7	MEM	0	.00[illegible]	1	1	1.000	1
8	DISK-IF	0	.001	1	1	.999	1
9	IFB	0	.003	1	1	.997	1
10	PS-BOARD	0	.013	1	1	.987	1
11	IG-IF	0	.009	1	1	.991	1
12	DISK	0	.012	1	1	.988	1
14	PROC	0	.033	1	1	.967	1
15	REF-MEM	0	.043	1	1	.957	1
16	BLNK-CNT	0	.002	1	1	.992	1
17	PS-CHASS	0	.002	1	1	.998	1
18	TV-MON	0	.055	1	1	.945	1
19	EG-AMP	0	.0[illegible]	[illegible]	1	1.000	1
20	VIDEO-SW	0	.003	1	1	.997	1
21	PROJ	0	.153	1	1	.847	1

SEED	1	C	D	1	.[illegible]57[illegible]12[illegible]36
SEED	1	C	D	2	.9993515101455
SEED	1	C	D	3	.99[illegible]45462
SEED	1	C	D	4	.9959426632[illegible]22
SEED	1	C	D	5	.9996417799[illegible]7
SEED	1	C	D	6	.9998454564102
SEED	1	C	D	7	.9996121761499
SEED	1	C	D	8	.99957268[illegible]65
SEED	1	C	D	9	.99943[illegible]48[illegible]438[illegible]
SEED	1	C	D	10	.9998529[illegible]1[illegible]432
SEED	1	C	D	11	.9998441671[illegible]24
SEED	1	C	D	12	.9992158624791
SEED	1	C	D	13	.9993161059[illegible]
SEED	1	C	D	14	.99991760[illegible]1[illegible]
SEED	1	C	D	15	.[illegible]37637147 44
SEED	1	C	D	16	.99996[illegible]1466463
SEED	1	C	D	17	1.
SEED	1	C	D	18	.9997223863916
SEED	1	C	D	19	.999653534[illegible]36
SEED	1	C	D	20	.9993190432521
SEED	1	C	D	21	.9998[illegible]5262587
SEED	1	C	D	22	.9991637794363
SEED	1	C	D	23	.9998[illegible]2[illegible]95646
SEED	1	C	D	24	.999886534654[illegible]
SEED	1	C	D	25	.9999661433935
SEED	1	C	D	26	.999344394[illegible]373
SEED	1	C	D	27	.9998396406778
SEED	1	C	D	28	.9996711675367
SEED	1	C	D	29	.9999064347263
SEED	1	C	D	30	.999827222131
SEED	1	C	D	31	.9998571837333
SEED	1	C	D	32	.9999379599953
SEED	1	C	D	33	.99993435167[illegible]27
SEED	1	C	D	34	.9999140036613
SEED	1	C	D	35	.9991078303376
SEED	1	C	D	36	.9985743834727
SEED	1	C	D	37	.9998872492365
SEED	1	C	D	38	.9999705997849
SEED	1	C	D	39	.999459123[illegible]516
SEED	1	C	D	40	.9998981358[illegible]5
SEED	1	C	D	41	.9998496671593
SEED	1	C	D	42	.999962901[illegible]33
SEED	1	C	D	43	.99996[illegible]91[illegible]73[illegible]7
SEED	1	C	D	44	.9997946221529

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.094	1	1	.906	1
2	LVL-3	0	.093	1	1	.907	1
3	ADP-TERM	0	.022	1	1	.978	1
4	ADP-HDCY	0	.023	1	1	.977	1
5	LAN-IU	0	.023	1	1	.972	1
6	CPU	0	.002	1	1	.998	1
7	MEM	0	.028	1	1	.972	1
8	DISK-IF	0	.017	1	1	.983	1
9	IFB	0	.000	1	1	1.000	1
10	PS-BOARD	0	0.000	0	1	1.000	1
11	IG-IF	0	.011	1	1	.989	1
12	DISK	0	.002	1	1	.998	1
14	PROC	0	.004	1	1	.996	1
15	REF-MEM	0	.076	1	1	.924	1
16	BLNK-CNT	0	.002	1	1	.998	1
17	PS-CHASS	0	.011	1	1	.989	1
18	TV-MON	0	.062	1	1	.938	1
19	EO-AMP	0	0.000	0	1	1.000	1
20	VIDEO-SW	0	.001	1	1	.999	1
21	PROJ	0	.017	1	1	.983	1

SEED 3 C D 1 .9[illegible]83[illegible]45[illegible]
SEED 3 C D 2 .9[illegible]5811278424
SEED 3 C D 3 .9[illegible]67634[illegible]478
SEED 3 C D 4 .9995637064979
SEED 3 C D 5 .9998123411696
SEED 3 C D 6 .9998839039376
SEED 3 C D 7 .9993246261477
SEED 3 C D 8 .9991253271539
SEED 3 C D 9 .9997299[illegible]958[illegible]67
SEED 3 C D 10 .99963649562207
SEED 3 C D 11 .99866[illegible]4473478
SEED 3 C D 12 .999562763 569
SEED 3 C D 13 .99930[illegible]61891595
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SEED 3 C D 18 .99965237849564
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SEED 3 C D 21 .99981[illegible]344 1[illegible]1
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SEED 3 C D 25 .9998999245193
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SEED 3 C D 34 .9995902131[illegible]991
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SEED 3 C D 37 .99980326663[illegible]74
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SEED 3 C D 40 .99982437969[illegible]85
SEED 3 C D 41 .99921[illegible]4419[illegible]55
SEED 3 C D 42 .99987995512364
SEED 3 C D 43 .99996767[illegible]7954
SEED 3 C D 44 .999899332[illegible]342

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.099	1	1	.901	1
2	LVL-3	0	.098	1	1	.902	1
3	ADP-TERM	0	.033	1	1	.967	1
4	ADP-HDCY	0	.004	1	1	.996	1
5	LAN-IU	0	.070	1	1	.930	1
6	CPU	1	.018	1	0	.982	1
7	MEM	0	.003	1	1	.997	1
8	DISK-IF	0	0.000	0	1	1.000	1
9	IFB	0	.013	1	1	.987	1
10	PS-BOARD	0	.002	1	1	.998	1
11	IG-IF	0	.003	1	1	.997	1
12	DISK	0	.015	1	1	.985	1
14	FLOC	0	.001	1	1	.999	1
15	REF-MEM	0	.013	1	1	.987	1
16	BLNK-CNT	0	.003	1	1	.997	1
17	PS-CHASS	0	.002	1	1	.998	1
18	TV-MON	0	.048	1	1	.952	1
19	EG-AMP	0	.023	1	1	.977	1
20	VIDEO-SW	0	.002	1	1	.998	1
21	PROJ	0	.025	1	1	.975	1

SEED	1	A	B	C	D	1	[illegible]
SEED	1	A	B	C	D	2	.9[illegible]7[illegible]64[illegible]
SEED	1	A	B	C	D	3	.9[illegible]45462
SEED	1	A	B	C	D	4	.9999426632[illegible]22
SEED	1	A	B	C	D	5	.99997366220[illegible]4
SEED	1	A	B	C	D	6	.9998454564162
SEED	1	A	B	C	D	7	.999812176[illegible]499
SEED	1	A	B	C	D	8	.9997742482328
SEED	1	A	B	C	D	9	.9999337996333
SEED	1	A	B	C	D	10	.99986239463232
SEED	1	A	B	C	D	11	.99997[illegible]67112627
SEED	1	A	B	C	D	12	.99934[illegible]5835411
SEED	1	A	B	C	D	13	.99997535317523
SEED	1	A	B	C	D	14	.99991960[illegible]501[illegible]
SEED	1	A	B	C	D	15	.9998763784744
SEED	1	A	B	C	D	16	.9999631466463
SEED	1	A	B	C	D	17	1.
SEED	1	A	B	C	D	18	.99972238638218
SEED	1	A	B	C	D	19	.99971189412733
SEED	1	A	B	C	D	20	.99989726414[illegible]
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SEED	1	A	B	C	D	22	.9992[illegible]349774
SEED	1	A	B	C	D	23	.999817075637
SEED	1	A	B	C	D	24	.99988853466548
SEED	1	A	B	C	D	25	.99996[illegible]1439935
SEED	1	A	B	C	D	26	.99988652C6944
SEED	1	A	B	C	D	27	.9998836406778
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SEED	1	A	B	C	D	29	.9999[illegible]84347263
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SEED	1	A	B	C	D	32	.99993795597953
SEED	1	A	B	C	D	33	.99994351670239
SEED	1	A	B	C	D	34	.99991400356613
SEED	1	A	B	C	D	35	.99998981327231
SEED	1	A	B	C	D	36	.99946255928334
SEED	1	A	B	C	D	37	.99998724[illegible]2365
SEED	1	A	B	C	D	38	.99997 5597349
SEED	1	A	B	C	D	39	.999824278[illegible]02[illegible]
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SEED	1	A	B	C	D	41	.99998496071593
SEED	1	A	B	C	D	42	.9999629601633
SEED	1	A	B	C	D	43	.99999639117307
SEED	1	A	B	C	D	44	.99979[illegible]6221529

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.100	2	2	1.900	2
2	LVL-3	0	.024	1	1	.976	1
3	ADP-TERM	0	.016	1	2	1.984	2
4	ADP-HDCY	0	.025	1	2	1.975	2
5	LAN-IU	0	.027	1	2	1.973	2
6	CPU	0	.011	1	2	1.989	2
7	MEM	0	.001	1	2	1.999	2
8	DISK-IF	0	.005	1	2	1.995	2
9	IFB	0	.002	1	2	1.998	2
10	PS-BOARD	0	.001	1	2	1.999	2
11	IG-IF	0	.009	1	2	1.991	2
12	DISK	0	.033	1	2	1.967	2
14	PROC	0	.005	1	2	1.995	2
15	REF-MEM	0	.051	2	2	1.949	2
16	BLNK-CNT	0	.010	1	2	1.990	2
17	PS-CHASS	0	.001	1	2	1.999	2
18	TV-MON	0	.022	2	2	1.978	2
19	EG-AMP	0	.001	1	2	1.999	2
20	VIDEO-SW	0	.002	1	2	1.998	2
21	PROJ	0	.063	2	2	1.937	2

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SEED 2 A B C D 8 .9996776781862
SEED 2 A B C D 9 .9998302357193
SEED 2 A B C D 10 .9992670741683
SEED 2 A B C D 11 .99839557596213
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SEED 2 A B C D 13 .99971552[illegible]3586
SEED 2 A B C D 14 .9999230[illegible]534
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SEED 2 A B C D 17 .9996[illegible]6308538[illegible]
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SEED 2 A B C D 29 .999902317[illegible]527
SEED 2 A B C D 30 .99994[illegible]2527559
SEED 2 A B C D 31 .99994836[illegible]1977
SEED 2 A B C D 32 .999919925[illegible]213
SEED 2 A B C D 33 .9999175376541
SEED 2 A B C D 34 .999874533[illegible]935
SEED 2 A B C D 35 .9999665653165
SEED 2 A B C D 36 .99989412175[illegible]2
SEED 2 A B C D 37 .999751121124
SEED 2 A B C D 38 .99951[illegible]4251574
SEED 2 A B C D 39 .9998425627656
SEED 2 A B C D 40 .9999624756147
SEED 2 A B C D 41 .999829002[illegible]375
SEED 2 A B C D 42 1.
SEED 2 A B C D 43 .99985[illegible]1672805
SEED 2 A B C D 44 .9998[illegible]149.723
```

RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.036	2	2	1.904	2
2	LVL-3	0	.019	1	1	.981	1
3	ADP-TERM	0	.032	1	2	1.968	2
4	ADP-HDCY	0	.007	1	2	1.993	2
5	LAN-IU	0	.033	1	2	1.967	2
6	CFU	0	.003	1	2	1.997	2
7	MEM	0	.034	2	2	1.966	2
8	DISK-IF	0	.016	1	2	1.984	2
9	IFB	0	.000	1	2	2.000	2
10	FS-BOARD	0	.001	1	2	1.999	2
11	IG-IF	0	.005	1	2	1.995	2
13	DISK	0	.002	1	2	1.998	2
14	PROC	0	.002	1	2	1.998	2
15	REF-MEM	0	.061	2	2	1.939	2
16	BLNK-CNT	0	.009	1	2	1.991	2
17	PS-CHASS	0	.001	1	2	1.999	2
18	TV-MON	0	.051	2	2	1.949	2
19	EG-AMP	0	.001	1	2	1.999	2
20	VIDEC-SW	0	.001	1	2	1.999	2
21	PFOJ	0	.042	2	2	1.958	2

SEED	3	A	B	C	D	1	.[illegible]
SEED	3	A	B	C	D	2	.9[illegible]7[illegible]1339[illegible]3[illegible]
SEED	3	A	B	C	D	3	.9[illegible]98[illegible]132116
SEED	3	A	B	C	D	4	.999[illegible]6[illegible]687957
SEED	3	A	B	C	D	5	.999[illegible]2[illegible]527717
SEED	3	A	B	C	D	6	.999886173[illegible]
SEED	3	A	B	C	D	7	.999687133[illegible]558
SEED	3	A	B	C	D	8	.9998137739273
SEED	3	A	B	C	D	9	.9998132172506
SEED	3	A	B	C	D	10	.99993586647375
SEED	3	A	B	C	D	11	.99996[illegible]30137717
SEED	3	A	B	C	D	12	.99996[illegible]64[illegible]5155
SEED	3	A	B	C	D	13	.99997[illegible]5173[illegible]361
SEED	3	A	B	C	D	14	.999914223157
SEED	3	A	B	C	D	15	.99991[illegible] 33698
SEED	3	A	B	C	D	16	.9999[illegible]6342[illegible]134
SEED	3	A	B	C	D	17	.9[illegible]947416[illegible]35
SEED	3	A	B	C	D	18	.999[illegible]63237[illegible]4[illegible]64
SEED	3	A	B	C	D	19	.999[illegible]61[illegible]73[illegible]57
SEED	3	A	B	C	D	20	.99983[illegible]25341
SEED	3	A	B	C	D	21	.99[illegible]9[illegible]3[illegible]32[illegible]65
SEED	3	A	B	C	D	22	.9998[illegible]861[illegible]3[illegible]1
SEED	3	A	B	C	D	23	.99[illegible]9642781[illegible]557
SEED	3	A	B	C	D	24	.99966[illegible]1424539
SEED	3	A	B	C	D	25	.9999[illegible]4762[illegible]94
SEED	3	A	B	C	D	26	.99996539[illegible]6143
SEED	3	A	B	C	D	27	.9999613[illegible]12[illegible]7
SEED	3	A	B	C	D	28	.999797[illegible]437716
SEED	3	A	B	C	D	29	.9999611[illegible]2123
SEED	3	A	B	C	D	30	.9999[illegible]7844333
SEED	3	A	B	C	D	31	.99983180[illegible]9436
SEED	3	A	B	C	D	32	1.
SEED	3	A	B	C	D	33	.99993[illegible]4427607
SEED	3	A	B	C	D	34	.999943991[illegible]2[illegible]1
SEED	3	A	B	C	D	35	.99987266[illegible]2221
SEED	3	A	B	C	D	36	.999973646 321
SEED	3	A	B	C	D	37	.9997479154196
SEED	3	A	B	C	D	38	.99986363759[illegible]24
SEED	3	A	B	C	D	39	.9998[illegible]62[illegible]54[illegible]99
SEED	3	A	B	C	D	40	.99964[illegible]872571
SEED	3	A	B	C	D	41	.9999339[illegible]9[illegible]21
SEED	3	A	B	C	D	42	.99986624368[illegible]3
SEED	3	A	B	C	D	43	.999934[illegible]53166
SEED	3	A	B	C	D	44	.9998544497931

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RESOURCE UTILIZATION

RESOURCE	LABEL	NOW IN USE	AVE. IN USE	MAX. IN USE	NOW AVAILABLE	AVE. AVAILABLE	MAX. AVAILABLE
1	LVL-5	0	.098	2	2	1.902	2
2	LVL-3	0	.021	1	1	.979	[illegible]
3	ADP-TERM	0	.005	1	2	1.995	2
4	ADP-HDCY	0	.011	1	2	1.989	2
5	LAN-IU	0	.043	2	2	1.957	2
6	CPU	0	.002	1	2	1.998	2
7	MEM	0	.019	1	2	1.981	2
8	DISK-IF	0	.000	1	2	2.000	2
9	IFB	0	.013	1	2	1.987	2
10	PS-BOARD	0	.005	1	2	1.995	2
11	IG-IF	0	.005	1	2	1.995	2
12	DISK	0	.015	2	2	1.985	2
13	PROC	0	.016	1	2	1.984	2
15	REF-MEM	0	.027	2	2	1.973	2
16	BLNK-CNT	0	.011	1	2	1.989	2
17	PS-CHASS	0	.003	1	2	1.997	2
18	TV-MON	0	.058	2	2	1.942	2
19	EG-AMP	0	.007	1	2	1.993	2
20	VIDEO-SW	0	.004	1	2	1.996	2
21	PROJ	0	.082	2	2	1.918	2

APPENDIX C

Simulated History

EQUIPMENT NAME	OPERATING TIME START DAY	TIME	FAILURE DAY	TIME	REPLACED LRU	LRU REPAIR TIME START DAY	TIME	FINISH DAY	TIME		
ACP 4	0	0: 0	2	0:23	TERM	2	0:56	2	4:48	2	0:56
ACP 3	0	0: 0	13	14:12	TERM	13	14:45	13	23:43	13	14:45
TV MON 3	0	0: 0	16	3:36	TV MON	16	4:14	16	8:58	16	4:14
ADP 6	0	0: 0	18	3:19	TERM	18	3:55	18	14:38	18	3:55
TV MON 2	0	0: 0	19	0:44	TV MON	19	1:18	19	7:44	19	1:18
TV MON 2	19	1:18	20	15: 4	TV MON	20	15:36	20	20:24	20	15:36
D COMP 2	0	0: 0	23	0:46	CHASSIS	23	0:46	23	6:32	23	6:32
IM GEN 4	0	0: 0	24	14:2[illegible]	BLAK CTL	24	14:54	24	20:32	24	14:54
TV MON 8	0	0: 0	27	21: 3	TV MON	27	21:30	28	4:51	27	21:30
TV MON12	0	0: 0	27	21: 4	TV MON	27	21: 4	28	5:49	28	5:49
ACP 5	0	0: 0	28	20:19	LAN IU	28	20:53	29	2: 3	28	20:53
IM GEN 1	0	0: 0	29	18:35	REF MEM	29	19: 4	36	14:44	29	19: 4
TV MON10	0	0: 0	40	5:24	TV MON	4	5:57	40	10:48	40	5:57
PROJ 4	0	0: 0	44	21:15	PROJ	44	21:44	45	5:52	44	21:44
ACP 7	0	0: 0	53	2:25	TERM	53	2:55	53	15:54	53	2:55
D COMP 2	23	6:32	66	12:49	DISK IF	66	13:21	67	0:38	66	13:21
ADP 5	28	20:53	69	19:44	TERM	69	20:31	79	2:36	69	20:31
D COMP 2	66	13:21	74	15: 7	IG IF	74	15:42	74	20:33	74	15:42
IM GEN 1	29	19: 4	77	22: 4	REF MEM	77	22:32	78	14:40	77	22:32
IM GEN 4	24	14:54	79	19:25	PROC	79	20: 3	80	5:14	79	20: 3
TV MON 5	0	0: 0	81	0:32	TV MON	81	1: 6	81	9:10	81	1: 6
D COMP 1	0	0: 0	81	21:15	IG IF	81	21:46	82	5:22	81	21:46
IM GEN 5	0	0: 0	82	7:44	REF MEM	82	8:25	82	15:50	82	8:25
IM GEN 4	79	20: 3	85	10: [illegible]	REF MEM	85	10:46	85	22:21	85	10:46
D COMP 2	74	15:42	88	[illegible]	IG IF	88	9: [illegible]	92	13:51	88	[illegible]
IM GEN 1	77	22:32	90	6:48	REF MEM	90	7:33	90	16:39	90	7:33
ACP 10	0	0: 0	91	20: 3	TERM	91	20:45	91	13:23	91	20:45
IM GEN 1	90	7:33	94	22:53	PS CHAS	94	23:31	95	3:42	94	23:31
IM GEN 1	94	23:31	110	7:23	REF MEM	110	8: 5	110	14: [illegible]	110	8: 5
ACP		0: 0	113	6:3[illegible]	HDCY	113	7: 7	113	14: 5	113	7: 7
ACP 7	53	2:55	116	1: [illegible]	LAN IU	116	1:4[illegible]	116	4:41	116	1:4[illegible]
D DISK 1		0: 0	119	13:1[illegible]	DISK	119	13:43	119	23:11	119	13:43
ACP 7	116	1:4[illegible]	125	12:25	LAN IU	125	13:11	126	5:34	125	13:11

ACP 2	[illegible]	[illegible]	126	10:42	HCCY	126	11:19	126	17:59	126	11:19
CF COMP	[illegible]	[illegible]	134	[illegible]:23	IFB	134	21: 2	135	3:54	134	21: 2
PROJ 3	[illegible]	0: 6	147	20:52	PROJ	147	21:36	148	5:30	147	21:36
TV MON 6	[illegible]	0: 0	148	17:25	TV MON	148	17:55	149	3:32	149	17:55
ACP 2	126	11:19	149	6:21	TERM	149	6:57	149	13: 9	149	6:57
PROJ 3	147	21:36	151	8: 6	PROJ	151	9:42	151	15:15	151	9:42
ACP 3	13	14:48	157	8:14	HDCY	157	8:53	157	15:22	157	8:53
PROJ 4	44	21:44	163	0:57	PROJ	163	1:33	172	10:54	163	1:33
TV MON 3	16	4:18	170	1: 7	TV MON	170	1:37	170	5:53	170	1:37
TM GEN 4	45	10:46	173	2:5[illegible]	BLNK CTL	173	3:24	173	12: 1	173	3:24
TM GEN 6	0	0: 0	174	16:18	REF MEM	174	16:45	174	22:48	174	16:45
TV MON12	2[illegible]	5:45	175	20:57	VIDEO SW	175	21:32	176	0:51	175	21:32
ACP 8	113	7: 5	176	12:11	LAN IU	176	12:47	178	14:20	178	12:47
TM GEN 3	0	0: 0	179	0: 7	REF MEM	179	0:42	179	15:22	179	1:42
PROJ 2	0	0: 0	182	13:3[illegible]	PROJ	182	14: 5	182	21:43	182	14: 5
TV MON 2	2[illegible]	15:36	184	14: 4	TV MON	184	14:45	184	15: 7	184	14:45
TM GEN 1	11[illegible]	0: 5	187	2:49	PS CHAS	187	3:24	187	9:47	187	3:24
TM GEN 4	173	3:24	191	6:1[illegible]	REF MEM	191	6:55	191	14:36	191	6:55
ACP 8	178	12:47	193	21: [illegible]	HDCY	193	21:45	194	8:24	193	21:45
PROJ 1	[illegible]	0: 0	194	23: 3	PROJ	194	23:47	195	11:24	194	23:47
TM GEN 3	17[illegible]	0:42	2[illegible]	19:52	REF MEM	2[illegible]	[illegible]	201	1:59	2[illegible]	[illegible]
VID PS 2	0	0: 0	207	14:55	VIDEO PS	207	14:59	207	22:17	207	22:17
C COMP 1	61	21:46	209	21:46	LAN IU	209	22:23	210	18:52	209	22:23
TV MON 4	0	0: 0	213	4:23	VIDEO SW	213	5: 1	213	13:32	213	5: 1
TM GEN 4	191	6:55	222	11:22	REF MEM	222	12: 6	222	15:57	222	12: 6
PROJ 4	163	1:30	230	13:1[illegible]	PROJ	230	13:34	230	20: [illegible]	230	13:34
TM GEN 4	222	12: 6	234	19:41	REF MEM	234	20:12	234	22:58	234	20:12
ACP 4	[illegible]	[illegible]	237	7:33	LAN IU	237	8:13	237	13:15	237	8:13
C COMP 2	[illegible]	[illegible]	238	3:44	DISK IF	238	4:26	238	9:34	238	4:26
TV MON 3	0	0: 0	239	23:26	TV MON	239	23:59	240	12: 4	239	23:59
D COMP 1	2[illegible]	23:23	243	11:1[illegible]	IG TF	243	12: 7	243	19:54	243	12: 7
PROJ 1	194	23:47	244	20:1[illegible]	PROJ	244	20:52	256	5:49	244	20:52
TM GEN 4	234	20:12	253	13:53	REF MEM	253	14:24	263	22:39	253	14:24
TV MON12	[illegible]	0: 0	264	7:3[illegible]	TV MON	264	8:17	264	15:35	264	8:17
TV MON1[illegible]	4[illegible]	5:57	264	21:42	VIDEO SW	264	22:17	265	2: 3	264	22:17
TV MON 4	213	5: 1	[illegible]	[illegible]	TV MON	[illegible]	13:4[illegible]	268	17:22	[illegible]	1 :4[illegible]

PROJ [illegible]	151	[illegible]:42	27[illegible]	[illegible]1:56	PROJ	278	22:32	279	7:[illegible]	278	2[illegible]:32
ADP 2	149	6:57	279	6:34	TERM	279	7:13	285	9:37	279	7:13
ADP 1[illegible]	9[illegible]	2[illegible]:48	279	20:26	HCCY	279	21:13	280	8: 2	279	21:13
ADP 7	125	19:11	283	5:25	HCCY	283	9:54	283	22:25	283	9:54
ADP [illegible]	2	[illegible]:56	285	13:49	HCCY	285	14:22	285	20:57	285	14:22
TV MON 7	6	0: 0	290	0:42	TV MON	290	1:12	290	5: 7	290	1:12
D COMP 1	243	12: 7	290	3:16	IG IF	290	3:49	290	11: 5	290	3:49
TV MON12	175	21:32	290	17:30	TV MON	290	18:10	291	2:34	290	18:10
D DISK 1	119	13:43	291	22:28	DISK	291	23: 2	299	2:40	291	23: 2
ADP 9	285	14:22	297	21:41	HCCY	297	22:11	298	7:47	297	22:11
PROJ 4	23	13:34	300	12: [illegible]	PROJ	300	12:36	300	16: 5	300	12:36
ADP 2	279	7:13	303	11:42	TERM	303	12:24	303	23:42	303	12:24
ADP 3	157	8:53	305	8:46	LAN IU	305	9:30	305	14:15	305	9:30
IM GEN 3	2[illegible]	20:25	309	8:43	BLNK CTL	309	9:11	309	14:48	309	9:11
IM GEN 1	187	3:24	319	20: 3	REF MEM	319	20:36	320	6:21	319	20:36
TV MON [illegible]	27	21:38	323	16:53	TV MON	323	17:33	323	22: 6	323	17:33
IM GEN 4	253	14:24	325	13: [illegible]	REF MEM	325	13:39	32[illegible]	19:5[illegible]	325	13:39
TV MON 3	17[illegible]	1:37	32[illegible]	0: 2	TV MON	328	0:36	331	7:44	328	[illegible]:36
TV MON [illegible]	9[illegible]	1: 6	333	15:58	TV MON	333	16:31	334	1:40	333	16:31
PROJ 8	178	22:32	341	1:37	PROJ	341	2:10	341	8: [illegible]	341	2:10
ADP 10	27[illegible]	21:10	342	19:43	LAN IU	342	20:15	343	3:24	342	20:15
TV MON 6	148	17:55	345	9:4[illegible]	TV MON	345	10:25	346	3:26	345	10:25
IM GEN 3	3[illegible]	[illegible]:11	352	14:48	REF MEM	352	15:27	353	1:32	352	15:27
PROJ 1	244	2[illegible]:52	354	17:27	PROJ	354	17:57	355	2:32	354	17:57
PROJ 8	341	2:10	356	14:[illegible]6	PROJ	356	14:43	370	4:35	356	14:43
IM GEN 6	174	16:49	368	15:23	PROC	368	15:57	369	1: 8	368	15:57
ADP 1	[illegible]	[illegible]	36[illegible]	22:38	TERM	369	23:2[illegible]	370	7:25	369	23:2[illegible]
PROJ 5	[illegible]	0: 0	376	0:3[illegible]	PROJ	378	1: 3	378	4:30	378	1: 3
TV MON 1	[illegible]	[illegible]: 0	378	17:35	TV MON	378	18:14	392	15:21	378	18:14
TV MON 4	25	1:4[illegible]	3[illegible]9	12:14	TV MON	389	12:14	389	13:25	389	1[illegible]:25
ADP 3	30[illegible]	[illegible]:30	401	6: [illegible]	LAN IU	401	6:37	401	14:39	401	6:37
TV MON12	29	1[illegible]:10	409	11: 4	VIDEO SW	409	11:56	409	18:22	409	11:56
D COMP 1	2[illegible]	3:49	41[illegible]	[illegible]	DISK IF	411	[illegible]:51	411	8:44	411	[illegible]:51
IM GEN 3	352	15:27	413	10:23	P LC	413	13:49	413	15:52	413	13:49
PROJ [illegible]	37[illegible]	1: 3	41[illegible]	5:46	PROJ	416	6:17	416	14:21	416	6:17
IM GEN [illegible]	[illegible]	[illegible]:25	422	1[illegible]	REF MEM	422	[illegible]	422	23:4[illegible]	422	[illegible]

TV MON 5	239	23:59	437	5:17	TV MON	437	5:55	437	10: 1	437	5:53
ADP 8	193	21:45	440	4:54	LAN IU	440	5:33	452	10:54	440	5:33
IM GEN 5	422	18:22	442	22: 5	REF MEM	442	22:40	443	5:23	442	22:40
ADP [illegible]	441	5:33	447	23:37	LAN IU	447	23:37	448	7: 8	448	7: 8
ADP 9	297	22:11	457	18:33	HDCY	457	19: 0	458	3: 0	457	19: 0
PROJ 3	0	0: 0	462	12: 9	PROJ	462	12:36	463	0:41	462	12:36
IM GEN 1	319	20:36	[illegible]	11:41	REF MEM	480	12:11	489	11:51	480	12:11
TV MON10	264	22:17	493	11:23	TV MON	493	12: 0	493	17:21	493	12: 0
ADP 7	283	9:54	507	14: 6	TERM	507	14:41	507	22:35	507	14:41
CF COMP	134	21: 2	507	23:54	MEM	508	0:37	508	7:11	508	0:37
D COMP 1	410	20:51	513	19:45	IFB	513	20:16	514	10:52	513	20:16
TV MON 6	345	10:25	521	23: 1	TV MON	521	23:27	522	4:39	521	23:27
IM GEN 5	442	22:40	525	19:3[illegible]	REF MEM	525	20: 1	526	8: 6	525	20: 1
D DISK 2	0	0: 0	526	17:2[illegible]	DISK	526	17:54	527	1:44	526	17:54
PROJ 5	356	14:43	532	3:13	PROJ	532	3:45	532	8:36	532	3:45
IM GEN 3	413	10:49	536	20:31	REF MEM	536	21: 5	539	1: 8	539	21: 5
ADP 5	457	19: 0	544	14:25	HDCY	544	14:55	548	8:38	544	14:55
CF DISK	0	0: 0	547	16:17	DISK	547	1[illegible]:55	548	2:22	547	16:55
ADP 2	303	12:24	548	14:23	TERM	549	15: 2	549	5:34	548	15: 2
TV MON 7	250	1:12	551	23:14	TV MON	551	23:44	552	4:27	551	23:44
D COMP 2	235	4:26	568	3: 2	PS BOARD	568	3:48	578	0:49	568	3:48
CF COMP	538	0:37	570	10:59	IFB	570	1:3	570	8:49	570	1:31
PROJ 3	459	12:36	572	0:3[illegible]	PROJ	572	1:12	572	12: 0	572	1:12
IM GEN 3	536	21: 5	574	19:47	PS CHAS	574	11:19	574	18: 2	574	11:19
ADP 4	237	6:13	584	6: 5	HDCY	584	6:34	584	18:4[illegible]	584	6:34
PROJ 6	0	0: 0	584	20: [illegible]	PROJ	584	20:54	585	3: 9	584	20:54
IM GEN 2	0	0: 0	587	20:52	REF MEM	587	21:28	588	0:56	587	21:28
TV MON 3	325	1:36	591	10:26	TV MON	591	10:53	591	16: 4	591	10:53
TV MON 7	551	23:44	591	21: 1	TV MON	591	21:38	592	4:15	591	21:38
TV MON 2	134	14:45	592	5:52	TV MON	592	6:22	592	11: 7	592	6:22
IM GEN 4	325	13:39	592	8:11	REF MEM	592	6:47	592	13:17	592	6:47
IM GEN 2	537	21:29	593	4: 7	REF MEM	593	4:46	593	15: 1	593	4:46
PROJ 5	416	6:17	598	22: 4	PROJ	598	22:36	599	6:35	598	22:36
IM GEN 4	592	6:47	601	11:35	PROC	601	12: 9	601	18:53	601	12: 4
D DISK 3	526	17:54	602	17:46	DISK	602	18:21	603	5:42	602	18:21
D DISK 1	291	23: 2	605	6:14	DISK	605	6:44	605	10:25	605	6:44

C COMP 1	513	23:16	606	21:31	IG IF	606	22: 1	607	2:49	606	22: 1
CP COMP	571	1:36	613	17:13	CFU	610	16: 0	611	4: 5	610	16: 0
D COMP 2	558	3:48	614	5:37	IFB	614	1:17	614	10: 7	614	1:17
ADP 6	18	3:55	618	17:25	HCCY	618	15: 0	618	22:12	618	15: 0
CF COMP	616	18: 6	618	19:2[illegible]	IFB	618	19:52	619	19:14	618	19:52
PROJ 3	572	1:12	625	14:39	PROJ	625	15:15	626	2:51	625	15:15
ADP 5	618	18: 0	629	15:27	LAN IU	629	16: 5	630	5:17	629	16: 5
PROJ 5	550	22:36	636	20: 4	PROJ	638	20:51	639	3:29	638	20:51
PROJ 3	532	3:45	639	11:21	PROJ	639	11:55	639	19: 5	639	11:55
ADP 7	537	14:41	640	21:49	TERM	640	22:31	641	8:45	640	22:31
IM GEN 6	366	15:57	641	15:33	BLNK CTL	641	16:11	641	18:34	641	16:11
TV MON 7	591	21:38	642	23: 5	TV MON	642	23:36	643	3:15	642	23:36
D DISK 2	602	18:21	648	7:47	DISK	648	8:33	648	13:52	648	8:33
ADP 5	448	7: 8	648	19:25	TERM	648	18:56	654	16:57	648	18:56
IM GEN 5	525	20: 1	654	15: 1	REF MEM	654	15:46	659	10:21	654	15:46
TV MON 7	642	23:36	654	23:56	TV MON	655	0:39	655	10:11	655	0:39
ADP 5	544	14:55	655	6:14	LAN IU	655	6:52	655	15:36	655	6:52
CF COMP	619	19:52	662	19:55	PS BCAFD	662	20:22	663	4:22	662	20:22
TV MON 7	655	0:39	673	13: 3	TV MON	673	13:40	673	23:17	673	13:40
CF COMP	662	20:22	681	20:41	CFU	681	21:23	682	13:57	681	21:23
D COMP 1	606	22: 1	682	4:54	LAN IU	682	5:31	682	13:23	682	5:31
TV MON11	264	0:17	684	0:47	TV MON	684	1:15	684	6:36	684	1:15
TV MON11	684	1:15	698	3: 1	VIDEO SW	698	8:32	698	13: 5	698	8:32
PROJ 3	620	15:15	722	4: 6	PROJ	722	4:45	722	16:22	722	4:45
ADP 1	359	23:20	724	22:45	LAN IU	724	23:22	725	5:27	724	23:22
ADP 3	401	6:37	725	20:55	HCCY	725	21:25	726	15:11	725	21:25
PROJ 3	722	4:45	732	15:24	PROJ	732	15:56	732	21:54	732	15:56
IM GEN 4	631	12: 9	739	0:47	REF MEM	739	1:27	739	11:11	739	1:27
IM GEN 6	641	16:11	744	13:16	PROC	744	13:48	770	23:28	744	13:48
IM GEN 2	593	4:46	746	15:49	PROC	746	16:48	746	16:48	746	16:48
D COMP 2	514	1:17	757	10:33	IG IF	757	11: 4	757	16: 7	757	11: 4
IM GEN 1	[illegible]	12:11	757	10:55	REF MEM	757	11:42	757	21: 2	757	11:42
TV MON 6	521	23:27	757	14:43	TV MON	757	16:49	763	2:40	757	16:49
ADP 6	529	16: 5	759	10:12	LAN IU	759	10:42	759	13:10	759	10:42
TV MON11	[illegible]	0:32	760	21:51	TV MON	761	21:51	761	8:48	761	[illegible]:48
ADP 10	342	20:15	762	7:34	LAN IU	762	8: 6	762	12:32	762	8: 6

ADP 5	65	2[illegible]:31	765	23:21	TERM	765	23:55	766	3:56	765	23:55
ADP 5	765	23:55	775	0: 2	TERM	775	0:39	775	6: 1	775	0:39
IM GEN 5	654	15:46	775	3:14	REF MEM	775	3:51	775	12: 3	775	3:51
IM GEN 1	757	11:42	783	9:17	PROC	783	10: 4	783	14:41	783	10: 4
PROJ 3	732	15:56	783	21:13	PROJ	783	21:47	784	4:55	783	21:47
D COMP 2	757	11: 8	787	9:34	IFR	787	10:11	787	18:17	787	10:11
ADP 1	762	8: 6	790	8:30	TERM	790	8:57	794	0:22	790	8:57
C DISK 2	648	8:33	792	10: 8	DISK	792	10:41	792	19:18	792	10:41
D COMP 1	682	5:31	792	16:15	LAN IU	792	18:48	792	22: 9	792	18:48
C COMP 2	787	10:11	797	9:25	PS BOARD	797	9:56	797	13:31	797	9:58
IM GEN 1	783	10: 4	799	17:51	REF MEM	799	18:26	800	1:32	799	18:26
D COMP 1	792	18:48	808	5:11	IG IF	808	5:39	808	22: 1	808	5:39
TV MON 5	437	5:56	808	22: 6	VIDEO SW	808	22:46	809	5:23	808	22:48
IM GEN 2	746	16:46	809	20:45	REF MEM	809	21:17	810	8:46	809	21:17
ADP 6	755	10:42	813	11: 2	LAN IU	813	11:48	813	19: 2	813	11:48
ADP 2	548	15: 2	813	23:17	HDCY	814	0: 8	820	13: 3	814	0: 8
PROJ 7	0	0: [illegible]	817	23:3[illegible]	PROJ	818	0:16	818	4:47	818	0:16
ADP 1	724	23:22	820	17:43	HDCY	820	18:19	821	6:40	820	18:19
CP COMP	681	21:23	821	1:57	CPU	821	2:28	821	9:36	821	2:28
PROJ 1	354	17:57	823	19:16	PROJ	823	19:45	823	23: 3	823	19:45
ADP 3	725	21:25	824	10:27	TERM	824	11:16	824	16:11	824	11:16
ADP 3	814	0: 8	825	7:28	TERM	825	8: 3	825	13:36	825	8: 3
PROJ 5	636	20:51	831	12:12	PROJ	831	12:49	831	23: 0	831	12:49
PROJ 2	182	14: 5	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
ADP [illegible]	655	6:52	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
TV MON 3	333	16:31	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
TV MON 7	673	13:40	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
CP DISK	547	16:55	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
TV MON [illegible]	493	12: 0	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
C DISK 1	605	6:44	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
VID P[illegible] 2	237	22:17	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
PROJ 4	[illegible]	12:56	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
TV MON [illegible]	323	17:33	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
TV MON 1	378	13:14	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
IM GEN 3	574	11:1[illegible]	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
IM GEN 4	739	1:27	833	7:59	PROJ	833	7:59	833	7:59	833	7:59

IN GEN [illegible]	744	13:48	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
ADP 4	594	6:34	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
PROJ 6	584	20:54	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
TV MON 4	389	18:25	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
TV MON 6	757	16:49	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
PROJ [illegible]	639	10:55	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
TV MON11	761	8:40	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
ADP 7	640	22:31	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
TV MON 3	591	10:53	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
ADP 5	775	[illegible]:39	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
IN GEN 5	775	3:51	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
VID PS 1		0:[illegible]	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
PROJ 3	783	21:47	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
TV MON 2	592	6:22	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
ADP 1[illegible]	79[illegible]	8:57	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
D DISK 2	792	10:41	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
ADP [illegible]	545	16:58	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
D COMP 2	797	9:50	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
IN GEN 1	798	15:26	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
D COMP 1	[illegible]	5:39	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
TV MON 5	[illegible]	22:46	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
IN GEN 2	809	21:17	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
ADP 6	313	11:46	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
TV MON12	405	11:56	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
PROJ 7	810	:16	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
ADP 1	42[illegible]	18:19	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
CF COMP	321	2:28	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
PROJ 1	323	19:45	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
ADP 3	324	11:16	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
ADP [illegible]	325	[illegible]:3	833	7:59	PROJ	833	7:59	833	7:59	833	7:59
PROJ [illegible]	[illegible]	[illegible]	833	7:59	PROJ	833	7:59	833	7:59	833	7:59

VITA

Captain Harold R. Agnew was born on 27 November 1947 in Tyler, Texas. He graduated from high school in Atchison, Kansas, in 1965 and enlisted in the Air Force after one year of college. While in the Air Force he attended college part time and received a Bachelor of General Studies degree in Mathematics from the University of Nebraska at Omaha in May 1978. Upon graduation, he attended Officer Training School at Lackland AFB, Texas, where he received his commission. After receiving his commission Captain Agnew attended the Systems Analyst course at Keesler AFB for three months, enroute to Peterson AFB, Colarado. At Peterson AFB, he served as a Systems Technology Officer for the Directorate for Technical Engineering, Headquarters NORAD/ADCOM. Later he served in the newly formed Systems Integration Office, where he preformed systems engineering until he entered the School of Engineering, Air Force Institute of Technology, in May 1982.

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17. COSATI CODES

FIELD	GROUP	SUB. GR.
14	01	
14	04	

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number): Availability, reliability, Mean time to repair, mean time between failures, crew size, analysis of variance, Q-GERT.

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The purpose of this thesis is to develop a model which can be used to determine the number of Air Force technicians required to maintain the equipment planned for the SAC Command Post Upgrade. The modes was developed, tested and validated using the system science paradigm as a conceptual framework.

The results of the simulation model were analyzed using multiple analysis of variance. The results indicated that two technicians, one 5-level and one 3-level, were sufficient to provide an equipment availability of greater than 99 percent. Furthermore, the results indicate that the utilization of the technicians would be so low that the same technicians would be able to maintain another system of the size, in addition to the upgraded SAC Command Post, and still maintain the availability of the Command Post equipment at greater than 99 percent.

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Block 11 Continued. MAINTENANCE CREW SIZE FOR THE SAC COMMAND POST UPGRADE

Block 17 continued.

Field	Group
05	06
09	02
12	02

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Block 11 Continued. MAINTENANCE CREW SIZE FOR THE SAC COMMAND POST UPGRADE

Block 17 continued.

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09	02
12	02