SIMULATION OF A FUNCTIONALLY DISTRIBUTED COMPUTING FACILITY

by

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Chapter 1

INTRODUCTION

1.1 PROBLEM STATEMENT AND MOTIVATION

The research facility of the School of Aerospace Medicine consists of many laboratories which are located in several buildings [3], some of which contain more than one computer; see Table 1. The function of the laboratory machines is to collect experimental data. There is also off-campus hardware support for data collection and reduction. The off-campus resources are an IBM 360/65 and a Univac 1108. The IBM machine has almost reached its maximum utilization at the present; therefore, no time-sharing support can be provided because of unavailability of resources. The other off-campus resource, Univac 1108, could be discontinued at any time.

All of the data received in the laboratories must be put into machine-readable form. This is a very slow process since it involves human interaction. The machine-readable form must be transferred onto a magnetic tape or some storage media, and then the information is sent to the central site computer, PDP 11/70, to be analyzed.

In order to improve the present situation, a computer network is proposed, to connect each laboratory machine to the central point. This will maximize the local user computing resource. There are two possible computer network alternatives, star and hierarchical configura-

Building #	Division/Name	Present Hardware	Usage
150	BR/Engelken	PDP 12/30	Digitizing System
150	BR/Balusek	PDP 8M	Graphic Digitizer, Num. Control
150	BR/Nixon	IBM System 3	Remote Job Entry (SADSC)
150	BR/Albanese	WANG 2200	Alert Calculations
150	BR/Engelken	PDP 12/40	Utility Machine
110	NG/Keiser	DG 1200	Treadmill, Multiuser Basic
125	NG/Wolfe	Nicolet	Vestibular Studies
150	NG/Keiser	DG S-200	ECG Record Scanner, Multiuser
125	RZ/Farrer	Nova 800	UT El Paso Application
175	RZ/Tastch	PDP 11/05	Whole Body Counter
176	RZ/Allen	PDP 11/34	VECP
186	RZ/Lof	PDP 12/30	PEP
110	VN/Storm	PDP 12/30	Link Trainers/Tracking Tasks
110	VN/Storm	PDP 8M	(Portable) Tracking Task
160	VN/Storm	DG 210	(Zelesky) Acquisition System
160	VN/Stribley	PDP 11/05	Manikin
160	VN/Stribley	WANG 2200	IFDAS
170	VN/Ikels	DG 1200	Analytic Inst.
170	VN/Conkle	HP 2100S(3)	Analytic Inst.

Table 1

On Campus Facilities

tion. The selection should be made based on performance, cost, and resource requirements.

Due to a limited number of vendors' software packages supporting homogeneous hardware, DECNET has been selected as the network system software. The only computers that can be included in the network at the present are PDP-8's and PDP-11's; therefore, any laboratory machine which is not of either of the above types must be replaced in the near future.

1.2 APPROACH

Several simulation models have been designed and implemented for the functionally distributed computing facility to be developed at U.S. Air Force School of Aerospace Medicine. The initial model of the network consists of the central machine, PDP 11/70, with thirty-two terminals. Two network configurations, star and hierarchical configurations, have been modeled with the star configuration consisting of three different phases. All of the three phases of the star configuration have the PDP 11/70 as the central point that has supervisory control over the system. The system also consists of the thirty-two terminals by which all users communicate with the PDP 11/70 and three, six, or eight laboratory machines depending upon the phase. Each laboratory machine is connected directly to the central point and has the function of collecting and transmitting messages.

As a result of unavailability of data on the performance of a PDP 11/70, some parameters in the model were gained by means of experiments on the IBM 370, educated guessing, and vendor's documents. The parameters used in this study could be easily changed as soon as more specific determination of these parameters is made available by the installation of PDP-11 equipment.

The purpose of this study is to determine potential performance characteristics of each configuration and present the configuration, star or hierarchical, which is best suited for the environment needs.

1.3 OVERVIEW OF REPORT

In the next chapter, a general background about the networks, simulation and the language which is used for implementation are explained. In Chapter 3, the different models used in this study are presented. In Chapter 4 the implementation of the models will be presented. The general assumptions and the system parameters also will be discussed, and Chapter 5 presents the results from the different runs and analysis is made for selecting one configuration as a more desirable one. In Chapter 6 the conclusion of the study is given with some future work.

Chapter 2

BACKGROUND

2.1 NETWORK

Two different computer networks have been presented in this study, a star configuration network and a hierarchical network. The star configuration network has the PDP 11/70 as the central node with thirty-two terminals. Four PDP 11/34's, two 11/05's, one 11/03, and one PDP 8M are communicating with the central point; see Figure 1. The hierarchical network configuration also has the PDP 11/70 as the central point and consists of three intermediate nodes, two PDP 11/34's and one 11/05. Figure 2 illustrates the hierarchical network configuration.

At the present time, there are only a few number of vendor software packages that support homogeneous hardware; therefore, DECNET was chosen as the network system software for the school, a replacement schedule for the laboratory machines was arranged. Priority, one through three, was given to every computer in the network which was not either a PDP-11 or PDP-8. See Table 2 for a complete listing. Therefore, the network was constructed in three phases. At each phase a number of processors were added to the network. Table 3 associates the phases of the network with the laboratory machines to be added.

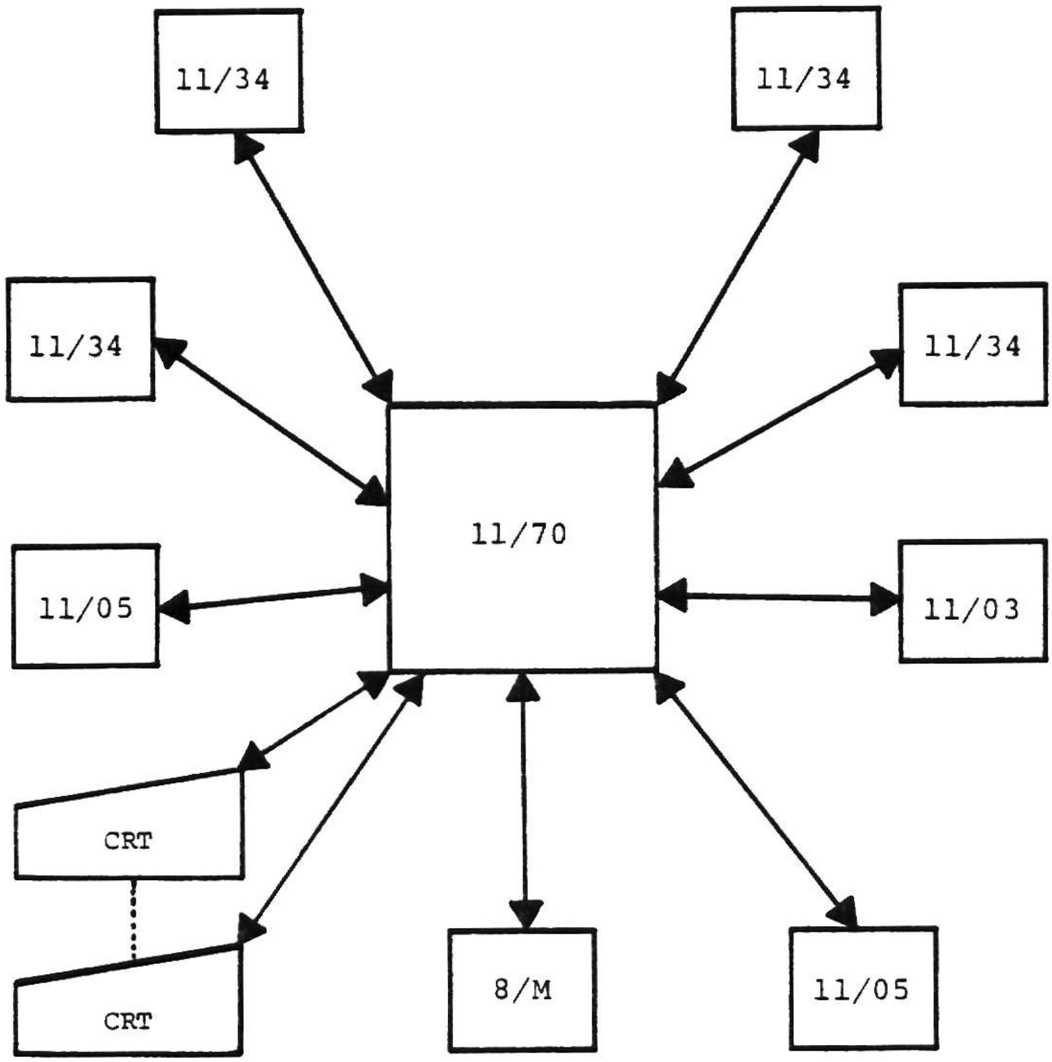

Figure 1

Star Network Configuration

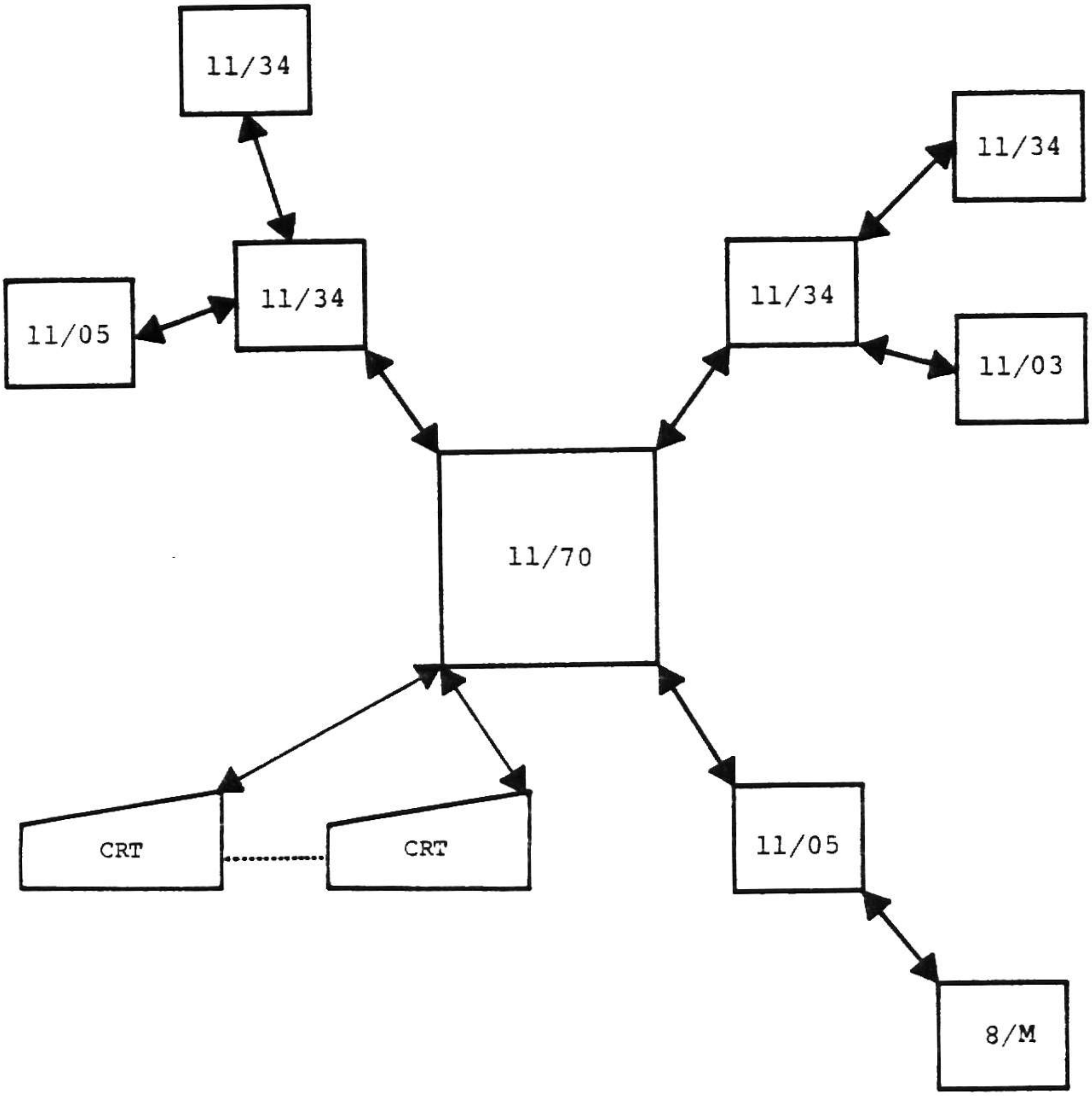

Figure 2

Hierarchical Network Configuration

Hardware	Use	Priority for Entry into the Network
PDP 11/34	Dr. Wolf's	1
PDP 11/34	Lof	1
PDP 11/05	Manikin	1
PDP 11/34	NG Concentrator	2
PDP 11/34	Allen/RZL	2
PDP 11/03	Data Reduction	2
PDP 11/03	Treadmill	3
PDP 8/M	Tracking Task	3

Table 2

Priority for Network Entry

Phase	Laboratory Machines Added
1	11/34, 11/34, 11/05
2	11/34, 11/34, 11/03
3	11/05, 8/M

Table 3

The Three Phases of Network

2.2 SIMULATION

Simulation is a method of studying and solving a problem. It is a very useful tool for evaluating the performance and characteristic of a system. Simulation replaces a system to be studied by representing a model that is easier to solve [4]. Several simulation models have been developed and tested to study the performance of the central machine system and various network configurations for U.S. Air Force School of Aerospace Medicine. The model has been simplified so that it includes only the essentials of the system and it hides away all of the unnecessary details which do not have any significant relationship to the goals of the study.

Chapter 3

MODEL

3.1 GENERAL STRUCTURE OF MODEL

Several simulation models have been implemented, in GPSS, and tested to represent the computing environment at the School of Aerospace Medicine. The initial model, which is also used as a baseline model, consists of the PDP 11/70 as the central machine with thirty-two CRT terminals. The central machine gets its entire workload from the interactive users. The job mix of the terminal users is shown in Table 4. The disc access requirements and average CPU usage per command line for the different job types per line are indicated in order to keep twenty terminals busy, on the average, at any given time.

Each network model was constructed by direct linkage of additional laboratory machines to the central machine. In the first phase of the network model, the three laboratory machines indicated in phase one, Table 3, were linked to the central point. The second phase of the network model is developed in the same manner. For phase one and phase two only a star model was designed. Phase three was developed in a different model and it is constructed in both star and hierarchical configurations. The results from each configuration have been compared with the other one.

The model which is implemented in GPSS is described by the high level diagrams in Figure 3.

Job Type	Relative Frequency
Data Entry	40%
Data Edit	30%
Basic	15%
Fortran	15%

Table 4

Job Mix

Job Type	Disk Access per Line	Ave. CPU Usage per Line (MS)
Data Entry	1	15
Data Edit	2	30
Basic	0	40
Fortran	0	90

Table 5

CPU and Disk Access Requirements

HIGH LEVEL DIAGRAM OF THE MODEL

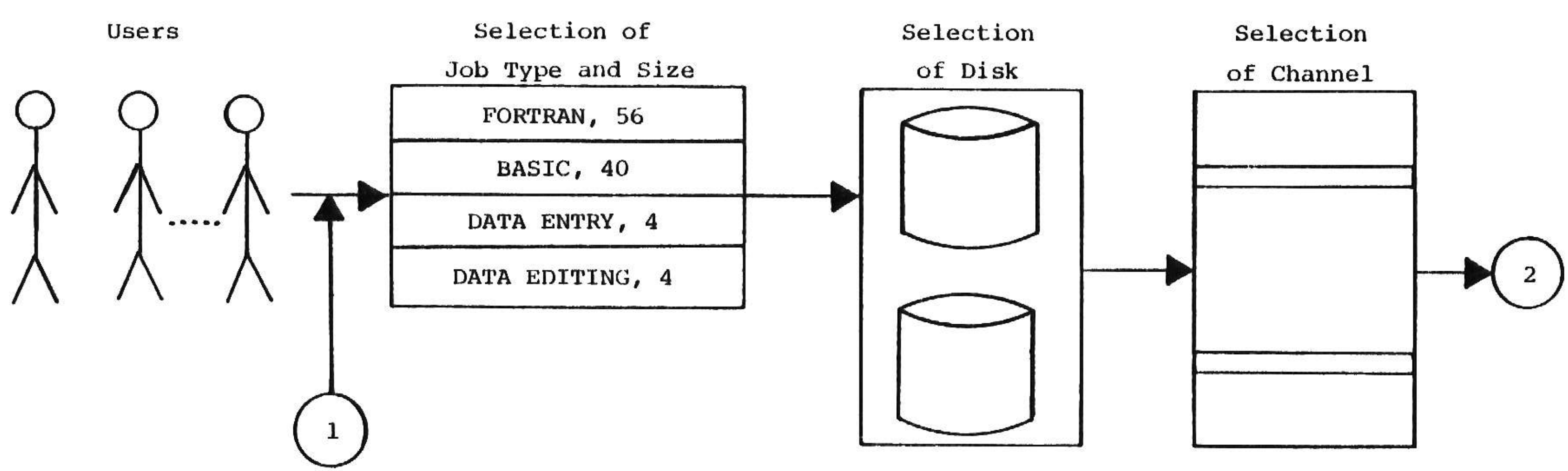

Figure 3A

Terminal Processing

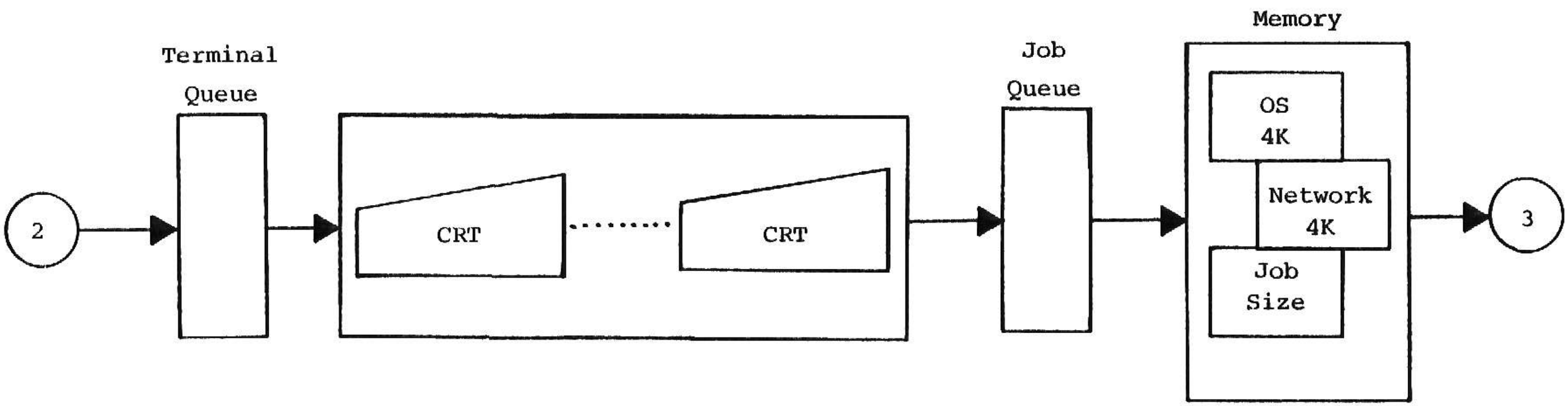

Figure 3A (Continued)

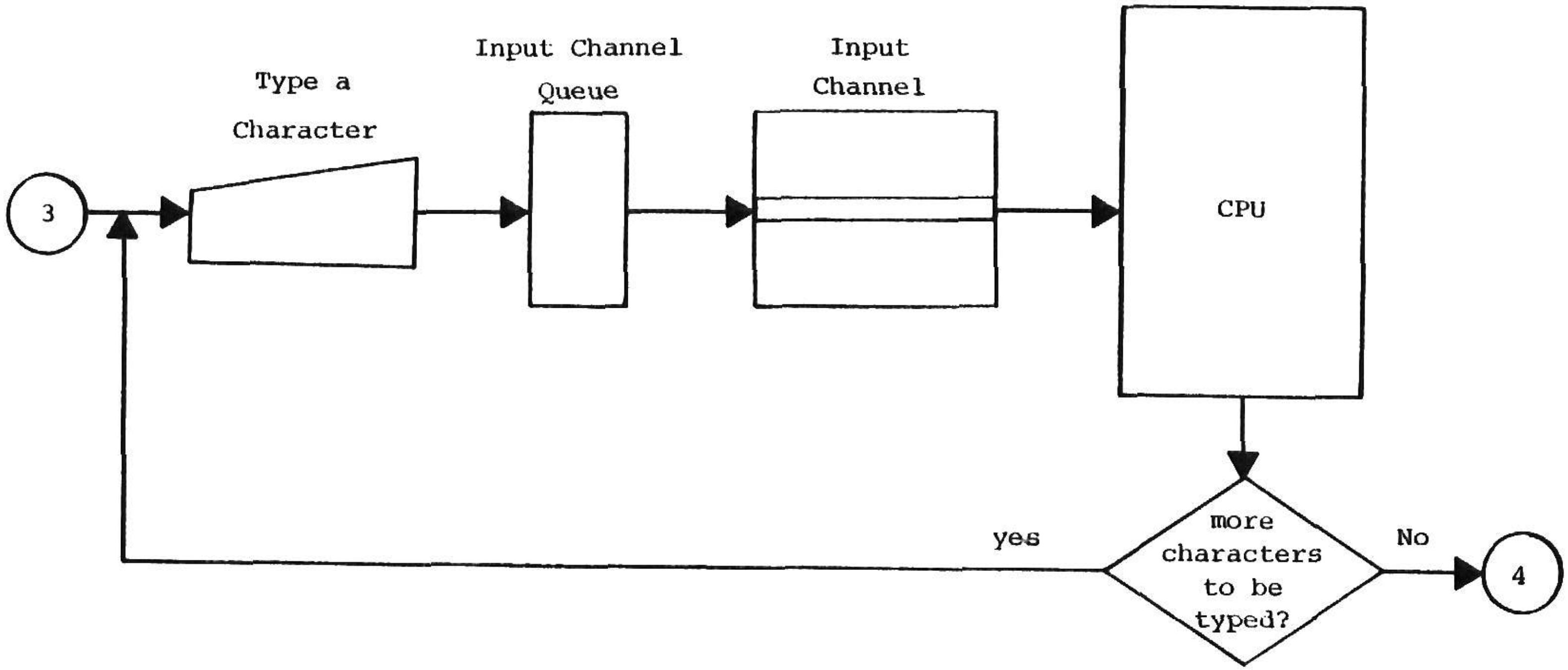

Figure 3A (Continued)

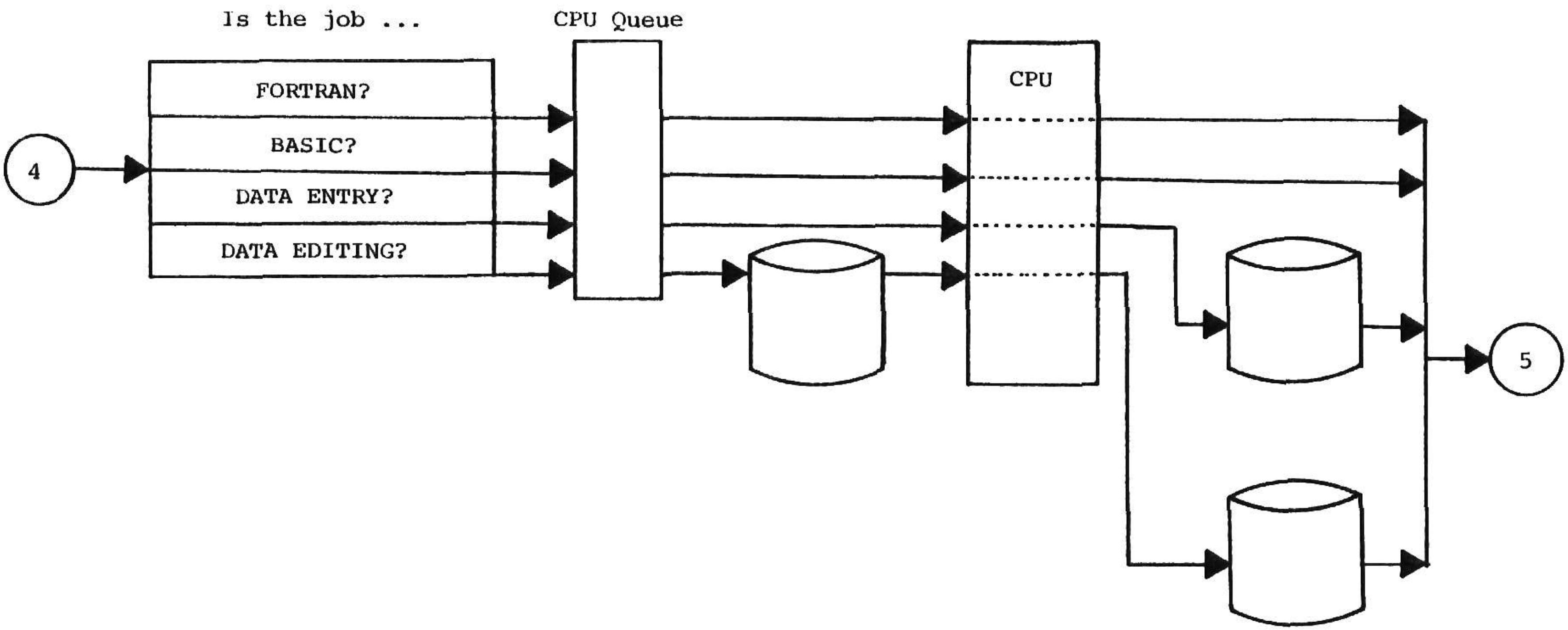

Figure 3A (Continued)

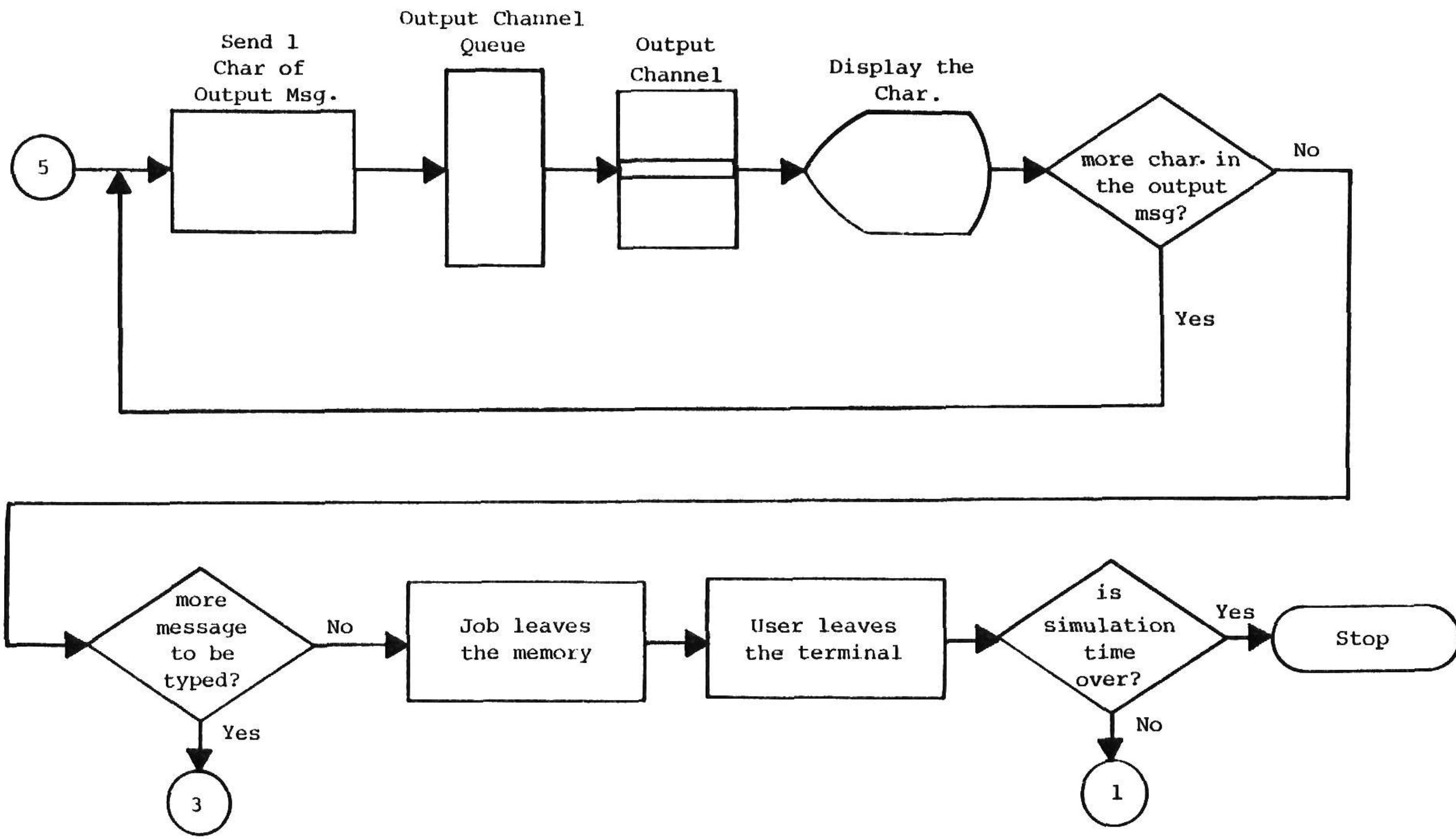

Figure 3A (Continued)

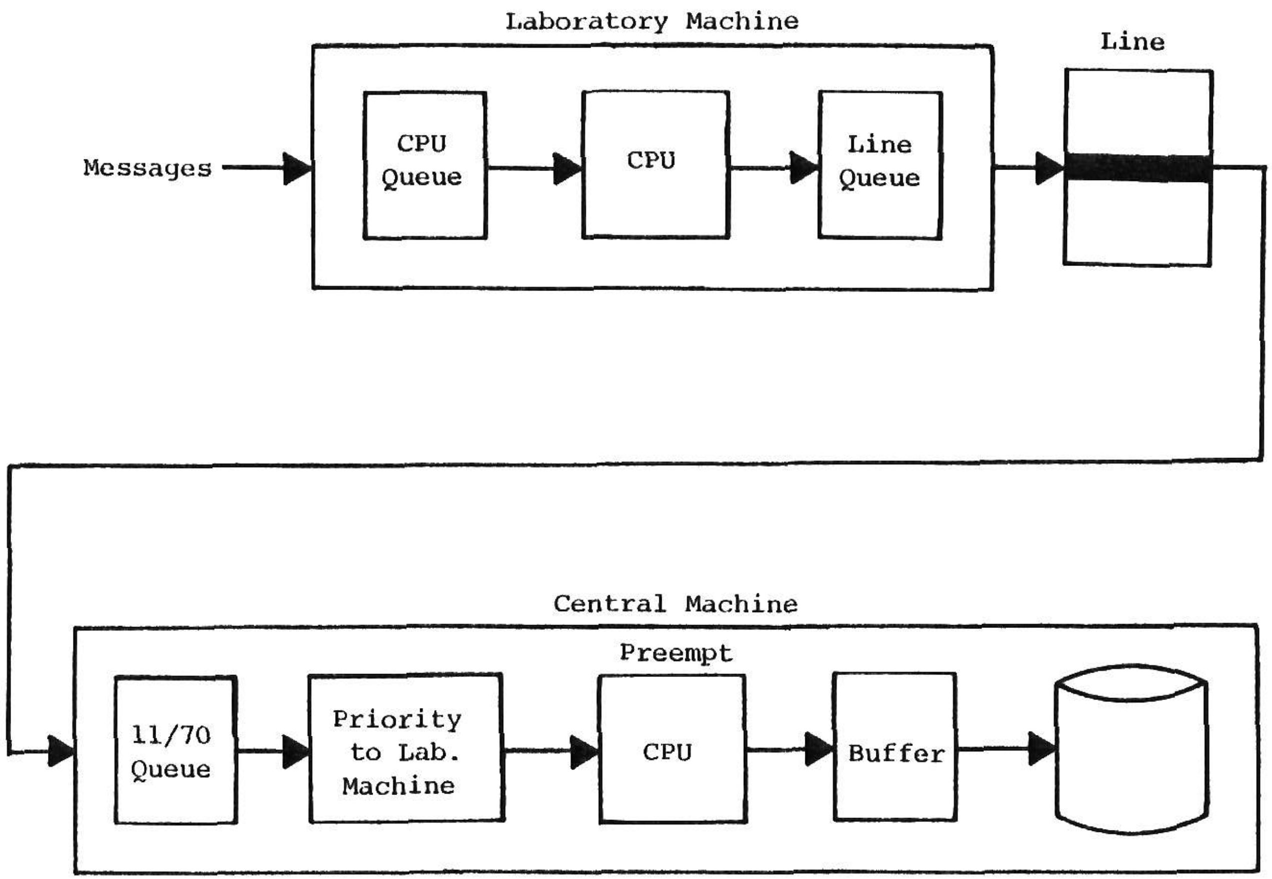

Figure 3B

Message Processing

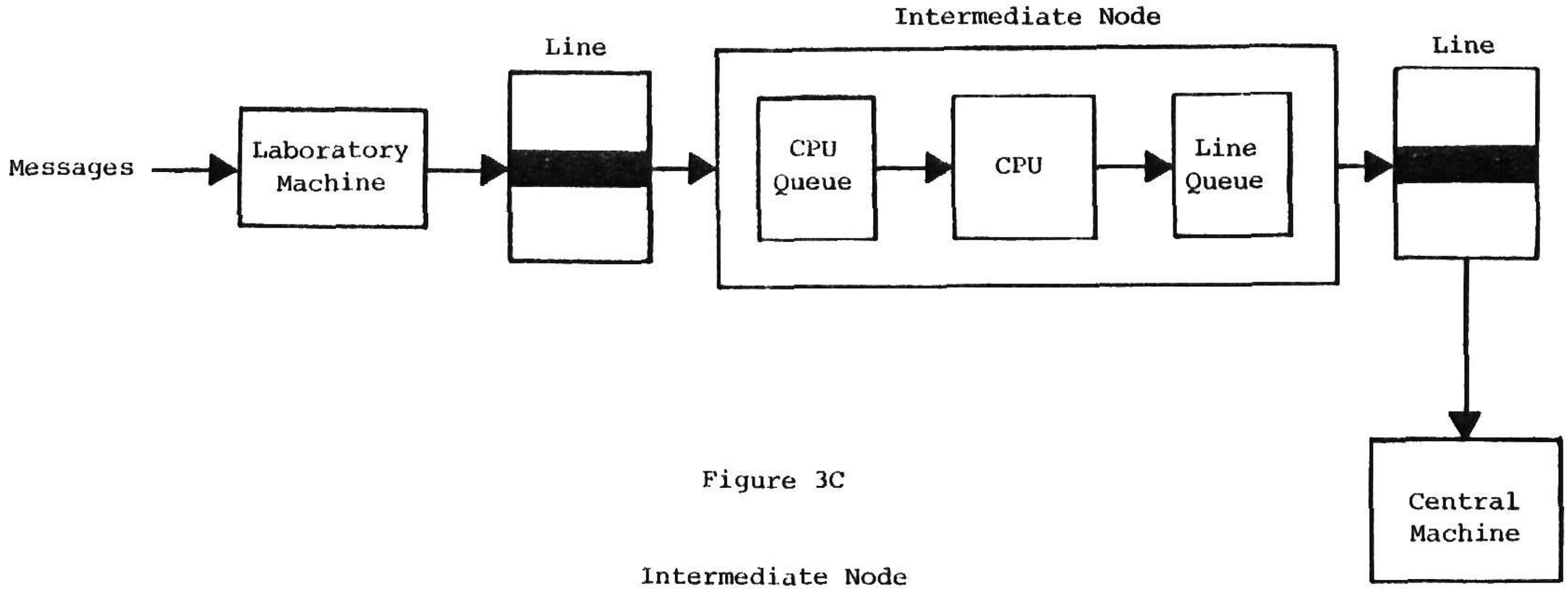

Figure 3C

Intermediate Node

(Hierarchical)

3.2 PARAMETERS

Parameterization of the models is highly dependent on the availability of the information on the performance of PDP 11/70 and the network system software, DECNET, and the usage characteristics of the network. Most of the data on the performance characteristics of DECNET were obtained from the vendor [2].

The user message size was determined to be 256 characters, which is equal to 2048 bits, and the line speed of 19.2 KB was dictated by physical constraints at the School of Aerospace Medicine. In order to determine the maximum number of user messages that can be transmitted over the line, the line speed, 19.2 KB, is divided by the length of a data message, 2048 bits, which results 9.3 user messages/sec.

The CPU overhead for network system software for the laboratory machines and the central machine were obtained by use of two graphs, Figure 4 and Figure 5. CPU overhead for PDP 11/70 was found to be 8.2 percent at 9.3 user msgs/sec. and 1.5 percent at 1.125 user msgs/sec. for 11/34, Figure 4. CPU usage of 11/05 is about two times as much as 11/34, since its performance is only half of 11/34 performance, PDP 11/03 and 8/M performance are also half of 11/05 performance. Figure 5 is used to find the CPU overhead for network software for PDP 11/05, 11/03, and 8/M by determining the CPU usage for 11/34 according to this graph. The message capacity (user msgs/sec.) is 1.125 for all laboratory machines, which is determined by dividing the number of user messages by the maximum number of laboratory machines.

The net line utilization is another parameter of the models which is found in the vendor documents. Figure 6 is used to find the net line utilization percentage according to user msg. size (characters).

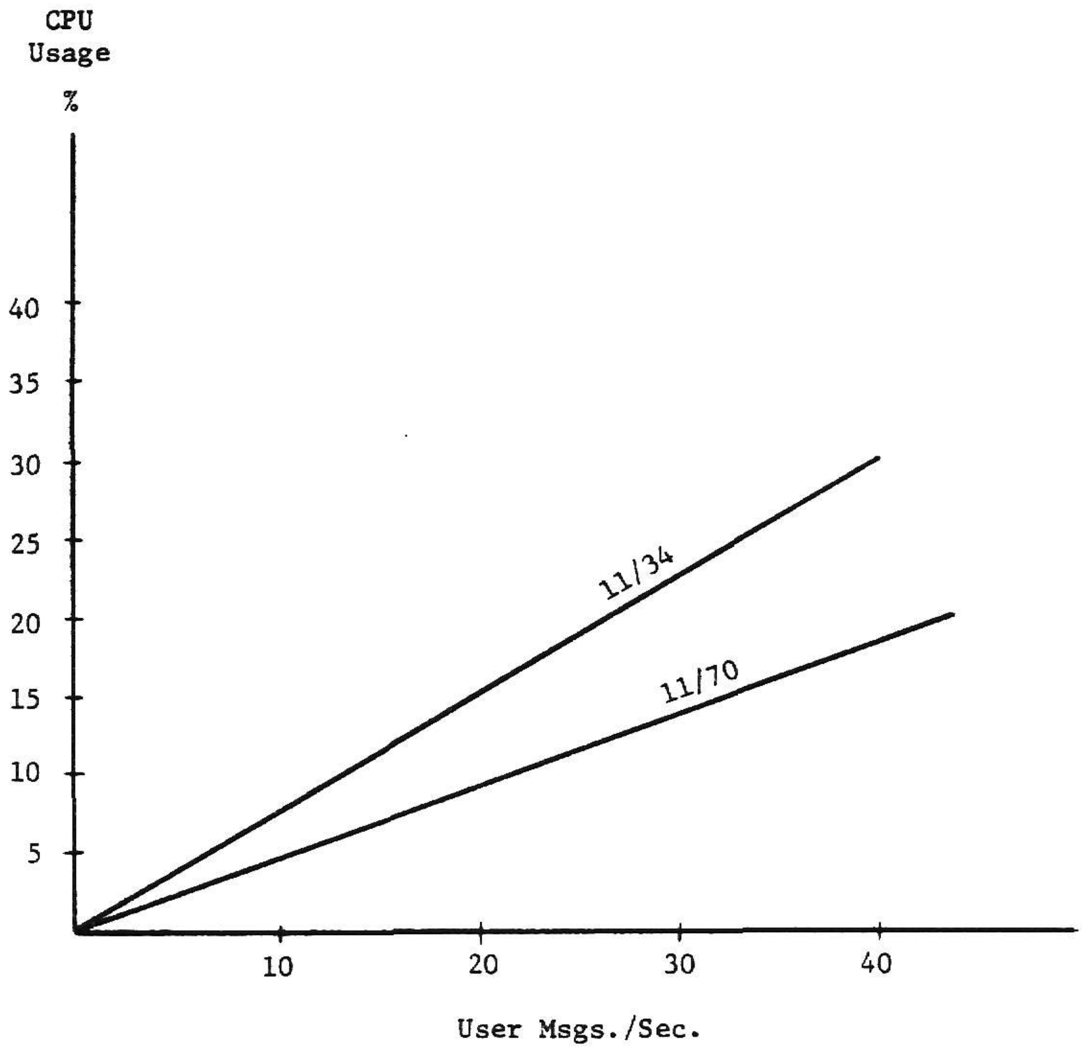

Figure 4

CPU Usage for Network Software

on 11/70 and 11/34

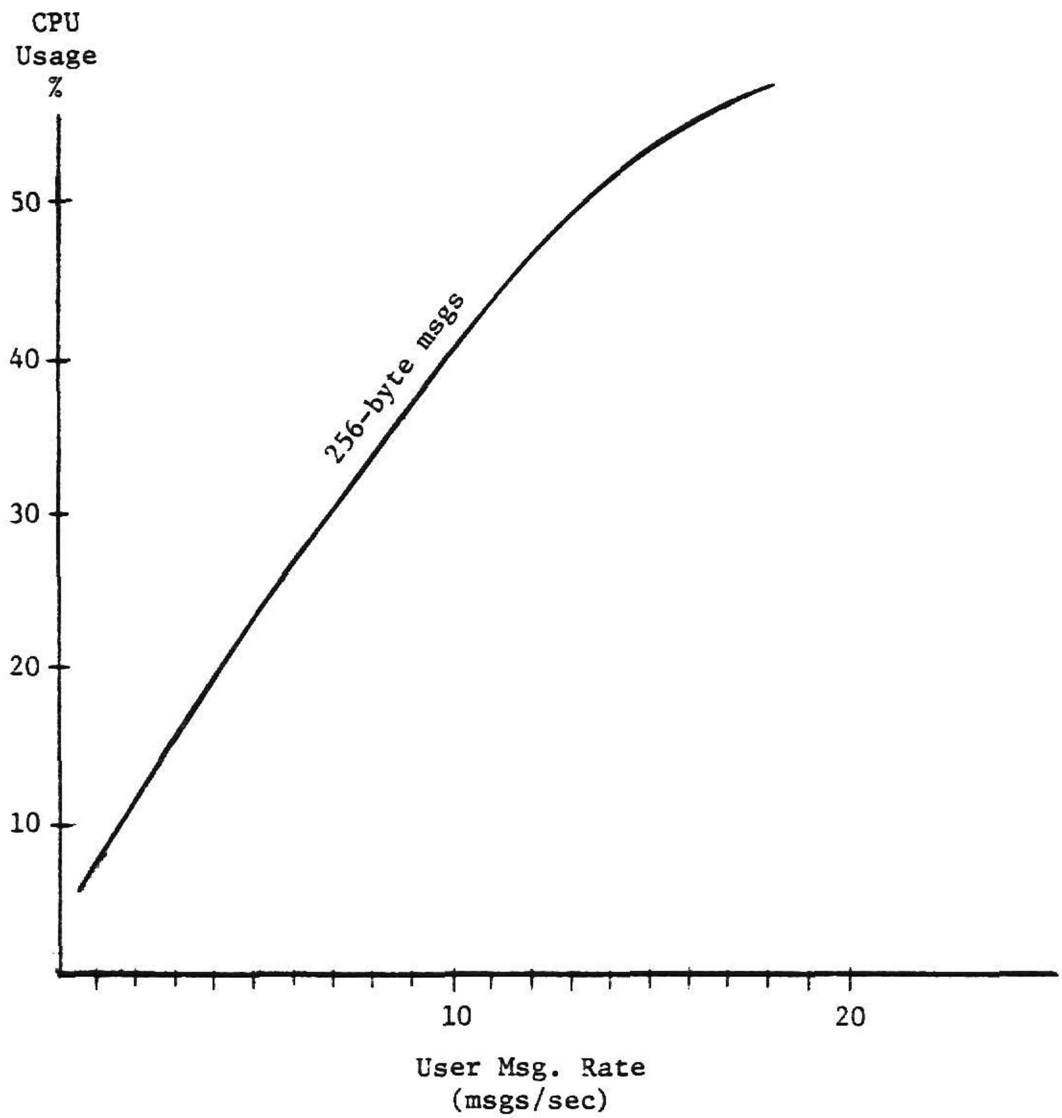

Figure 5

CPU Usage for Network Software on 11/05, 11/03,
and 8/M by Using 11/34 CPU Usage

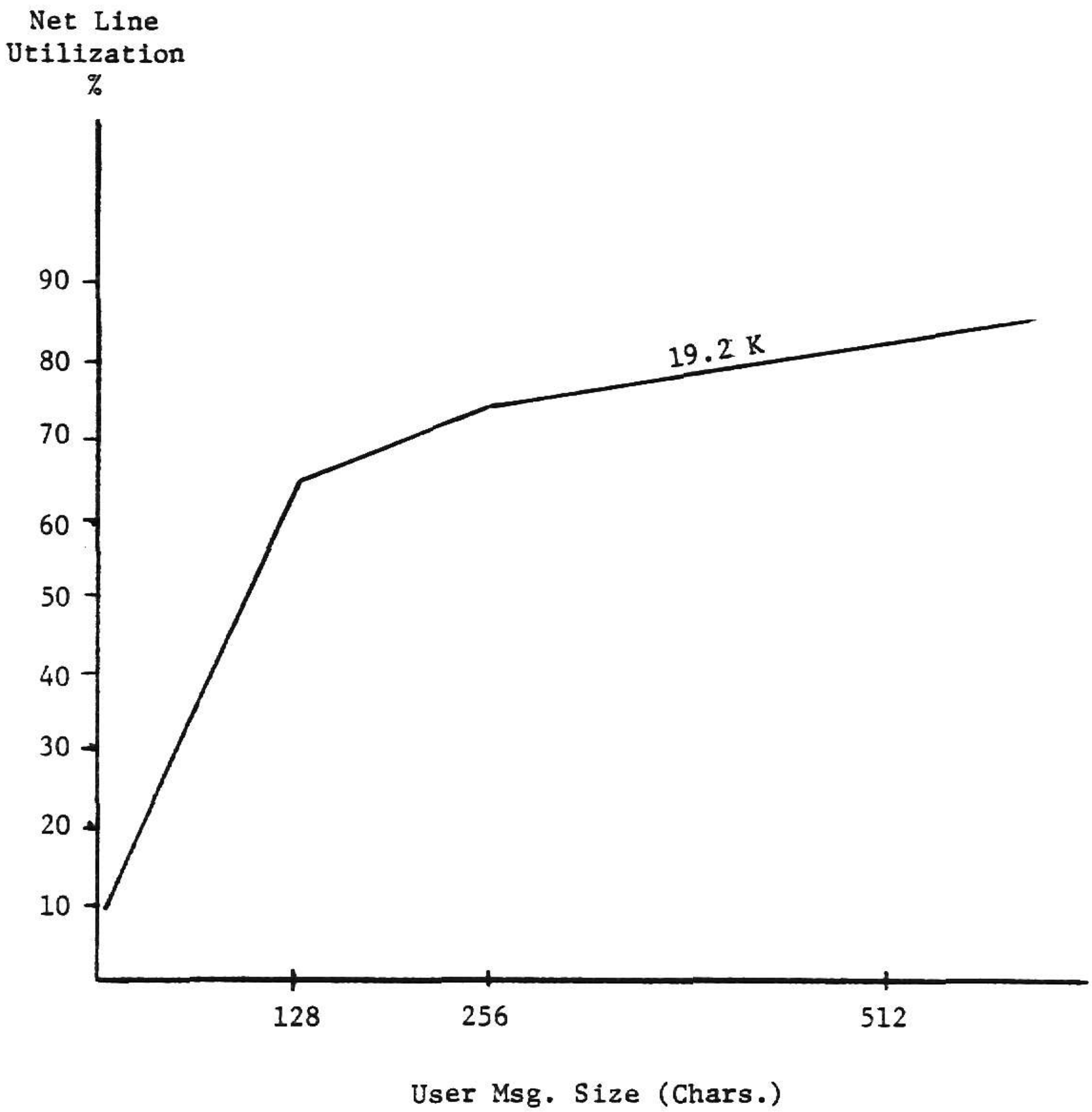

Figure 6

Net Line Utilization

Table 6 lists a summary of the parameters which are indicated above.

3.3 VERIFICATION

Verification of a simulation model is one of the necessary and difficult stages of any simulation study. Any simulation model should be validated in order to obtain some confidence in the model. Only at this point can one rely on the results of the model performance.

In order to gain confidence, the simulation model can be verified by comparing predicted performance of the model with an independent prediction, or the simulation program that implements the model can be validated to be a correct model of the system, and then the program can be verified to be "correct" with respect to the model definition [6].

The simulation programs can also be proven to be correct and equivalent to the design specifications of the system it models. This requires a formal proof of equivalence which is not practical for large programs.

Since the simulation model of this study represents the biomedical research network which is in the design stage, no real verification can be performed because of unavailability of software or hardware measurements of system or user performance. Therefore, no comparison of real performance can be made at this time. In order to verify these types of simulation models and programs, an independent queueing model can be used to measure the degree of comparability between the predicted performance of the model and the results of the queueing model.

A queueing network model is used in this study for the baseline model according to some equations which are explained thoroughly by Denning and Buzen [1].

Parameter	Laboratory Machines				
	11/34	11/05	11/03	8/M	11/70
CPU Usage	1.5%	16%	32%	32%	8.2%
Message Capacity (msg/sec)	1.125	1.125	1.125	1.125	9.3

Net Line Utilization 74%

Table 6

Network Model Parameters

By using the following equations, the throughput rate and the mean response time can be evaluated:

1) Throughput Rate Formula

$X_0 = U_1/VISI$

where

U_1 is CPU utilization
VISI is mean CPU time per job
X_0 is throughput rate

2) Interactive Response Time Formula

$R = M/X_0 - Z$

where

R is mean response time
M is mean number of active
X_0 is throughput rate
Z is user think time

The complexity of the queueing network equations will increase substantially in order to describe computer networks [7]. Therefore, the queueing network model equation was not applied to the various network models. However, some form of checking was made by using vendor-supplied measurements on the overhead associated with DECNET [2].

Chapter 4

SIMULATION EXPERIMENT

4.1 PARAMETERS

There are two types of parameters that are used in this experiment, system parameters and experimental parameters. System parameters are those parameters that stay fixed throughout the experiment; their values do not change. Experimental parameters, on the other hand, are the ones that change on each run in order to analyze the behavior of the model at various circumstances.

Table 7 shows the fixed parameters that are used in the model. For additional fixed parameters, see Table 6 of Chapter 3 of this report.

The arrivals and departures of users at the CRT terminals are assumed to be exponentially distributed. For the initial iterations of the central model, these parameters were randomized so that on the average twenty terminals were busy at any given time. As a result, the CPU utilization was very high. Since CPU utilization of over seventy percent for the network is considered a potential performance problem by the vendor [5], the arrival and departures were readjusted to obtain a lower CPU utilization. The model simulates for eight minutes. Minutes represent hours since it will save time and money for each run. The experimental parameters of the models are the number of computers in the network which range from one to nine computers, and the network configurations.

Name	Value
Line Speed	19.2 KB
Message Rate	9.3 msg/sec
Disk	2
Disk Channels	2
Terminal	32
Memory	768 KB
Arrival	8 seconds
Departure	1 minute

Table 7

Network Model Fixed Parameters

4.2 CENTRAL MODEL

A model of the central machine executing in a stand-alone manner was exercised for the purpose of establishing a baseline model. The initial iterations of the central model were driven by expected usage parameters supplied by the users. These initial simulation runs projected a very high CPU utilization, approximately eighty-five percent [5]. The vendor-supplied documentation cautions against the use of DECNET when CPU utilization is greater than seventy percent [2]. Therefore, a second set of iterations was carried out with lighter user demands. The resultant performance projections for the single machine system appear in Table 8. These figures will serve as the baseline for comparison with the network configurations.

4.3 NETWORK MODEL

The star configuration was modeled for all three phases while the hierarchical configuration is only reasonable for the final nine computer network. The results for the star configurations presented in Table 8 show little difference in the demand for resources on the central machine or in response to the interactive users. The t-test was applied to determine if any statistically significant differences in throughput exist between the baseline model and any network configurations. The only statistically significant difference, at the .90 level, was between the baseline model and the Phase II star configuration. The number of interactive user commands completed dropped significantly when the second set of laboratory machines was added to the network. However, the interactive throughput of the Phase III model does not differ significantly with either the baseline or Phase II models.

	Single Machine	Phase I Star	Phase II Star	Phase III Star
Avg. 11/70 CPU Utilization	.524	.560	.527	.581
Avg. # Active Users	7.32	7.07	6.14	6.79
Avg. 11/70 Job Queue Length	.563	.642	.474	.576
Mean Response Time (Sec.)	.124	.138	.134	.139
Avg. # Commands Completed	6574	6217	5440	5976
Avg. # Messages Processed	---	1600	3214	4292

Table 8

Star Network Performance Projections

The key reason for the small changes in the demands for central machine resources is that the vendor's constraints on loading the system were not exceeded. As indicated in Table 6, the central machine can process a maximum of 9.3 messages per second. Thus, the laboratory machines are limited to a rate of 1.125 messages per second. Since the processing of the messages received at the central machine involves a small amount of CPU time, the net effect upon the demand for resources of the central machine is minimal.

The simulation study suggests that when six or more laboratory machines are attached to the central machine in a star configuration, the throughput of the interactive users may suffer. In addition, the results of this segment of the study give rise to another serious performance question. The restriction of 1.125 messages per second transmitted by the laboratory machines does not permit the movement of large amounts of data between the individual laboratory machines and the central facility. Because the network is in its earliest stage of evolution, it is not yet possible to predict the minimal data transmission requirements. However, the possibility exists that the capacity of the network may not measure up to original user expectations. For example, the development of a distributed data base management system, which was an option considered in the early stages of network planning, is not feasible under the aforementioned performance constraints.

The results of the experiments with the hierarchical model are summarized in Table 9, which compares performance factors of the baseline model, the nine-node star network and the nine-node hierarchical network. The number of user commands processed exhibits a significant

	Single Machine	9 Computer Star	9 Computer Hierarchical
Avg. 11/70 CPU Utilization	.524	.581	.555
Avg. # Active Users	7.32	6.79	6.16
Avg. 11/70 Job Queue Length	.563	.576	.460
Mean Response Time (Sec.)	.124	.139	.136
Avg. # Commands Completed	6574	5976	5445
Avg. # Messages Processed	---	4292	4321
Avg. 11/34 CPU Utilization	---	.015	.075
Avg. 11/34 Job Queue Length	---	.000	.002
Avg. 11/05 CPU Utilization	---	.271	.804
Avg. 11/05 Job Queue Length	---	.048	1.695

Table 9

Hierarchical Network Performance Projections decrease, at the .90 level, between the baseline and hierarchical models. However, the throughput rates of the Phase III star and hierarchical models do not differ significantly. Another noticeable difference between the star and hierarchical models occurs in the utilization of the intermediate nodes, i.e., two PDP 11/34's and a PDP 11/05. For all intermediate nodes, both the processor utilization and the length of the message queues jump dramatically with the change from the star to the hierarchical configuration. In fact, the PDP 11/05 intermediate node has become a bottleneck in the system, as indicated by the message queueing figures listed in Table 9.

The simulation results indicate that some performance degradation will occur at Phase II of the network development. In terms of performance, there is no significant difference between the star and hierarchical configurations, although the hierarchical organization has some potential for bottlenecks at the intermediate nodes.

4.4 VERIFICATION

As it was explained in Chapter 3, a queueing network model [1] of the initial model has been constructed to compare the simulation results and the results of the queueing model.

The theoretical throughput rate and response time (R) for the baseline model can be computed as follows:

$U_1 = .524$ CPU utilization

$VISI = .04$ mean CPU time per job

then

$$X_0 = U_1/VISI$$

$$= 13.1 \text{ commands/sec.}$$

also

$$M = 7.323 \text{ users}$$

$$Z = .423 \text{ sec.}$$

then

$$R = M/X_0 - Z$$

$$= .136$$

The value for Z is the expected value, not the observed mean. The theoretical value for X_0 is close to the observed value of 13.69 commands/seconds for the baseline model. Also, there is a similarity between the theoretical value for R and the observed value of .124 seconds for the baseline model. If the observed value of 13.69 is used for X_0 in the response time formula, the value of .112 will be obtained, which is also comparable with the observed value of R.

The flowchart of the baseline model, the program listings, and the results of all executions can be found in Appendices 1, 2, and 3.

Chapter 6

CONCLUSION

6.1 SUMMARY

This simulation study has been done for application in a biomedical research environment at the U.S. Air Force School of Aerospace Medicine. The study consists of development of a series of simulation runs for a computer network for biomedical research.

The initial model of the network consists of PDP 11/70 as the central point with thirty-two interactive terminals. This model is used as the baseline for comparing and measuring the effect of any network configuration. A theoretical queueing network model of the central system has been synthesized for verification purposes, the simulation results are checked with the results of the queueing network model.

The star configurations consist of the central system linked with three, six, and eight computers, respectively. Parameters describing the behavior of the terminal users were adjusted to achieve CPU utilization less than seventy percent, which is a restriction of the network software. For the experimental machine and line parameters, transmission of the messages throughout the network proceeded with no bottleneck. The demand for resources on the central machine may increase noticeably when six or more laboratory computers are added to the network. As a result, the interactive terminal user's throughput may suffer.

The hierarchical configuration which has nine processors is also compared with the central machine model. Besides the fact that the interactive terminal users would have to stay longer at the terminals to get their jobs done, as in the case of the star configuration, there is also a potential bottleneck in the hierarchical network which makes the star configuration a more desirable network.

6.2 FURTHER WORK

After the installation of PDP 11/70 at the School of Aerospace Medicine, the complete characteristics of the machine should be examined. Also, the user's workload and other factors which will have some effects on the simulation runs must be considered. Since the model is sufficiently general, changes to the model and parameters can be made as soon as more specific determination becomes available. The experiment must be repeated again and each network evaluated in order to select the more efficient network for the School.

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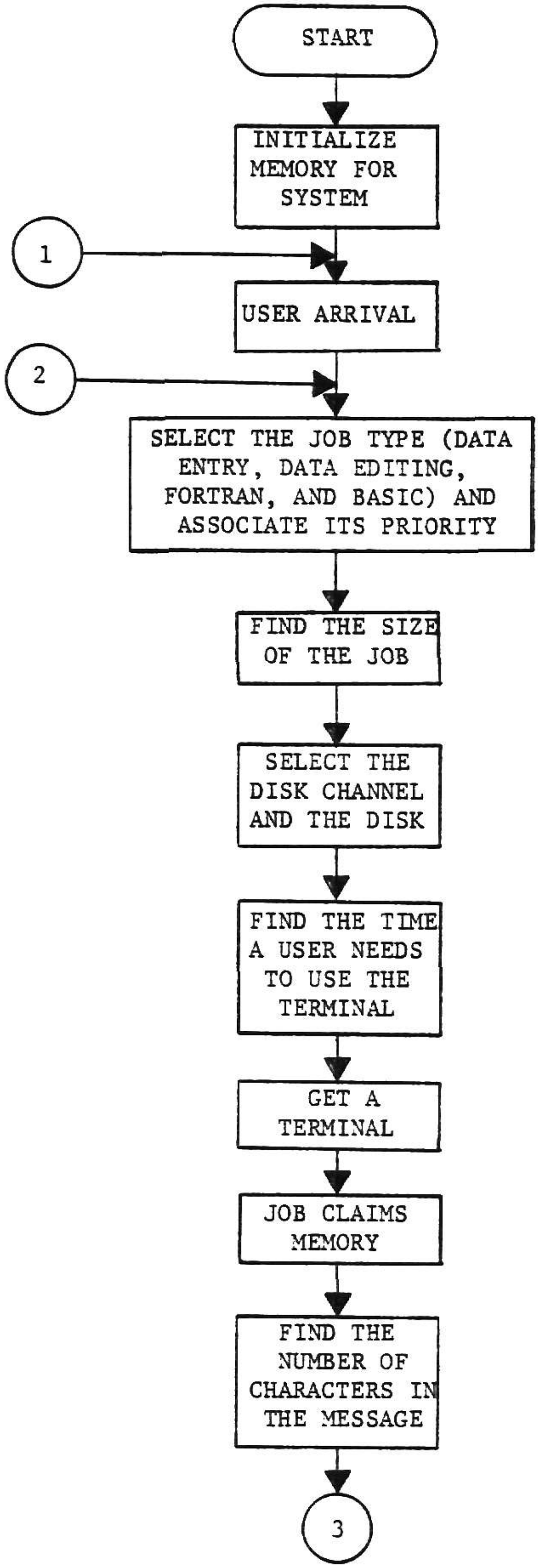
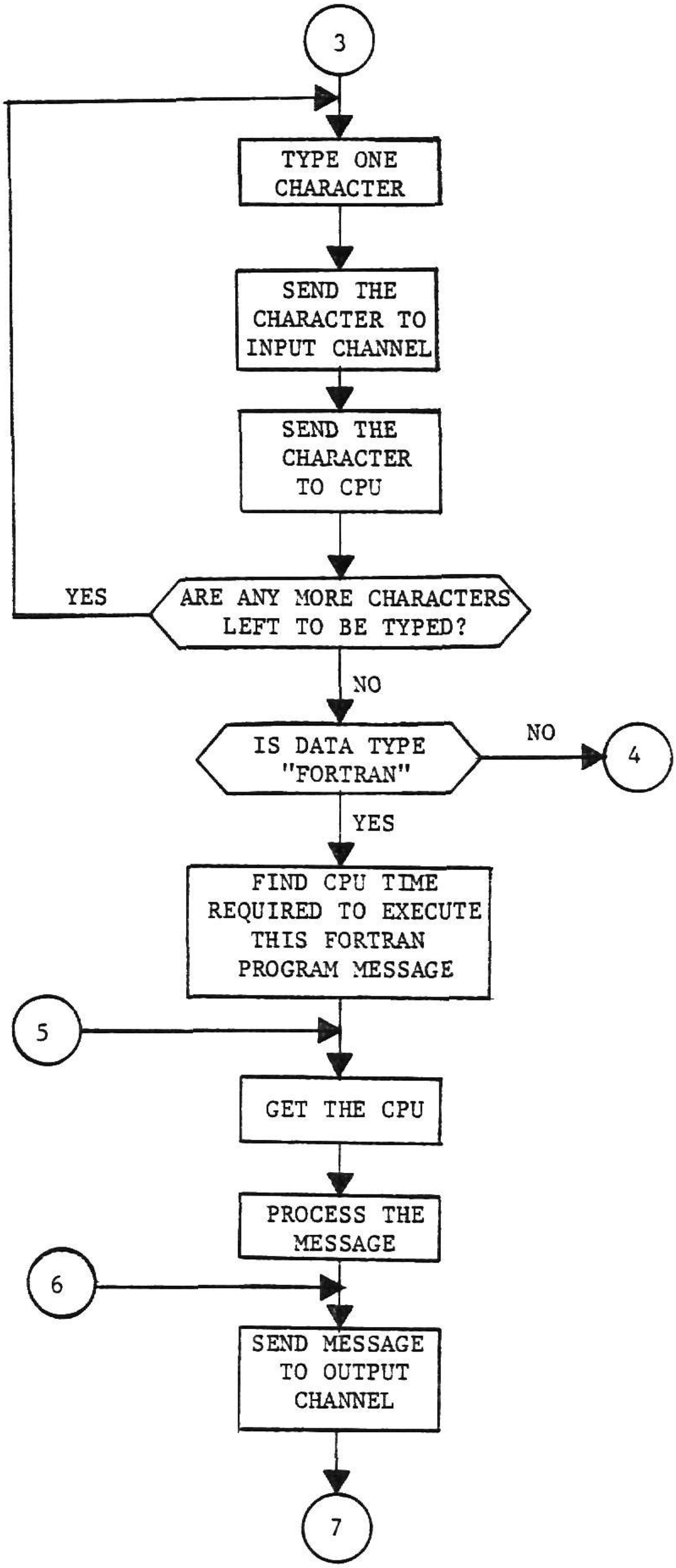
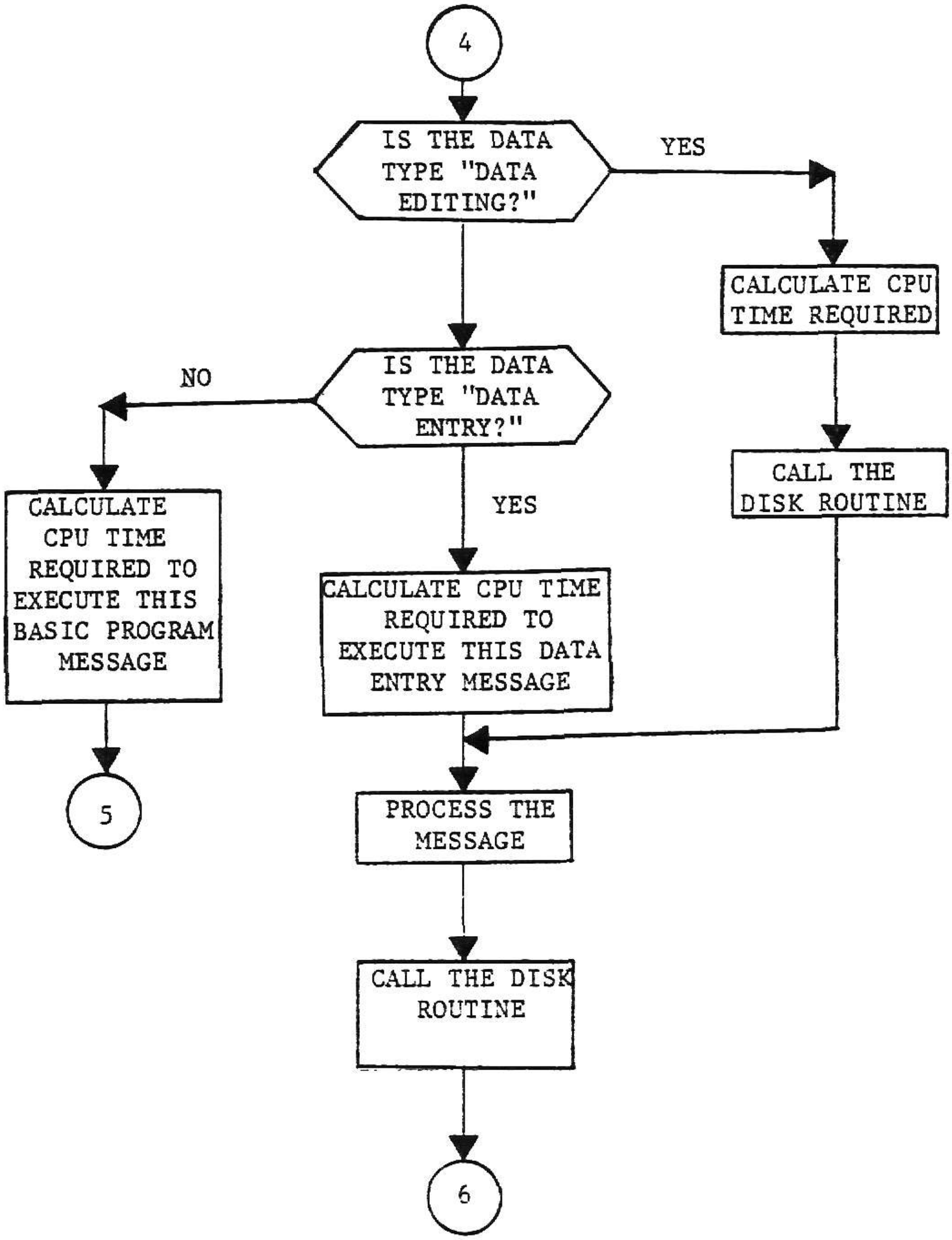
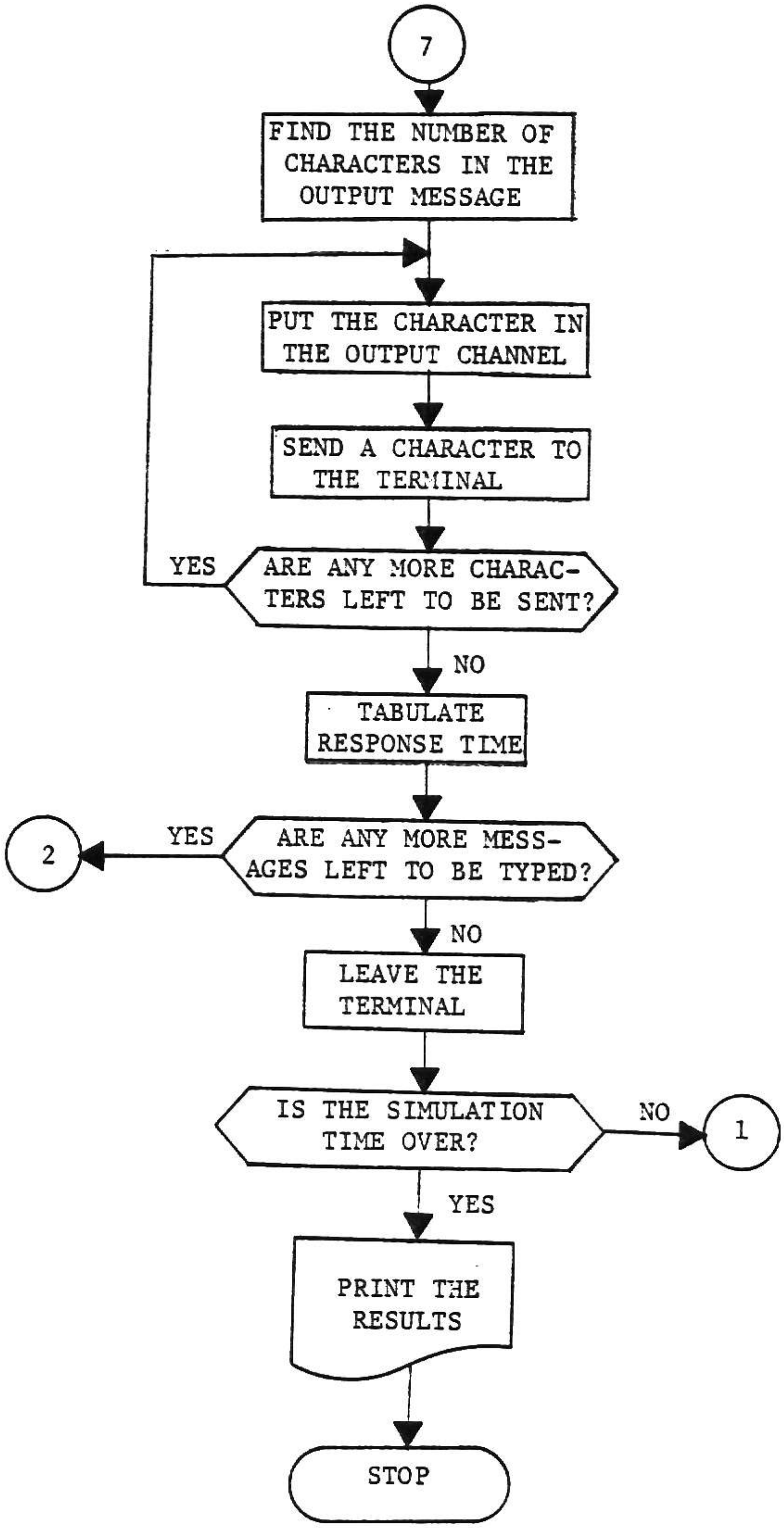
Appendix 1

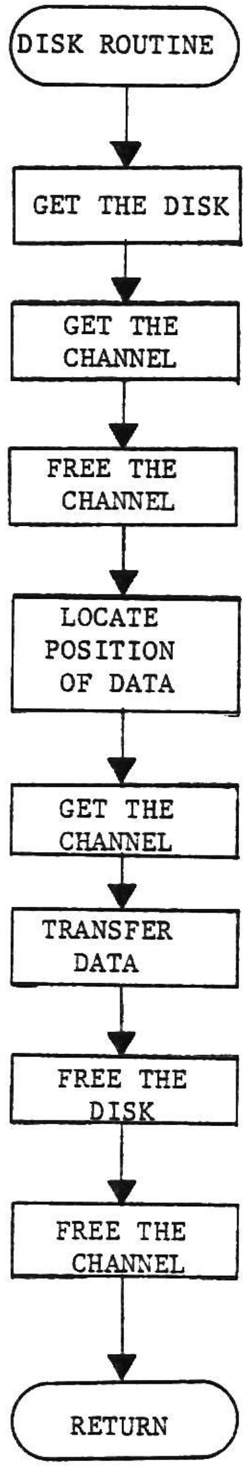
FLOWCHART OF THE BASELINE MODEL


START
INITIALIZE MEMORY FOR SYSTEM
1
USER ARRIVAL
2
SELECT THE JOB TYPE (DATA ENTRY, DATA EDITING, FORTRAN, AND BASIC) AND ASSOCIATE ITS PRIORITY
FIND THE SIZE OF THE JOB
SELECT THE DISK CHANNEL AND THE DISK
FIND THE TIME A USER NEEDS TO USE THE TERMINAL
GET A TERMINAL
JOB CLAIMS MEMORY
FIND THE NUMBER OF CHARACTERS IN THE MESSAGE
3


3
TYPE ONE CHARACTER
SEND THE CHARACTER TO INPUT CHANNEL
SEND THE CHARACTER TO CPU
ARE ANY MORE CHARACTERS LEFT TO BE TYPED?
YES
NO
IS DATA TYPE "FORTRAN"
NO
4
YES
FIND CPU TIME REQUIRED TO EXECUTE THIS FORTRAN PROGRAM MESSAGE
5
GET THE CPU
PROCESS THE MESSAGE
6
SEND MESSAGE TO OUTPUT CHANNEL
7


4
IS THE DATA TYPE "DATA EDITING?"
YES
CALCULATE CPU TIME REQUIRED
CALL THE DISK ROUTINE
IS THE DATA TYPE "DATA ENTRY?"
NO
CALCULATE CPU TIME REQUIRED TO EXECUTE THIS BASIC PROGRAM MESSAGE
5
YES
CALCULATE CPU TIME REQUIRED TO EXECUTE THIS DATA ENTRY MESSAGE
PROCESS THE MESSAGE
CALL THE DISK ROUTINE
6


7
FIND THE NUMBER OF CHARACTERS IN THE OUTPUT MESSAGE
PUT THE CHARACTER IN THE OUTPUT CHANNEL
SEND A CHARACTER TO THE TERMINAL
YES
ARE ANY MORE CHARACTERS LEFT TO BE SENT?
NO
TABULATE RESPONSE TIME
2
YES
ARE ANY MORE MESSAGES LEFT TO BE TYPED?
NO
LEAVE THE TERMINAL
IS THE SIMULATION TIME OVER?
NO
1
YES
PRINT THE RESULTS
STOP


DISK ROUTINE
GET THE DISK
GET THE CHANNEL
FREE THE CHANNEL
LOCATE POSITION OF DATA
GET THE CHANNEL
TRANSFER DATA
FREE THE DISK
FREE THE CHANNEL
RETURN

Appendix 2

THE PROGRAM LISTING

```
BLOCK                                                                          STATEMENT
NUMBER *LOC   OPERATION  A,B,C,D,E,F,G,H,I           COMMENTS                   NUMBER
       ****************************************
       *                                      *
       *              TABLE                   *
       *                                      *
       ****************************************
        TPUT  TABLE       M1,0,500,50
       ****************************************
       *                                      *
       *              FUNCTIONS               *
       *                                      *
       ****************************************
        PRIOR FUNCTION    PF1,D4               PRIORITY FUNCTION
       1,40/2,30/3,10/4,20/
        DTAEN FUNCTION    RN3,D4               JOB TYPE
       .4,1/.7,2/.85,3/1.0,4/
        EXPON FUNCTION    RN1,C24              EXPONENTIAL FUNCTION
       0,0/.1,.104/.2,.222/.3,.355/.4,.509/.5,.69/.6,.915/.7,1.2/.75,1.38
       .8,1.6/.84,1.83/.88,2.12/.9,2.3/.92,2.52/.94,2.81/.95,2.99/.96,3.2
       .97,3.5/.98,3.9/.99,4.6/.995,5.3/.998,6.2/.999,7/.9997,8
        MEMF  FUNCTION    PF1,D4               MEMORY SIZE
       1,4/2,4/3,56/4,40/
        DISK2 FUNCTION    RN2,D2               DISK SELECTION
       .5,51/1.0,52/
        DCHNL FUNCTION    RN2,D2               DISK CHANNEL SELECTION
       .5,53/1.0,54/
        TRNS  FUNCTION    P2,L8                TRANSPORTATION OVER C. LINE
       1,144/2,144/3,144/4,144/5,144/6,144/7,144/8,144
       ****************************************
       *                                      *
       *              VARIABLES               *
       *                                      *
       ****************************************
        CHAR  FVARIABLE  (1*FN$EXPON)+1        MESSAGE LENGTH
       ****************************************
       *                                      *
       *              STORAGES                *
       *                                      *
       ****************************************
        TERML STORAGE     32
        MEMRY STORAGE     768
1             GENERATE    ,,,1                 GENERATE ONLY ONE TRANSACTION
2             ENTER       MEMRY,4              SYSTEM ENTERS MEMORY
3             TERMINATE   0                    REDUCE TERMINATION BY 0
4             GENERATE    8000,FN$EXPON,,,,9PF USER ARRIVAL
5             ASSIGN      1,FN$DTAEN,PF        ASSIGN JOB TYPE
6             ASSIGN      9,FN$MEMF,PF         ASSIGN THE SIZE OF THE JOB
7             ASSIGN      6,FN$DISK2,PF        SELECT A DISK
8             ASSIGN      7,FN$DCHNL,PF        SELECT A CHANNEL
9             PRIORITY    FN$PRIOR             FIND THE PRIORITY FOR THE JOB
10            ASSIGN      5,60000,3,PF        TIME NEEDED TO TYPE ALL MESSAGES
11            ASSIGN      5+,C1,PF             ADD THE ABOVE VALUE TO CLOCK
12            QUEUE       TER                  LINE UP FOR TERMINAL
13            ENTER       TERML                GET A TERMINAL TO USE
14            DEPART      TER                  LEAVE THE LINE
15            QUEUE       MEM                  JOB WAITS TO ENTER THE MEMORY
```

```
16            ENTER      MEMRY,PF9         JOB ENTERS MEMORY
17            DEPART     MEM               LEAVE THE WAITING LINE
18     MSG    ASSIGN     2,V$CHAR,PF       ASSIGN # OF CHARACTERS IN JOB
19     TYPE   ADVANCE    250               TYPE THE CHARACTER
20            ADVANCE    6                 SEND THE CHAR TO INPUT CHANNEL
21            QUEUE      ICHNL             LINE UP FOR INPUT CHANNEL
22            SEIZE      CHANL             SEIZE THE I/CHANNEL
23            DEPART     ICHNL             LEAVE THE LINE
24            ADVANCE    1                 SEND THE CHARACTER TO CPU
25            RELEASE    CHANL             LEAVE THE INPUT CHANNEL
26            ASSIGN     2-,1,PF           TAKE OFF 1 CHARACTER
27            TEST LE    PF2,0,TYPE        IF MORE CHAR LEFT GOTO TYPE
28            MARK                          MARK THE TIME
29            TEST NE    PF1,3,FORT        IF FORTRAN THEN GOTO "FORT"
30            TEST NE    PF1,2,DEDIT       IF DATA EDITING THEN GOTO "DEDIT
31            TEST NE    PF1,1,DENTR       IF DATA ENTRY THEN GOTO "DENTR"
32     BASIC  ASSIGN     3,40,3,PF         COMPUTE CPU TIME
33            QUEUE      JOB               QUEUE FOR CPU
34            SEIZE      CPU               GET THE CPU
35            DEPART     JOB                   DEPART THE QUEUE
36            ADVANCE    5                 TASK SWITCH OVERHEAD
37            ADVANCE    PF3               PROCESS THE MESSAGE
38            RELEASE    CPU               END PROCESSING
39            TRANSFER   ,COMP             GO TO "COMP"
40     FORT   ASSIGN     3,90,3,PF         COMPUTE CPU TIME
41            QUEUE      JOB               QUEUE FOR CPU
42            SEIZE      CPU               GET THE CPU
43            DEPART     JOB                   DEPART THE QUEUE
44            ADVANCE    5                 TASK SWITCH OVERHEAD
45            ADVANCE    PF3               PROCESS THE MESSAGE
46            RELEASE    CPU               END PROCESSING
47            TRANSFER   ,COMP             GOTO COMP
48     DENTR  ASSIGN     3,15,3,PF         COMPUTE CPU TIME
49            QUEUE      JOB               QUEUE FOR CPU
50            SEIZE      CPU               GET THE CPU
51            DEPART     JOB                   DEPART THE QUEUE
52            ADVANCE    5                 TASK SWITCH OVERHEAD
53            ADVANCE    PF3               PROCESS THE MESSAGE
54            RELEASE    CPU               END PROCESSING
55            TRANSFER   SBR,DISK,8PF      GOTO USE THE DISK
56            TRANSFER   ,COMP             GOTO "COMP"
57     DEDIT  ASSIGN     3,30,3,PF         COMPUTE CPU TIME
58            TRANSFER   SBR,DISK,8PF      GOTO USE THE DISK
59            QUEUE      JOB               QUEUE FOR CPU
60            SEIZE      CPU               GET THE CPU
61            DEPART     JOB                   DEPART THE QUEUE
62            ADVANCE    5                 TASK SWITCH OVERHEAD
63            ADVANCE    PF3               PROCESS THE MESSAGE
64            RELEASE    CPU               END PROCESSING
65            TRANSFER   SBR,DISK,8PF      GOTO USE THE DISK
66     COMP   ADVANCE    1                 SEND THE MSG TO OUTPUT CHANNEL
67            ASSIGN     4,V$CHAR,PF       ASSIGN # OF CHAR IN OUTPUT MSG
68     OUT    QUEUE      OCHNL             QUEUE FOR OUTPUT CHANNEL
69            SEIZE      CHANL             GET THE CHANNEL
70            DEPART     OCHNL             LEAVE THE QUEUE
71            ADVANCE    1                 THE CHARACTER IS QUEUED UP
72            RELEASE    CHANL             LEAVE THE CHANNEL
```

```
73            ADVANCE    6            SEND THE CHAR TO THE TERMINAL
74            ASSIGN     4-,1,PF      TAKE OFF ONE CHARACTER
75            TEST LE    PF4,0,OUT    IF MORE CHAR LEFT GOTO OUT
76            TABULATE   TPUT         TABULATE THE THROUGHPUT TABLE
77            TEST GE    C1,PF5,MSG   IF MORE MSGS TO TYPE GOTO "MSG"
78            LEAVE      MEMRY,PF9    LEAVE MEMORY
79            LEAVE      TERML        IF FINISHED LEAVE THE TERMINAL
80            TERMINATE  0            REDUCE TERMINATION BY 0
81      DISK  QUEUE      P6           ENTER DISK QUEUE
82            SEIZE      P6           GET DISK
83            DEPART     P6           LEAVE DISK Q.
84            QUEUE      P7           ENTER CHANNEL C.
85            SEIZE      P7           GET CHANNEL
86            DEPART     P7           LEAVE CHANNEL
87            RELEASE    P7           RELEASE CHANNEL
88            ADVANCE    30           DO DISK ACCESS TIME
89            QUEUE      P7           ENTER CHANNEL C.
90            SEIZE      P7           GET CHANNEL.
91            DEPART     P7           LEAVE CHANNEL C.
92            ADVANCE    2            DISK TRANSFER CATA TIME.
93            RELEASE    P6           RELEASE DISK.
94            RELEASE    P7           RELEASE CHANNEL
95            TRANSFER   PF,8,1       RETURN TO THE CALLER.
96            GENERATE   480000       SIMULATE FOR 8 MINUTES
97            TERMINATE  1            REDUCE TERMINATION TIME BY 1
              START      1            PROCESS 1 MESSAGE.
              END
```

```
BLOCK                                                                              STATEMENT
NUMBER *LOC   OPERATION  A,B,C,D,E,F,G,H,I        COMMENTS                         NUMBER
       ****************************************                                        1
       *                                      *                                        2
       *               TABLE                  *                                        3
       *                                      *                                        4
       ****************************************                                        5
        TPUT  TABLE      M1,0,500,50                                                   6
       ****************************************                                        7
       *                                      *                                        8
       *             FUNCTIONS                *                                        9
       *                                      *                                       10
       ****************************************                                       11
        PRIOR FUNCTION   PF1,D4                  PRIORITY FUNCTION                    12
       1,40/2,30/3,10/4,20/                                                           13
        DTAEN FUNCTION   RN3,D4                  JOB TYPE                             14
       .4,1/.7,2/.85,3/1.0,4/                                                         15
        EXPON FUNCTION   RN1,C24                 EXPONENTIAL FUNCTION                 16
       0,0/.1,.104/.2,.222/.3,.355/.4,.509/.5,.69/.6,.915/.7,1.2/.75,1.38             17
       .8,1.6/.84,1.83/.88,2.12/.9,2.3/.92,2.52/.94,2.81/.95,2.99/.96,3.2             18
       .97,3.5/.98,3.9/.99,4.6/.995,5.3/.998,6.2/.999,7/.9997,8                       19
        MEMF  FUNCTION   PF1,D4                  MEMORY SIZE                          20
       1,4/2,4/3,56/4,40/                                                             21
        DISK2 FUNCTION   RN2,D2                  DISK SELECTION                       22
       .5,51/1.0,52/                                                                  23
        DCHNL FUNCTION   RN2,D2                  DISK CHANNEL SELECTICN               24
       .5,53/1.0,54/                                                                  25
        TRNS  FUNCTION   P2,L8                   TRANSPORTATION OVER C. LINE          26
       1,144/2,144/3,144/4,144/5,144/6,144/7,144/8,144                                27
       ****************************************                                       28
       *                                      *                                       29
       *             VARIABLES                *                                       30
       *                                      *                                       31
       ****************************************                                       32
        COMPT FVARIABLE  8                       NUMBER OF LABORATORY MACHINES        33
        LINE  FVARIABLE  P1+V$CCMPT              COMPUTER LINE                        34
        CHAR  FVARIABLE  (1*FN$EXPON)+1          MESSAGE LENGTH                       35
       ****************************************                                       36
       *                                      *                                       37
       *             STORAGES                 *                                       38
       *                                      *                                       39
       ****************************************                                       40
        TERML STORAGE    32                                                           41
        MEMRY STORAGE    768                                                          42
        BUFF  STCRAGE    16                                                           43
  1           GENERATE   ,,,1                    GENERATE ONLY ONE TRANSACTION        44
  2           ENTER      MEMRY,8                 SYSTEM ENTERS MEMORY,TAKES 8K        45
  3           TERMINATE  0                       REDUCE TERMINATICN BY 0              46
  4           GENERATE   889,FN$EXPON,,,,8PF     GENERATE A MESSAGE                   47
  5           ASSIGN     2,K1                    ASSIGN SAMPLE #                      48
  6           ASSIGN     1,K15                   ASSIGN PDP 11/34 #                   49
  7           ASSIGN     3,V$LINE                ASSIGN LINE #                        50
  8           QUEUE      P1                      ENTER PDP 11/34                      51
  9           SEIZE      P1                      GET THE CPU                          52
 10           DEPART     P1                      LEAVE PDP 11/34 Q                    53
 11           ADVANCE    1                       MSG PREPARATICN                      54
 12           ADVANCE    13                      CECNET OVERHEAD                      55
```

```
13    RELEASE    P1                     FREE 11/34
14    QUEUE      P3                     LINE Q
15    SEIZE      P3                     GET THE LINE
16    DEPART     P3                     LEAVE THE LINE Q
17    ADVANCE    FN$TRNS                TRANSPORTATICN TIME
18    RELEASE    P3                     LEAVE THE LINE
19    TRANSFER   ,BIG                   GO TO BIG
20    GENERATE   889,FN$EXPON,,,,8PF    GENERATE A MESSAGE
21    ASSIGN     2,K2                   ASSIGN SAMPLE #
22    ASSIGN     1,K16                  ASSIGN PDP 11/34 #
23    ASSIGN     3,V$LINE               ASSIGN LINE #
24    QUEUE      P1                     ENTER PDP 11/34
25    SEIZE      P1                     GET THE CPU
26    DEPART     P1                     LEAVE PDP 11/34 Q
27    ADVANCE    1                      MSG PREPARATION
28    ADVANCE    13                     CECNET OVERHEAD
29    RELEASE    P1                     FREE 11/34
30    QUEUE      P3                     LINE Q
31    SEIZE      P3                     GET THE LINE
32    DEPART     P3                     LEAVE THE LINE Q
33    ADVANCE    FN$TRNS                TRANSPORTATICN TIME
34    RELEASE    P3                     LEAVE THE LINE
35    TRANSFER   ,BIG                   GO TO BIG
36    GENERATE   889,FN$EXPON,,,,8PF    GENERATE A MESSAGE
37    ASSIGN     2,K3                   ASSIGN SAMPLE #
38    ASSIGN     1,K17                  ASSIGN PDP 11/C5 #
39    ASSIGN     3,V$LINE               ASSIGN LINE #
40    QUEUE      P1                     ENTER PDP 11/05
41    SEIZE      P1                     GET THE CPU
42    DEPART     P1                     LEAVE PDP 11/C5 Q
43    ADVANCE    1                      MSG PREPARATION
44    ADVANCE    142                    CECNET OVERHEAD
45    RELEASE    P1                     FREE 11/05
46    QUEUE      P3                     LINE Q
47    SEIZE      P3                     GET THE LINE
48    DEPART     P3                     LEAVE THE LINE Q
49    ADVANCE    FN$TRNS                TRANSPCRTATICN TIME
50    RELFASE    P3                     LEAVE THE LINE
51    TRANSFER   ,BIG                   GO TO BIG
52    GENERATE   889,FN$EXPON,,,,8PF    GENERATE A MESSAGE
53    ASSIGN     2,K4                   ASSIGN SAMPLE #
54    ASSIGN     1,K18                  ASSIGN PDP 11/34 #
55    ASSIGN     3,V$LINE               ASSIGN LINE #
56    QUEUE      P1                     ENTER PDP 11/34
57    SEIZE      P1                     GET THE CPU
58    DEPART     P1                     LEAVE PDP 11/34 Q
59    ADVANCE    1                      MSG PREPARATION
60    ADVANCE    13                     DECNET OVERHEAC
61    RELEASE    P1                     FREE 11/34
62    QUEUE      P3                     LINE Q
63    SEIZE      P3                     GET THE LINE
64    DEPART     P3                     LEAVE THE LINE Q
65    ADVANCE    FN$TRNS                TRANSPORTATICN TIME
66    RELEASE    P3                     LEAVE THE LINE
67    TRANSFER   ,BIG                   GO TO BIG
68    GENERATE   889,FN$EXPON,,,,8PF    GENERATE A MESSAGE
69    ASSIGN     2,K5                   ASSIGN SAMPLE #
```

```
70    ASSIGN     1,K19                ASSIGN PDP 11/34 #
71    ASSIGN     3,V$LINE             ASSIGN LINE #
72    QUEUE      P1                   ENTER PDP 11/34
73    SEIZE      P1                   GET THE CPU
74    DEPART     P1                   LEAVE PDP 11/34 Q
75    ADVANCE    1                    MSG PREPARATION
76    ADVANCE    13                   DECNET OVERHEAD
77    RELEASE    P1                   FREE 11/34
78    QUEUE      P3                   LINE Q
79    SEIZE      P3                   GET THE LINE
80    DEPART     P3                   LEAVE THE LINE Q
81    ADVANCE    FN$TRNS              TRANSPORTATION TIME
82    RELEASE    P3                   LEAVE THE LINE
83    TRANSFER   ,BIG                 GO TO BIG
84    GENERATE   889,FN$EXPON,,,,8PF  GENERATE A MESSAGE
85    ASSIGN     2,K6                 ASSIGN SAMPLE #
86    ASSIGN     1,K20                ASSIGN PDP 11/03 #
87    ASSIGN     3,V$LINE             ASSIGN LINE #
88    QUEUE      P1                   ENTER PDP 11/03
89    SEIZE      P1                   GET THE CPU
90    DEPART     P1                   LEAVE PDP 11/03 Q
91    ADVANCE    1                    MSG PREPARATION
92    ADVANCE    284                  DECNET OVERHEAD
93    RELEASE    P1                   FREE 11/03
94    QUEUE      P3                   LINE Q
95    SEIZE      P3                   GET THE LINE
96    DEPART     P3                   LEAVE THE LINE Q
97    ADVANCE    FN$TRNS              TRANSPORTATION TIME
98    RELEASE    P3                   LEAVE THE LINE
99    TRANSFER   ,BIG                 GO TO BIG
100   GENERATE   889,FN$EXPON,,,,8PF  GENERATE A MESSAGE
101   ASSIGN     2,K8                 ASSIGN SAMPLE #
102   ASSIGN     1,K21                ASSIGN PDP 11/05 #
103   ASSIGN     3,V$LINE             ASSIGN LINE #
104   QUEUE      P1                   ENTER PDP 11/05
105   SEIZE      P1                   GET THE CPU
106   DEPART     P1                   LEAVE PDP 11/05 Q
107   ADVANCE    1                    MSG PREPARATION
108   ADVANCE    242                  DECNET OVERHEAD
109   RELEASE    P1                   FREE 11/05
110   QUEUE      P3                   LINE Q
111   SEIZE      P3                   GET THE LINE
112   DEPART     P3                   LEAVE THE LINE Q
113   ADVANCE    FN$TRNS              TRANSPORTATION TIME
114   RELEASE    P3                   LEAVE THE LINE
115   TRANSFER   ,BIG                 GO TO BIG
116   GENERATE   889,FN$EXPON,,,,8PF  GENERATE A MESSAGE
117   ASSIGN     2,K7                 ASSIGN SAMPLE #
118   ASSIGN     1,K22                ASSIGN PDP 8/M
119   ASSIGN     3,V$LINE             ASSIGN LINE #
120   QUEUE      P1                   ENTER PDP 8/M
121   SEIZE      P1                   GET THE CPU
122   DEPART     P1                   LEAVE PDP 8/M C
123   ADVANCE    1                    MSG PREPARATION
124   ADVANCE    284                  DECNET OVERHEAD
125   RELEASE    P1                   FREE 8/M
126   QUEUE      P3                   LINE Q
```

```
127              SEIZE      P3                     GET THE LINE
128              DEPART     P3                     LEAVE THE LINE Q
129              ADVANCE    FN$TRNS                TRANSPORTATICN TIME
130              RELEASE    P3                     LEAVE THE LINE
131       BIG    QUEUE      PDP                    ENTER 11/70
132              PRIORITY   5                      TO LAB. MACHINES
133              PREEMPT    CPU                    GET 11/70 CPU
134              DEPART     PDP                    LEAVE 11/70
135              ENTER      BUFF
136              ADVANCE    5                      SWAP TASKS
137              ADVANCE    9                      CPU USAGE CN THE 11/70
138              RETURN     CPU                         FREE 11/70 CPU
139              ASSIGN     6,FN$DISK2,PF          SELECT A DISK
140              ASSIGN     7,FN$DCHNL,PF          SELECT A CHANNEL
141              TRANSFER   SBR,DISK,8PF
142              LEAVE      BUFF
143              TERMINATE  0
144              GENERATE   8000,FN$EXPON,,,,9PF   USER ARRIVAL
145              ASSIGN     1,FN$DTAEN,PF          ASSIGN JOB TYPE
146              ASSIGN     9,FN$MEMF,PF           ASSIGN THE SIZE OF THE JGB
147              ASSIGN     6,FN$DISK2,PF          SELECT A DISK
148              ASSIGN     7,FN$DCHNL,PF          SELECT A CHANNEL
149              PRIORITY   FN$PRIOR               FIND THE PRIORITY FCR THE JOB
150              ASSIGN     5,60000,3,PF          TIME NEEDED TO TYPE ALL MESSAGES
151              ASSIGN     5+,C1,PF               ADD THE ABCVE VALUE TO CLOCK
152              QUEUE      TER                    LINE UP FOR TERMINAL
153              ENTER      TERML                  GET A TERMINAL TO USE
154              DEPART     TER                    LEAVE THE LINE
155              QUEUE      MEM                    JOB WAITS TO ENTER THE MEMORY
156              ENTER      MEMRY,PF9              JOB ENTERS MEMCRY
157              DEPART     MEM                    LEAVE THE WAITING LINE
158       MSG    ASSIGN     2,V$CHAR,PF            ASSIGN # OF CHARACTERS IN JOB
159       TYPE   ADVANCE    250                    TYPE THE CHARACTER
160              ADVANCE    6                      SEND THE CHAR TO INPUT CHANNEL
161              QUEUE      ICHNL                  LINE UP FOR INPUT CHANNEL
162              SEIZE      CHANL                  SEIZE THE I/CHANNEL
163              DEPART     ICHNL                  LEAVE THE LINE
164              ADVANCE    1                      SEND THE CHARACTER TC CPU
165              RELEASE    CHANL                  LEAVE THE INPUT CHANNEL
166              ASSIGN     2-,1,PF                TAKE OFF 1 CHARACTER
167              TEST LE    PF2,0,TYPE             IF MORE CHAR LEFT GCTO TYPE
168              MARK                               MARK THE TIME
169              TEST NE    PF1,3,FORT             IF FORTRAN THEN GOTC "FORT"
170              TEST NE    PF1,2,DEDIT            IF DATA EDITING THEN GOTO "DEDIT
171              TEST NE    PF1,1,DENTR            IF DATA ENTRY THEN GOTO "DENTR"
172       BASIC  ASSIGN     3,40,3,PF              COMPUTE CPU TIME
173              QUEUE      JOB                    CUEUE FOR CPU
174              SEIZE      CPU                    GET THE CPU
175              DEPART     JOB                         DEPART THE QUEUE
176              ADVANCE    5                      TASK SWITCH OVERHEAD
177              ADVANCE    PF3                    PROCESS THE MESSAGE
178              RELEASE    CPU                    END PROCESSING
179              TRANSFER   ,COMP                  GO TO "CCMP"
180       FORT   ASSIGN     3,90,3,PF              COMPUTE CPU TIME
181              QUEUE      JOB                    CUEUE FOR CPU
182              SEIZE      CPU                    GET THE CPU
183              DEPART     JOB                         DEPART THE QUEUE
```

```
184         ADVANCE    5               TASK SWITCH OVERHEAD
185         ADVANCE    PF3             PROCESS THE MESSAGE
186         RELEASE    CPU             END PROCESSING
187         TRANSFER   ,COMP           GOTO COMP
188   DENTR ASSIGN     3,15,3,PF       COMPUTE CPU TIME
189         QUEUE      JOB             CUEUE FCR CPU
190         SEIZE      CPU             GET THE CPU
191         DEPART     JOB                 DEPART THE QUEUE
192         ADVANCE    5               TASK SWITCH OVERHEAD
193         ADVANCE    PF3             PROCESS THE MESSAGE
194         RELEASE    CPU             END PROCESSING
195         TRANSFER   SBR,DISK,8PF    GOTO USE THE DISK
196         TRANSFER   ,COMP           GOTO "COMP"
197   DEDIT ASSIGN     3,30,3,PF       COMPUTE CPU TIME
198         TRANSFER   SBR,DISK,8PF    GOTO USE THE DISK
199         QUEUE      JOB             CUEUE FOR CPU
200         SEIZE      CPU             GET THE CPU
201         DEPART     JOB                 DEPART THE QUEUE
202         ADVANCE    5               TASK SWITCH OVERHEAC
203         ADVANCE    PF3             PROCESS THE MESSAGE
204         RELEASE    CPU             END PROCESSING
205         TRANSFER   SBR,DISK,8PF    GOTO USE THE CISK
206   COMP  ADVANCE    1               SEND THE MSG TO OUTPUT CHANNEL
207         ASSIGN     4,V$CHAR,PF     ASSIGN # OF CHAR IN OUTPUT MSG
208   OUT   QUEUE      OCHNL           QUEUE FOR OUTPLT CHANNEL
209         SEIZE      CHANL           GET THE CHANNEL
210         DEPART     OCHNL           LEAVE THE CUEUE
211         ADVANCE    1               THE CHARACTER IS QUEUED UP
212         RELEASE    CHANL           LEAVE THE CHANNEL
213         ADVANCE    6               SEND THE CHAR TO THE TERMINAL
214         ASSIGN     4-,1,PF         TAKE OFF ONE CHARACTER
215         TEST LE    PF4,0,OUT       IF MORE CHAR LEFT GCTO OUT
216         TABULATE   TPUT            TABULATE THE THROUGHPUT TABLE
217         TEST GE    C1,PF5,MSG      IF MORE MSGS TC TYPE GOTO "MSG"
218         LEAVE      MEMRY,PF9       LEAVE MEMORY
219         LEAVE      TERML           IF FINISHED LEAVE THE TERMINAL
220         TERMINATE  0               REDUCE TERMINATICN BY 0
221   DISK  QUEUE      P6              ENTER DISK QUEUE
222         SEIZE      P6              GET DISK
223         DEPART     P6              LEAVE DISK Q.
224         QUEUE      P7              ENTER CHANNEL C.
225         SEIZE      P7              GET CHANNEL
226         DEPART     P7              LEAVE CHANNEL
227         RELEASE    P7              RELEASE CHANNEL
228         ADVANCE    30              DO DISK ACCESS TIME
229         QUEUE      P7              ENTER CHANNEL C.
230         SEIZE      P7              GET CHANNEL.
231         DEPART     P7              LEAVE CHANNEL C.
232         ADVANCE    2               DISK TRANSFER DATA TIME.
233         RELEASE    P6              RELEASE DISK.
234         RELEASE    P7              RELEASE CHANNEL
235         TRANSFER   PF,8,1          RETURN TO THE CALLER.
236         GENERATE   480000          SIMULATE FOR 8 MINUTES
237         TERMINATE  1               REDUCE TERMINATION TIME BY 1
            START      1               PROCESS 1 MESSAGE.
            END
```

```
BLOCK                                                                        STATEMENT
NUMBER *LOC   OPERATION  A,B,C,D,E,F,G,H,I        COMMENTS                    NUMBER
       ****************************************                                  1
       *                                      *                                  2
       *               TABLE                  *                                  3
       *                                      *                                  4
       ****************************************                                  5
        TPUT  TABLE      M1,0,500,50                                             6
       ****************************************                                  7
       *                                      *                                  8
       *             FUNCTIONS                *                                  9
       *                                      *                                 10
       ****************************************                                 11
        PRIOR FUNCTION   PF1,D4                PRIORITY FUNCTION                12
       1,40/2,30/3,10/4,20/                                                     13
        DTAEN FUNCTION   RN3,D4                JOB TYPE                         14
       .4,1/.7,2/.85,3/1.0,4/                                                   15
        EXPON FUNCTION   RN1,C24               EXPONENTIAL FUNCTION             16
       0,0/.1,.104/.2,.222/.3,.355/.4,.509/.5,.69/.6,.915/.7,1.2/.75,1.38       17
       .8,1.6/.84,1.83/.88,2.12/.9,2.3/.92,2.52/.94,2.81/.95,2.99/.96,3.2       18
       .97,3.5/.98,3.9/.99,4.6/.995,5.3/.998,6.2/.999,7/.9997,8                 19
        MEMF  FUNCTION   PF1,D4                MEMORY SIZE                      20
       1,4/2,4/3,56/4,40/                                                       21
        DISK2 FUNCTION   RN2,D2                DISK SELECTION                   22
       .5,51/1.0,52/                                                            23
        DCHNL FUNCTION   RN2,D2                DISK CHANNEL SELECTION           24
       .5,53/1.0,54/                                                            25
        TRNS  FUNCTION   P2,L8                 TRANSPORTATION OVER C. LINE      26
       1,144/2,144/3,144/4,144/5,144/6,144/7,144/8,144                          27
       ****************************************                                 28
       *                                      *                                 29
       *             VARIABLES                *                                 30
       *                                      *                                 31
       ****************************************                                 32
        OVRH1 FVARIABLE  13*P9                 DECNET OVERHEAD 11/34            33
        OVRH2 FVARIABLE  242*P9                DECNET OVERHEAD 11/05            34
        MSGPR FVARIABLE  2-P9                  NUMBER OF MESSAGES               35
        COMPT FVARIABLE  8                     NUMBER OF LABORATORY MACHINES    36
        LINE  FVARIABLE  P1+V$COMPT            COMPUTER LINE                    37
        CHAR  FVARIABLE  (1*FN$EXPON)+1        MESSAGE LENGTH                   38
       ****************************************                                 39
       *                                      *                                 40
       *             STORAGES                 *                                 41
       *                                      *                                 42
       ****************************************                                 43
        TERML STORAGE    32                                                     44
        MEMRY STORAGE    768                                                    45
        BUFF  STORAGE    16                                                     46
  1           GENERATE   ,,,1                  GENERATE ONLY ONE TRANSACTION    47
  2           ENTER      MEMRY,8               SYSTEM ENTERS MEMORY,TAKES 8K    48
  3           TERMINATE  0                     REDUCE TERMINATION BY 0          49
  4           GENERATE   889,FN$EXPON,,,,8PF   GENERATE A MESSAGE               50
  5           ASSIGN     9,K1                  NUMBER OF MESSAGES               51
  6     BIG1  ASSIGN     2,K1                  ASSIGN SAMPLE #                  52
  7           ASSIGN     1,K15                 ASSIGN PDP 11/34 #               53
  8           ASSIGN     3,V$LINE              ASSIGN LINE #                    54
  9           QUEUE      P1                    ENTER PDP 11/34                  55
```

```
10        SEIZE     P1                GET THE CPU               56
11        DEPART    P1                LEAVE POP 11/34 Q         57
12        ADVANCE   V$MSGPR           MSG PREPARATION           58
13        ADVANCE   V$OVRH1           DECNET OVERHEAD           59
14        RELEASE   P1                FREE 11/34                60
15        QUEUE     P3                LINE Q                    61
16        SEIZE     P3                GET THE LINE              62
17        DEPART    P3                LEAVE THE LINE Q          63
18        ADVANCE   FN$TRNS           TRANSPORTATION TIME       64
19        RELEASE   P3                LEAVE THE LINE            65
20        TRANSFER  ,BIG              GO TO BIG                 66
21        GENERATE  889,FN$EXPON,,,,9PF GENERATE A MESSAGE      67
22        ASSIGN    9,K2              NUMBER OF MESSAGES        68
23        ASSIGN    2,K2              ASSIGN SAMPLE #           69
24        ASSIGN    1,K16             ASSIGN POP 11/34 #        70
25        ASSIGN    3,V$LINE          ASSIGN LINE #             71
26        QUEUE     P1                ENTER POP 11/34           72
27        SEIZE     P1                GET THE CPU               73
28        DEPART    P1                LEAVE POP 11/34 Q         74
29        ADVANCE   1                 MSG PREPARATION           75
30        ADVANCE   13                DECNET OVERHEAD           76
31        RELEASE   P1                FREE 11/34                77
32        QUEUE     P3                LINE Q                    78
33        SEIZE     P3                GET THE LINE              79
34        DEPART    P3                LEAVE THE LINE Q          80
35        ADVANCE   FN$TRNS           TRANSPORTATION TIME       81
36        RELEASE   P3                LEAVE THE LINE            82
37        TRANSFER  ,BIG1             GO TO BIG                 83
38        GENERATE  889,FN$EXPON,,,,9PF GENFRATE A MESSAGE      84
39        ASSIGN    9,K2              NUMBER OF MESSAGES        85
40        ASSIGN    2,K3              ASSIGN SAMPLE #           86
41        ASSIGN    1,K17             ASSIGN POP 11/C5 #        87
42        ASSIGN    3,V$LINE          ASSIGN LINE #             88
43        QUEUE     P1                ENTER POP 11/05           89
44        SEIZE     P1                GET THE CPU               90
45        DEPART    P1                LEAVE POP 11/05 Q         91
46        ADVANCE   1                 MSG PREPARATION           92
47        ADVANCE   142               DECNET OVERHEAD           93
48        RELEASE   P1                FREE 11/05                94
49        QUEUE     P3                LINE Q                    95
50        SEIZE     P3                GET THE LINE              96
51        DEPART    P3                LEAVE THE LINE Q          97
52        ADVANCE   FN$TRNS           TRANSPORTATION TIME       98
53        RELEASE   P3                LEAVE THE LINE            99
54        TRANSFER  ,BIG1             GO TO BIG                 100
55        GENERATE  889,FN$EXPCN,,,,9PF GENERATE A MESSAGE      101
56        ASSIGN    9,K1              NUMBER OF MESSAGES        102
57  BIG2  ASSIGN    2,K4              ASSIGN SAMPLE #           103
58        ASSIGN    1,K18             ASSIGN POP 11/34 #        104
59        ASSIGN    3,V$LINE          ASSIGN LINE #             105
60        QUEUE     P1                ENTER POP 11/34           106
61        SEIZE     P1                GET THE CPU               107
62        DEPART    P1                LEAVE POP 11/34 Q         108
63        ADVANCE   V$MSGPR           MSG PREPARATION           109
64        ADVANCE   V$OVRH1           DECNET OVERHEAD           110
65        RELEASE   P1                FREE 11/34                111
66        QUEUE     P3                LINE Q                    112
```

```
67          SEIZE      P3                      GET THE LINE
68          DEPART     P3                      LEAVE THE LINE Q
69          ADVANCE    FN$TRNS                 TRANSPORTATION TIME
70          RELEASE    P3                      LEAVE THE LINE
71          TRANSFER   ,BIG                    GO TO BIG
72          GENERATE   889,FN$EXPCN,,,,9PF     GENERATE A MESSAGE
73          ASSIGN     9,K2                    NUMBER OF MESSAGES
74          ASSIGN     2,K5                    ASSIGN SAMPLE #
75          ASSIGN     1,K19                   ASSIGN PDP 11/34 #
76          ASSIGN     3,V$LINE                ASSIGN LINE #
77          QUEUE      P1                      ENTER PDP 11/34
78          SEIZE      P1                      GET THE CPU
79          DEPART     P1                      LEAVE PDP 11/34 Q
80          ADVANCE    1                       MSG PREPARATION
81          ADVANCE    13                      DECNET OVERHEAD
82          RELEASE    P1                      FREE 11/34
83          QUEUE      P3                      LINE Q
84          SEIZE      P3                      GET THE LINE
85          DEPART     P3                      LEAVE THE LINE Q
86          ADVANCE    FN$TRNS                 TRANSPORTATION TIME
87          RELEASE    P3                      LEAVE THE LINE
88          TRANSFER   ,BIG2                   GO TO BIG
89          GENERATE   889,FN$EXPCN,,,,9PF     GENERATE A MESSAGE
90          ASSIGN     9,K2                    NUMBER OF MESSAGES
91          ASSIGN     2,K6                    ASSIGN SAMPLE #
92          ASSIGN     1,K20                   ASSIGN PDP 11/03 #
93          ASSIGN     3,V$LINE                ASSIGN LINE #
94          QUEUE      P1                      ENTER PDP 11/03
95          SEIZE      P1                      GET THE CPU
96          DEPART     P1                      LEAVE PDP 11/03 Q
97          ADVANCE    1                       MSG PREPARATION
98          ADVANCE    234                     DECNET OVERHEAD
99          RELEASE    P1                      FREE 11/03
100         QUEUE      P3                      LINE Q
101         SEIZE      P3                      GET THE LINE
102         DEPART     P3                      LEAVE THE LINE Q
103         ADVANCE    FN$TRNS                 TRANSPORTATION TIME
104         RELEASE    P3                      LEAVE THE LINE
105         TRANSFER   ,BIG2                   GO TO BIG
106         GENERATE   889,FN$EXPCN,,,,9PF     GENERATE A MESSAGE
107         ASSIGN     9,K1                    NUMBER OF MESSAGES
108   BIG3  ASSIGN     2,K8                    ASSIGN SAMPLE #
109         ASSIGN     1,K21                   ASSIGN PDP 11/05 #
110         ASSIGN     3,V$LINE                ASSIGN LINE #
111         QUEUE      P1                      ENTER PDP 11/05
112         SEIZE      P1                      GET THE CPU
113         DEPART     P1                      LEAVE PDP 11/05 Q
114         ADVANCE    V$MSGPR                 MSG PREPARATION
115         ADVANCE    V$OVRH2                 DECNET OVERHEAD
116         RELEASE    P1                      FREE 11/05
117         QUEUE      P3                      LINE Q
118         SEIZE      P3                      GET THE LINE
119         DEPART     P3                      LEAVE THE LINE Q
120         ADVANCE    FN$TRNS                 TRANSPORTATION TIME
121         RELEASE    P3                      LEAVE THE LINE
122         TRANSFER   ,BIG                    GO TO BIG
123         GENERATE   889,FN$EXPCN,,,,9PF     GENERATE A MESSAGE
```

```
124          ASSIGN      9,K2
125          ASSIGN      2,K7                     ASSIGN SAMPLE #
126          ASSIGN      1,K22                    ASSIGN PDP 8/M
127          ASSIGN      3,V$LINE                 ASSIGN LINE #
128          QUEUE       P1                       ENTER PDP 8/M
129          SEIZE       P1                       GET THE CPU
130          DEPART      P1                       LEAVE PDP 8/M Q
131          ADVANCE     1                        MSG PREPARATION
132          ADVANCE     284                      DECNET OVERHEAD
133          RELEASE     P1                       FREE 8/M
134          QUEUE       P3                       LINE Q
135          SEIZE       P3                       GET THE LINE
136          DEPART      P3                       LEAVE THE LINE Q
137          ADVANCE     FN$TRNS                  TRANSPORTATION TIME
138          RELEASE     P3                       LEAVE THE LINE
139          TRANSFER    ,BIG3                    GO TO BIG
140   BIG    QUEUE       PDP                      ENTER 11/70
141          PRIORITY    5                        TO LAB. MACHINES
142          PREEMPT     CPU                      GET 11/70 CPU
143          DEPART      PDP                      LEAVE 11/70
144          ENTER       BUFF
145          ADVANCE     5                        SWAP TASKS
146          ADVANCE     9                        CPU USAGE ON THE 11/70
147          RETURN      CPU                          FREE 11/70 CPU
148          ASSIGN      6,FN$DISK2,PF            SELECT A DISK
149          ASSIGN      7,FN$DCHNL,PF            SELECT A CHANNEL
150          TRANSFER    SBR,DISK,8PF
151          LEAVE       BUFF
152          TERMINATE   0
153          GENERATE    8000,FN$EXPCN,,,,9PF     USER ARRIVAL
154          ASSIGN      1,FN$DTAEN,PF            ASSIGN JOB TYPE
155          ASSIGN      9,FN$MEMF,PF             ASSIGN THE SIZE OF THE JOB
156          ASSIGN      6,FN$DISK2,PF            SELECT A DISK
157          ASSIGN      7,FN$DCHNL,PF            SELECT A CHANNEL
158          PRIORITY    FN$PRIOR                 FIND THE PRIORITY FOR THE JOB
159          ASSIGN      5,60000,3,PF            TIME NEEDED TO TYPE ALL MESSAGES
160          ASSIGN      5+,C1,PF                 ADD THE ABOVE VALUE TO CLOCK
161          QUEUE       TER                      LINE UP FOR TERMINAL
162          ENTER       TERML                    GET A TERMINAL TO USE
163          DEPART      TER                      LEAVE THE LINE
164          QUEUE       MEM                      JOB WAITS TO ENTER THE MEMORY
165          ENTER       MEMRY,PF9                JOB ENTERS MEMORY
166          DEPART      MEM                      LEAVE THE WAITING LINE
167   MSG    ASSIGN      2,V$CHAR,PF              ASSIGN # OF CHARACTERS IN JOB
168   TYPE   ADVANCE     250                      TYPE THE CHARACTER
169          ADVANCE     6                        SEND THE CHAR TO INPUT CHANNEL
170          QUEUE       ICHNL                    LINE UP FOR INPUT CHANNEL
171          SEIZE       CHANL                    SEIZE THE I/CHANNEL
172          DEPART      ICHNL                    LEAVE THE LINE
173          ADVANCE     1                        SEND THE CHARACTER TO CPU
174          RELEASE     CHANL                    LEAVE THE INPUT CHANNEL
175          ASSIGN      2-,1,PF                  TAKE OFF 1 CHARACTER
176          TEST LE     PF2,0,TYPE               IF MORE CHAR LEFT GOTO TYPE
177          MARK                                  MARK THE TIME
178          TEST NE     PF1,3,FORT               IF FORTRAN THEN GOTO "FORT"
179          TEST NE     PF1,2,DEDIT              IF DATA EDITING THEN GOTO "DEDIT
180          TEST NE     PF1,1,DENTR              IF DATA ENTRY THEN GOTO "DENTR"
```

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181   BASIC ASSIGN    3,40,3,PF      COMPUTE CPU TIME                  227
182         QUEUE     JOB            QUEUE FOR CPU                     228
183         SEIZE     CPU            GET THE CPU                       229
184         DEPART    JOB               DEPART THE QUEUE               230
185         ADVANCE   5              TASK SWITCH OVERHEAD              231
186         ADVANCE   PF3            PROCESS THE MESSAGE               232
187         RELEASE   CPU            END PROCESSING                    233
188         TRANSFER  ,COMP          GO TO "COMP"                      234
189   FORT  ASSIGN    3,90,3,PF      COMPUTE CPU TIME                  235
190         QUEUE     JOB            QUEUE FOR CPU                     236
191         SEIZE     CPU            GET THE CPU                       237
192         DEPART    JOB               DEPART THE QUEUE               238
193         ADVANCE   5              TASK SWITCH OVERHEAD              239
194         ADVANCE   PF3            PROCESS THE MESSAGE               240
195         RELEASE   CPU            END PROCESSING                    241
196         TRANSFER  ,COMP          GOTO COMP                         242
197   DENTR ASSIGN    3,15,3,PF      COMPUTE CPU TIME                  243
198         QUEUE     JOB            QUEUE FOR CPU                     244
199         SEIZE     CPU            GET THE CPU                       245
200         DEPART    JOB               DEPART THE QUEUE               246
201         ADVANCE   5              TASK SWITCH OVERHEAD              247
202         ADVANCE   PF3            PROCESS THE MESSAGE               248
203         RELEASE   CPU            END PROCESSING                    249
204         TRANSFER  SBR,DISK,8PF   GOTO USE THE DISK                 250
205         TRANSFER  ,COMP          GOTO "COMP"                       251
206   DEDIT ASSIGN    3,30,3,PF      COMPUTE CPU TIME                  252
207         TRANSFER  SBR,DISK,8PF   GOTO USE THE DISK                 253
208         QUEUE     JOB            QUEUE FOR CPU                     254
209         SEIZE     CPU            GET THE CPU                       255
210         DEPART    JOB               DEPART THE QUEUE               256
211         ADVANCE   5              TASK SWITCH OVERHEAD              257
212         ADVANCE   PF3            PROCESS THE MESSAGE               258
213         RELEASE   CPU            END PROCESSING                    259
214         TRANSFER  SBR,DISK,8PF   GOTO USE THE DISK                 260
215   COMP  ADVANCE   1              SEND THE MSG TO OUTPUT CHANNEL    261
216         ASSIGN    4,V$CHAR,PF    ASSIGN # OF CHAR IN OUTPUT MSG    262
217   OUT   QUEUE     OCHNL          QUEUE FOR OUTPUT CHANNEL          263
218         SEIZE     CHANL          GET THE CHANNEL                   264
219         DEPART    OCHNL          LEAVE THE QUEUE                   265
220         ADVANCE   1              THE CHARACTER IS QUEUED UP        266
221         RELEASE   CHANL          LEAVE THE CHANNEL                 267
222         ADVANCE   6              SEND THE CHAR TO THE TERMINAL     268
223         ASSIGN    4-,1,PF        TAKE OFF ONE CHARACTER            269
224         TEST LE   PF4,0,OUT      IF MORE CHAR LEFT GOTO OUT        270
225         TABULATE  TPUT           TABULATE THE THROUGHPUT TABLE     271
226         TEST GE   C1,PF5,MSG     IF MORE MSGS TO TYPE GOTO "MSG"   272
227         LEAVE     MEMRY,PF9      LEAVE MEMORY                      273
228         LEAVE     TERML          IF FINISHED LEAVE THE TERMINAL    274
229         TERMINATE 0              REDUCE TERMINATION BY 0           275
230   DISK  QUEUE     P6             ENTER DISK QUEUE                  276
231         SEIZE     P6             GET DISK                          277
232         DEPART    P6             LEAVE DISK Q.                     278
233         QUEUE     P7             ENTER CHANNEL C.                  279
234         SEIZE     P7             GET CHANNEL                       280
235         DEPART    P7             LEAVE CHANNEL                     281
236         RELEASE   P7             RELEASE CHANNEL                   282
237         ADVANCE   30             DO DISK ACCESS TIME               283
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238        QUEUE       P7          ENTER CHANNEL C.                              284
239        SEIZE       P7          GET CHANNEL.                                  285
240        DEPART      P7          LEAVE CHANNEL C.                              286
241        ADVANCE     2           DISK TRANSFER DATA TIME.                      287
242        RELEASE     P6          RELEASE DISK.                                 288
243        RELEASE     P7          RELEASE CHANNEL                               289
244        TRANSFER    PF,8,1      RETURN TO THE CALLER.                         290
245        GENERATE    480000      SIMULATE FOR 8 MINUTES                        291
246        TERMINATE   1           REDUCE TERMINATION TIME BY 1                  292
           START       1           PROCESS 1 MESSAGE.                            293
           END                                                                   294
```

Appendix 3

THE RESULTS

	1st RUN	2nd RUN	3rd RUN	4th RUN	5th RUN	AVG.
11/70 CPU Utilization	.6	.593	.527	.451	.451	.524
Avg. # Active Users	8.48	7.58	8.28	6.35	5.93	7.32
Avg. 11/70 Job Queue Length	.693	.706	.646	.359	.412	.563
Mean Response Time (Sec.)	.133	.129	.134	.117	.108	.124
# Commands Completed	7533	6754	7294	5434	5855	6574

Single Machine

	1st RUN	2nd RUN	3rd RUN	4th RUN	5th RUN	AVG.
11/70 CPU Utilization	.57	.502	.563	.542	.629	.561
Avg. # Active Users	7.49	5.36	6.73	7.82	7.96	7.07
Avg. 11/70 Job Queue Length	.61	.532	.584	.741	.744	.642
Mean Response Time (Sec.)	.135	.146	.130	.146	.133	.138
Avg. # Commands Completed	6658	4684	5961	6731	7051	6217
# Messages Processed	1637	1597	1607	1540	1619	1600

Phase I
Star Configuration

	1st RUN	2nd RUN	3rd RUN	4th RUN	5th RUN	AVG.
11/70 CPU Utilization	.52	.469	.538	.62	.49	.527
Avg. # Active Users	6.37	4.87	5.93	7.68	5.88	6.14
Avg. 11/70 Job Queue Length	.404	.372	.543	.709	.344	.474
Mean Response Time (Sec.)	.122	.135	.137	.158	.118	.134
# Commands Completed	5804	4311	5205	6523	5358	5440
# Messages Processed	3260	3208	3169	3211	3221	3214

Phase II
Star Configuration

	1st RUN	2nd RUN	3rd RUN	4th RUN	5th RUN	AVG.
11/70 CPU Utilization	.584	.623	.542	.607	.548	.581
Avg. # Active Users	7.07	7.69	6.10	7.25	5.85	6.79
Avg. 11/70 Job Queue Length	.569	.693	.556	.559	.505	.576
Mean Response Time (Sec.)	.133	.145	.135	.151	.131	.139
# Commands Completed	6333	6698	5413	6189	5245	5976
# Messages Processed	4268	4379	4210	4289	4313	4292

Phase III
Star Configuration

	1st RUN	2nd RUN	3rd RUN	4th RUN	5th RUN	AVG.
11/70 CPU Utilization	.495	.584	.561	.561	.573	.555
Avg. # Active Users	5.16	6.13	6.14	6.54	6.82	6.16
Avg. 11/70 Job Queue Length	.324	.477	.497	.47	.53	.46
Mean Response Time (Sec.)	.138	.138	.137	.138	.127	.136
# Commands Completed	4549	5442	5410	5713	6110	5445
# Messages Processed	4356	4391	4248	4282	4326	4321

Hierarchical Configuration

SIMULATION OF A FUNCTIONALLY DISTRIBUTED COMPUTING FACILITY

by

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B.S. Pittsburg State University, Pittsburg, 1977

AN ABSTRACT OF A MASTER'S REPORT

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MASTER OF SCIENCE

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1979

ABSTRACT

This report is a simulation study of a functionally distributed computing facility to determine the performance characteristics of several network configurations for application in a biomedical research environment at the U.S. Air Force School of Aerospace Medicine.

Five simulation network models have been constructed. An initial model of the network serves as the baseline for comparing the results of the rest of the network models; it also has been verified by a theoretical queuing network model. The two network configurations which are used in this study are star and hierarchical. The star configuration was modelled for four, seven and nine processors in the network, and the hierarchical configuration has been constructed with nine processors.

The performance of the two configurations has been compared and the star configuration was chosen as the better network configuration for the environment.