To the Graduate Council:

I am submitting herewith a thesis written by David B. Kennamer entitled "A Simulation Model of a Hospital Information System." I recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Industrial Engineering.

D. H. Hutchinson
Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:

Vice Chancellor
Graduate Studies and Research

A SIMULATION MODEL OF A HOSPITAL INFORMATION SYSTEM

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee

David B. Kennamer

March 1975

ABSTRACT

This study proposes that a computer simulation model can be constructed of a hospital real-time information system. The model can help the analyst in (1) specifying the system design and configuration, (2) studying utilization of the facilities, (3) observing the extent of queue formation, and (4) discovering problems with excessive response time.

The model is a discrete event simulation. The General Purpose Simulation System/360 language is used as a tool in the construction of the model. The system modeled is hypothetical and is not intended to represent any commercially available package.

The data used in the model was obtained at a 400 bed acute care hospital. The statistics were collected and assembled for example purposes.

This study is significant in that the technique of simulating a hospital information system has not been previously reported in the literature. The model allows the analyst to observe operational problems with the system before it is installed. Experiments can be performed with different design configurations at varying levels of transaction input.

1197646

TABLE OF CONTENTS

CHAPTER		PAGE
I.	INTRODUCTION	1
	Statement of the Problem	2
	Scope of the Study	3
	Selection of a Simulation Language	4
II.	LITERATURE REVIEW	6
	Introduction	6
	Technical Design and Evaluation Techniques Used	9
	Use of Simulation as a Tool for System Design	10
	Chapter Summary	12
III.	DEFINITION OF THE MODEL	14
	Introduction	14
	General Description of the Configuration	14
	Units of Traffic	18
	Data Base Files	22
	Functional Description of the System	22
	Assumptions	77
	Chapter Summary	78

CHAPTER PAGE

IV. SIMULATION OF THE SYSTEM 79

Introduction 79

Description of Input Parameters 79

Mean Interarrival Time Switch 88

Simulation of Area Stations 89

Length of the Simulation Run 106

Chapter Summary 107

V. VERIFICATION AND STABILITY OF THE MODEL 109

Introduction 109

Verification of the Model Construction 109

Startup and Stability of the Model 113

Chapter Summary 116

VI. RESULTS FROM THE MODEL 117

Introduction 117

Sensitivity of the Model 117

Data File Operations 124

Volume of Transactions 127

Analysis of Queueing in Admitting 127

Response Time for Terminals 129

Chapter Summary 131

VII. CONCLUSIONS 132

Construction of the Model 132

Recommendations for Future Research 133

BIBLIOGRAPHY 135

CHAPTER PAGE

APPENDIX 141

VITA 174

LIST OF TABLES

TABLE		PAGE
I.	Identification of Modeled Data Files	23
II.	Probability of Admission to Nursing Units	26
III.	Admitting Office Input Transaction Specifications	27
IV.	Distribution of Admitting Office Transaction Types	29
V.	Goodness of Fit Tests for Admitting Transaction Interarrivals	32
VI.	Probability of Transaction Occurrence in Emergency Room	34
VII.	Emergency Room Input Transaction Specifications	36
VIII.	Goodness of Fit Tests for Emergency Room Transaction Interarrivals	39
IX.	Goodness of Fit Tests for Laboratory Order Processing Times	41
X.	Central Supply Transaction Specifications . .	45
XI.	Goodness of Fit Tests for Central Supply Transaction Interarrivals	48
XII.	Pharmacy Input Transaction Specifications . .	50

TABLE		PAGE
XIII.	Goodness of Fit Tests for Pharmacy Transaction Interarrivals	53
XIV.	Radiology Input Transaction Specifications	55
XV.	Goodness of Fit Tests for Radiology Transaction Interarrivals	58
XVI.	Physical Therapy Input Transaction Specifications	61
XVII.	Goodness of Fit Tests for Physical Therapy Transaction Interarrivals	64
XVIII.	Goodness of Fit Tests for Surgery Case Interarrivals	67
XIX.	Probability of Transaction Occurrence in Surgery	69
XX.	Surgery Input Transaction Specifications	70
XXI.	Nursing Input Transaction Specifications	71
XXII.	Distribution of Transaction Types from Nursing	72
XXIII.	Mean Interarrival Time for Transactions by Hour of Day at Nursing Units	75
XXIV.	Goodness of Fit Tests for Nursing Unit Transaction Interarrivals	76
XXV.	Definition of Transaction Parameters	81
XXVI.	Comparison of Simulation Versus Actual Data	112

TABLE PAGE

XXVII. Sensitivity of Input Terminal Utilization 119

XXVIII. Sensitivity of Queue Formation at Input Terminals 120

XXIX. Sensitivity of Printer Terminal Utilization 122

XXX. Sensitivity of Queue Formation at Printer Terminals 123

XXXI. Data File Read/Write Operations 126

XXXII. Transaction Volumes by Origin and Type 128

XXXIII. Analysis of Queue Formation at Admitting Cathode Ray Tubes--70 Patient Admission Level 130

LIST OF FIGURES

FIGURE		PAGE
1.	Schematic Diagram of Computer Hardware Element Relationships	16
2.	Schematic Diagram of the Model Configuration	19
3.	Pictorial Representation of Activities Resulting From a Transaction Entry	21
4.	Frequency Distribution of Admitting Office Transaction Interarrival Times	30
5.	Profile of Mean Interarrival Times for Admitting Office Transactions	31
6.	Frequency Distribution of Emergency Room Case Interarrival Times	37
7.	Profile of Mean Interarrival Times for Emergency Room Cases	38
8.	Frequency Distribution of Laboratory Test Completion Times	42
9.	Frequency Distribution of CSR Transaction Interarrival Times	46
10.	Profile of Mean Interarrival Times for Central Supply Transactions	47

FIGURE PAGE

11. Frequency Distribution of Pharmacy Transaction Interarrival Times 51
12. Profile of Mean Interarrival Times for Pharmacy Transactions 52
13. Frequency Distribution of Radiology Transaction Interarrival Times 56
14. Profile of Mean Interarrival Times for Radiology Transactions 57
15. Frequency Distribution of Physical Therapy Transaction Interarrival Times 62
16. Profile of Mean Interarrival Times for Physical Therapy Transactions 63
17. Frequency Distribution of Surgery Case Completion Interarrival Times 65
18. Profile of Mean Interarrival Times for Surgery Cases 66
19. Frequency Distribution of Nursing Transaction Interarrival Times 73
20. GPSS Representation of the Admitting Office Interarrival Time Distribution 83
21. Schematic Diagram of the Simulation Logic for the Admitting Office 91
22. Schematic Diagram of the Simulation Logic for the Emergency Room 92

FIGURE PAGE

23. Schematic Diagram of the Simulation Logic for Laboratory and Radiology 96

24. Schematic Diagram of the Simulation Logic for Central Supply 97

25. Schematic Diagram of the Simulation Logic for Surgery 99

26. Schematic Diagram of the Simulation Logic for Nursing Stations 102

27. Schematic Diagram of the Simulation Logic for the Computer Processor 104

28. Message Processing as a Function of Throughput 105

29. Total Current Transactions in the System at Thirty Minute Intervals 114

30. Distribution of CPU Transaction Interarrivals . . 125

CHAPTER I

INTRODUCTION

A large hospital can be viewed as a complex industrial operation. Usually, a single product or a small variety of similar products are produced in an industrial plant. A hospital differs in that it is a network of several industries operating as single entities yet requiring extreme coordination.

Each department of a hospital such as Laundry, Dietary, Laboratory, Radiology, Surgery, or Nursing could be considered a subsystem. Each subsystem requires specific input information in order to function. The information may be destroyed, stored in a file, or output to another subsystem in its original or altered state. Hospitals are said to be notorious for their high volume of forms, memos, or telephone communications that transport information and patient data.

It is reported in the literature that by 1961 computerized hospital information systems were being developed. Today, there are at least thirteen hospital systems commercially available (3, p. 51). When the hospital's administrative staff feels a possible need for an automated data processing and communication system, they

usually begin their investigation by talking with computer manufacturers and looking at hardware.

Statement of the Problem

The administrators eventually find themselves in a confused situation. Each computer manufacturer naturally claims, and in some fashion justifies, his system to be superior to all others and exactly what the hospital needs. This study proposes that hospitals should first determine their own information and communication needs on the basis of inputs and outputs from the various subsystems or departments therein. Furthermore, the study proposes that a simulation model can be used as a design tool in specifying system requirements. It is hypothesized that the construction and use of a simulation model will allow the user to:

1. Itemize each piece of information or transaction needed to go into the system based on desired output.
2. Specify the volumes of each transaction.
3. Estimate the extent of queueing during peak usage periods and thus anticipate the number of input/output terminals required.
4. Observe the probable utilization of each piece of equipment in the system.

5. Determine the response time expected during peak periods, in other words, the time between transaction input and result output.

From the study, the hospital administrative staff should have a clearer picture of its information and hardware needs, the extent to which hardware will be used, and a set of quantitative specifications describing for the manufacturer the desired results.

Scope of the Study

The study will begin with a review of the literature related to hospital information systems and simulation used to model real-time computer configurations. It will be assumed that the hospital being considered has completed a documentation and analysis of its information needs. Chapter Three will deal with the identification of transactions which can be input to or output from the communication and data collection system. It will also describe the hardware equipment types and configuration that is to be experimented with and evaluated. The collection of data needed to describe the system quantitatively will be discussed. Chapter IV outlines the computer program needed for the simulation. Verification and stability of the model will be discussed in Chapter V. In Chapter VI, experiments will

be made with the model to study throughput, queueing, response time, utilization, and sensitivity.

The system will not intentionally represent any commercially available package. It will be a hypothetical but realistic model demonstrating the use of simulation in studying a computer functionally before its installation.

The study will deal with the design of a system from a macroscopic rather than a microscopic viewpoint. The time units involved in the model will be one-tenth second. Time units such as milliseconds used in specifying internal computer read, write, and arithmetic operations are negligible to the user and will be considered insignificant.

Although simulation is not considered the major issue in itself, instructions will be recommended for changing the simulation program to vary the number of terminals or printers. So that the model can be used and experimented with, the procedure for collecting and transposing data into a usable form will be discussed.

No attempt will be made to specify record layouts or application program logic to process input transactions.

Selection of a Simulation Language

In the proposed study, the main entities of interest will be the extent of queueing at the input terminals, the

utilization of hardware facilities, and the response time for transactions entered during peak usage periods.

IBM's General Purpose Simulation System/360 (GPSS) language is suited for studying the above factors. Furthermore, it is said to be especially applicable to the modeling of computer systems. It is anticipated that the simulation program will consist basically of a series of QUEUE, SEIZE, ADVANCE, and TRANSFER blocks and should be fairly straightforward after the conceptual model has been designed and transactions defined.

CHAPTER II

LITERATURE REVIEW

Introduction

In recent issues of hospital journals, many articles have appeared discussing hospital computer applications. Of these articles, most have dealt with experiences that various engineers, consultants, department heads, and administrators have had in centralized computer applications and not with planning and design. For example, P. W. Rathburn has reported the use of teletype terminals in the Admitting Office for providing all concerned hospital departments with an up-to-date bed census (12, p. 69).

Several articles have been written dealing with computer planned menus. One author noted the use of linear programming in selecting foods for menus in order to obtain certain minimal levels of scarce or expensive nutrients (15, p. 92). Platiau, Gallina, and Jeffery published an article on an accounting and drug utilization system in the Pharmacy. They describe a card system rather than a real-time communication subsystem (42, p. 90).

Another category of articles in the literature on the subject of hospital information systems has been reports of

hardware on the market. Marion J. Ball of Temple University in Philadelphia has published two such articles. First, she presented a paper "HIS: A Status Report" on the history of real-time information system development, a case study at a Miami hospital, and a table comparing vendor packages which are available (3, p. 48).

Smith published an article on a particular vendor system called REACH. His discussion dealt only with descriptions of the cathode ray tube input/output terminals and a summary of department functions performed by the system (51, p. 94).

Several articles have been published in the literature concerning design and planning of hospital information systems, but these have generally been of a nontechnical nature. This fact is probably due to the medically oriented audience reading the hospital literature. R. B. Kittle, of W. D. Fuller and Associates, a California consulting firm, has published one of the better articles (30, p. 102). He states that a hospital should undertake an intensive study of its information processing requirements before considering computer hardware. Kittle suggests that a hospital can be divided into nine elements: Nursing Units, Medical Staff, Ancillary Service-diagnosis, Ancillary Service-treatment, Admitting, Administration/Business Office, Hospital Service Operations (maintenance and food services), Medical Records,

and Community Interface (governmental agencies, professional groups, and insurance agencies). He recommends that each element be considered an information processing center. By studying these elements, he states that the bulk of the information requirements can be identified.

Gillette, Rathburn, and Wolfe take an approach similar to Kittle's (19, p. 45). They define the total system in terms of eight management functions:

1. Patient treatment subsystem
2. Patient record subsystem
3. Patient scheduling subsystem
4. Patient accounting and ordering subsystem
5. General accounting subsystem
6. Personnel subsystem
7. Supportive subsystem
8. Control subsystem

The article is one of few that reports a master plan for staffing the system development team, determining operational problems, documenting information needs, specifying subsystems to be implemented, and setting priorities and time constraints on subsystem installations. As a result of Gillette's study, a modular subsystem approach was recommended rather than an integrated total information or communication system.

Hospital literature has been found to contain a number of descriptions of modular computer systems and hardware characteristics. Few good systems approaches have been presented for designing and planning real-time hospital information systems. The articles that have dealt with this latter subject have been only sketches and philosophies of supposedly detailed studies.

Technical Design and Evaluation Techniques Used

Two examples of technical design and evaluation techniques were found. One article by S. D. Pomrinse, in Hospitals, discusses a four phase model for evaluating expected operating characteristics of various package systems proposed to hospitals (44, p. 76). The model consists of studying terminal utilization, user queueing, computer loading, and cost analysis. The model is in no way a simulation but is said to "depict the real world of the hospital in mathematical terms." The model is a computer program into which parameters characterizing vendor packages can be input.

Saul Stimler's text Real-time Data-processing Systems is subtitled A Methodology for Design and Cost Performance Analysis (53). The book does not deal specifically with hospitals but does present manual evaluation techniques that are applicable. Stimler's points of interest in measuring system performance are similar to those studied in this

paper. First, Stimler recommends the study of message inputs at the terminal stations. Second, he studies throughput-rate capability and defines throughput as the number of messages per hour that can be processed. Finally, he studies response time. Unlike the study for evaluating configurations proposed here, Stimler uses basic queueing models and develops mathematical throughput equations in his methodology.

Use of Simulation as a Tool for System Design

James Martin, in Design of Real-Time Computer Systems, states that simulation is "one of the most powerful tools that can be used in estimating the requirements of a system" (33). He includes a short GPSS model of a three disk pack file system and simulates messages arriving to access the files.

Murdick and Ross recommend the use of simulation as a tool in system design and state that it has an "advantage in permitting evaluation of the system against the criteria of gross-design performance specifications" (36). The authors do not explicitly mention the use of computer simulation. Instead, they discuss the Monte Carlo method of manual simulation in a rough step by step manner. The simulation of large systems using this technique would be laborious to perform and even more costly than computer simulation.

J. F. Thorne discusses some important considerations which must be made in designing real-time as opposed to batch processing systems (55, p. 36). He notes six specific problem areas:

1. Core and file size
2. Processing time
3. Channel utilization
4. Communication line utilization
5. Terminal utilization
6. Capability of terminal operators

Thorne recommends the use of three techniques in studying real-time system characteristics; probability theory, queueing theory, and simulation. He states that simulation, although complicated, can be used as a design tool for system estimates.

An extensive literature search was conducted and documented at the Wuesthoff Memorial Hospital in Rockledge, Florida in 1972 (39). The following sources were searched: USPHS Research Grant Index, U. S. Government Research and Development Reports, Abstracts of Hospital Management Studies, the Medical Literature Analysis and Retrieval System, the Defense Documentation Center, the Department of Commerce National Technical Information Service, the National Aeronautics and Space Administration automated literature search, current periodicals, and published books

and their bibliographies. More than one million articles were screened. Less than three thousand of these were found to deal with the subject of computer systems in hospitals.

In reviewing this search, it was found that only four articles of the three thousand included in the document pertained to the simulation of hospital systems. These models dealt with outpatient clinic, maternity ward, surgery, radiology, and admission-discharge systems. None of the models dealt with the simulation of hospital computerized information systems.

Chapter Summary

Hospital literature contains a large number of articles dealing with experiences users have had with computerized information systems. Several authors have written "state-of-the art" reports as well as descriptions of specific vendor packages available. Few technical articles have been written concerning quantitative approaches used in designing and evaluating the use of computer systems in hospitals.

Simulation has been said to be a good tool for studying important aspects of real-time computer systems. The hospital literature contains reports of simulation used to model operational activities in various hospital departments.

Reports cannot be found where simulation was used to model a hospital information system.

CHAPTER III

DEFINITION OF THE MODEL

Introduction

In this chapter, an overview of the computer hardware configuration and applications for a hospital data collection and communication system will be presented. A general description of the types and quantities of equipment being considered for use is first discussed. This is followed by a functional description of the system with respect to the sequence of activities in each hospital department. The assumptions that are made in order to develop the simulation model are stated.

General Description of the Configuration

Computer Hardware Elements

A real time data collection and communication system may be configured in various ways depending upon its applications and methods of data entry desired. The basic hardware would consist of a central processing unit (CPU), a memory, data channels, and a variety of peripheral devices. Remote input and output terminals are characteristic of real

time systems. These devices allow entry of data, messages, or inquiries at the source of their origin.

The CPU is the system's control facility. Its function is to transfer data between main memory and registers, to perform arithmetic and logical operations on data, to execute instructions, and to start the flow of data between main memory and peripheral devices.

The main memory, often called core, is used to hold instructions and data during the execution of a program. Data can be transferred to the CPU from memory in micro-seconds.

Data channels control the transfer of data between input and output devices and memory. They relieve the CPU from the need to communicate directly with input/output devices. This provides for better CPU utilization in that one program can be executing while another is waiting to receive or send data to a terminal. The relationship between these hardware elements is shown in Figure 1.

Peripheral devices are facilities in which data can be input to and output from the central processor or stored in masses. The major peripheral elements are card readers, high speed line printers, card punches, disk drives, tape drives, drums, remote input terminals, and remote character printers. Since this simulation model deals mainly with the

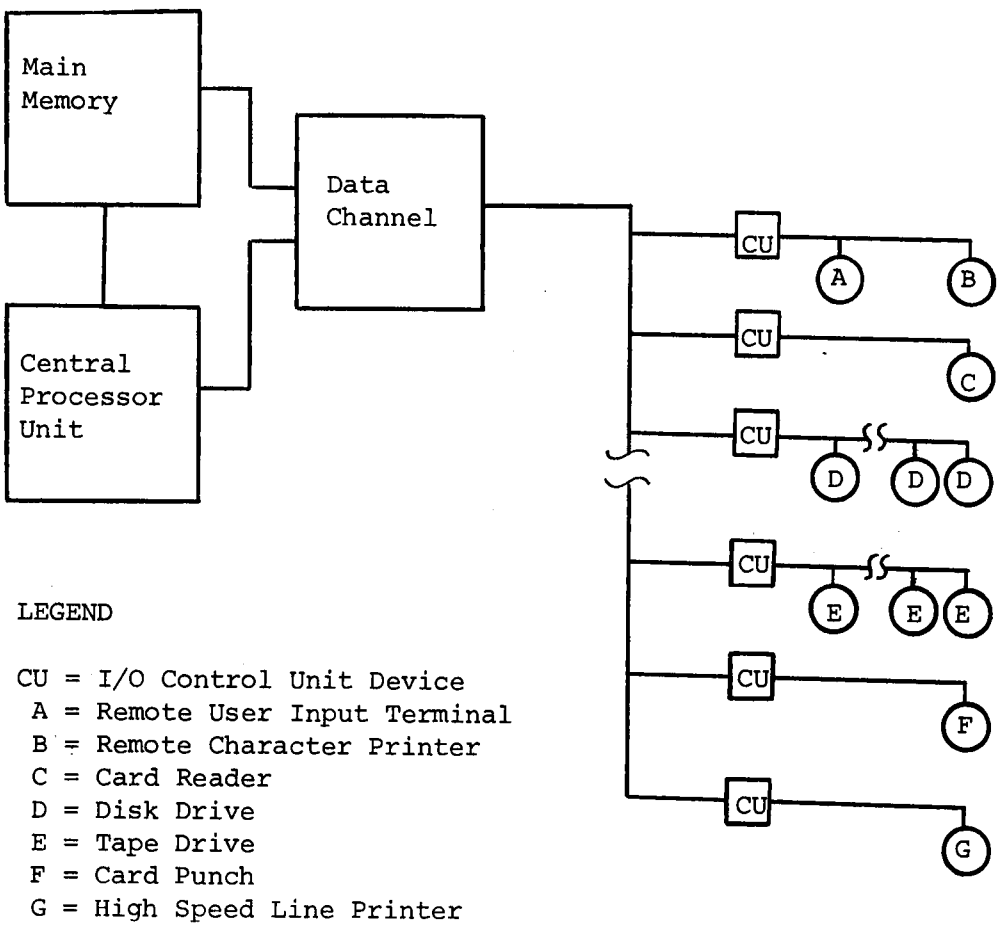

Figure 1. Schematic diagram of computer hardware element relationships.

Source: Principles of Operation IBM System/360. File No. S360-01, Form GA22-6821-8, November 1970, p. 7.

latter two elements, the specific types of terminals used in the model are described below.

1. Character printers are typewriter like devices without keyboards. They provide output of data in low volumes at speeds of six to fourteen characters per second.
2. Cathode ray tubes consist of a typewriter keyboard for input and a screen for visual display of data. When entering data, the user may be guided through each transaction by a series of formats or questions appearing on the screen.
3. Card entry units are terminals which provide for input of data contained on prepunched 80 column cards or data which can be represented completely by a series of numeric digits. A file of prepunched cards is provided at terminals for all possible transaction types. Each card is fed into a slot in the terminal manually and transmits a single charge, order, or message. A series of lights guide the user through each transaction. A set of ten keys is provided on the terminal with digits zero through nine. This allows entry of the numeric data such as patient account numbers.

Configuration of the Model

The central hardware will include, as previously stated, a CPU, data channels, a memory unit, one or more disk drives, one or more tape drives, and a high speed line printer.

For the purposes of this simulation, three different types of terminals will be modeled. Figure 2 depicts the overall configuration of the hardware to be used. It shows the location of terminals, with respect to hospital departments, the types of terminals, and the facility identification numbers used in the simulation program. Note also that the potential queues at each facility have been assigned identification numbers. In all cases, facilities with even numbers are output devices and facilities with odd numbers are input devices. The same implication holds true for queues.

Units of Traffic

Transactions

The units of traffic which flow through the model will be referred to as transactions. A transaction is a single function or inquiry at a data input terminal. There is one exception to this definition. In the Emergency Room a patient's visit is represented as a parent transaction. The entity to enter the system will be an offspring from the

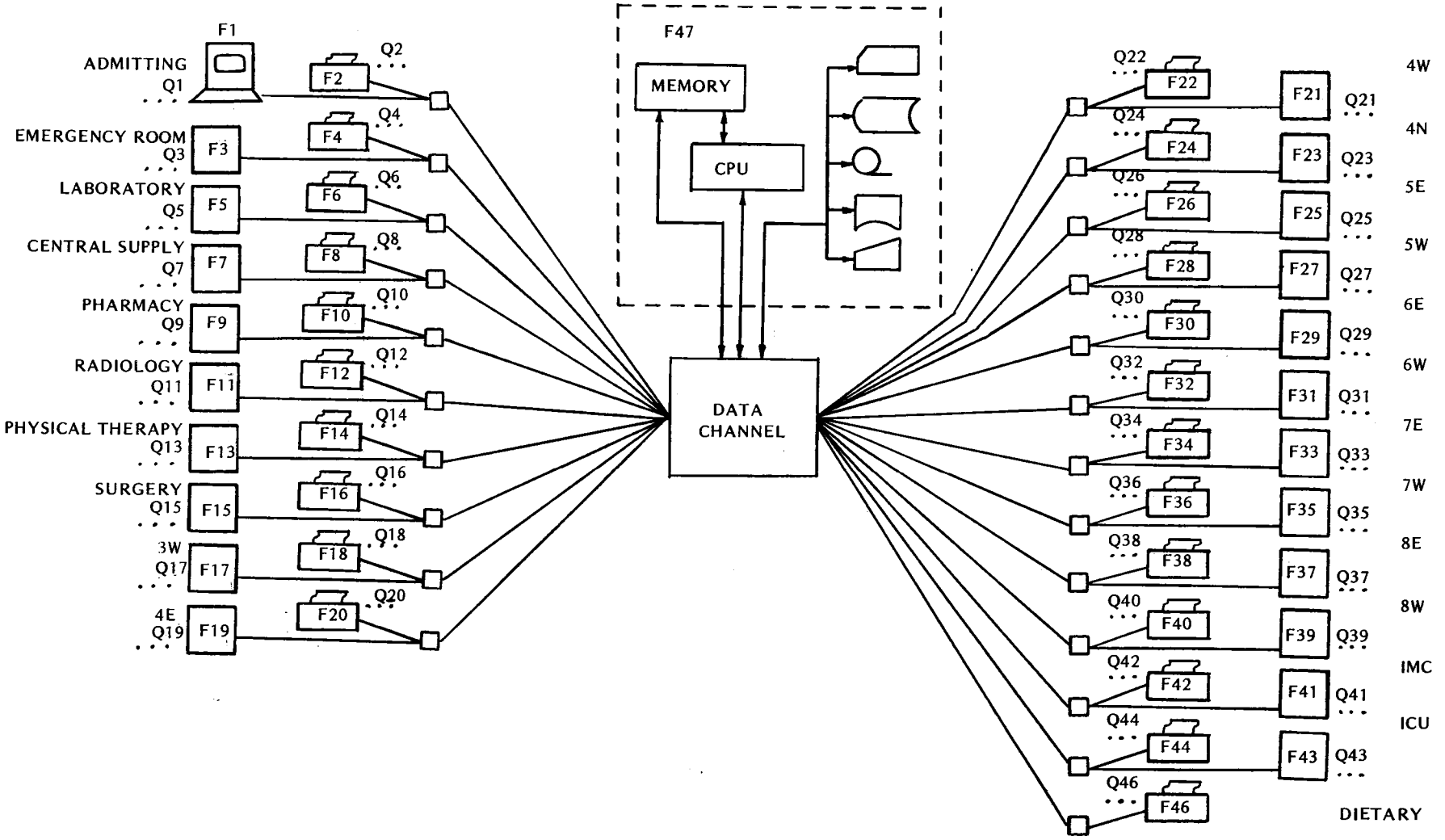

Figure 2. Schematic diagram of the model configuration.

parent transaction. Transactions entered into the system result from some external occurrence at a hospital department. These occurrences may consist of a doctor calling the Admitting Office to preadmit a patient, a doctor requesting a nurse to order medications, or a charge being made for a surgical procedure. The interarrival times for the transactions are random variables. Each different type of transaction will be represented by a punch card in departments that use card entry terminals. In departments that use cathode ray tubes, a listing of all transactions which are to be entered into the system can be displayed on the CRT screen. Operators then select the type of transaction they wish to enter.

Simply stated, a transaction is a piece of work which is submitted to the information system for processing or delivery to another department. The transaction enters the system as soon as it originates. This entrance may be to a queue or directly into a terminal if there is no queue. The transaction then flows through the system in a predefined manner based upon its programmed function. The same basic activities occur at each department in which remote terminals are located. These activities are shown for the Admitting Office in Figure 3.

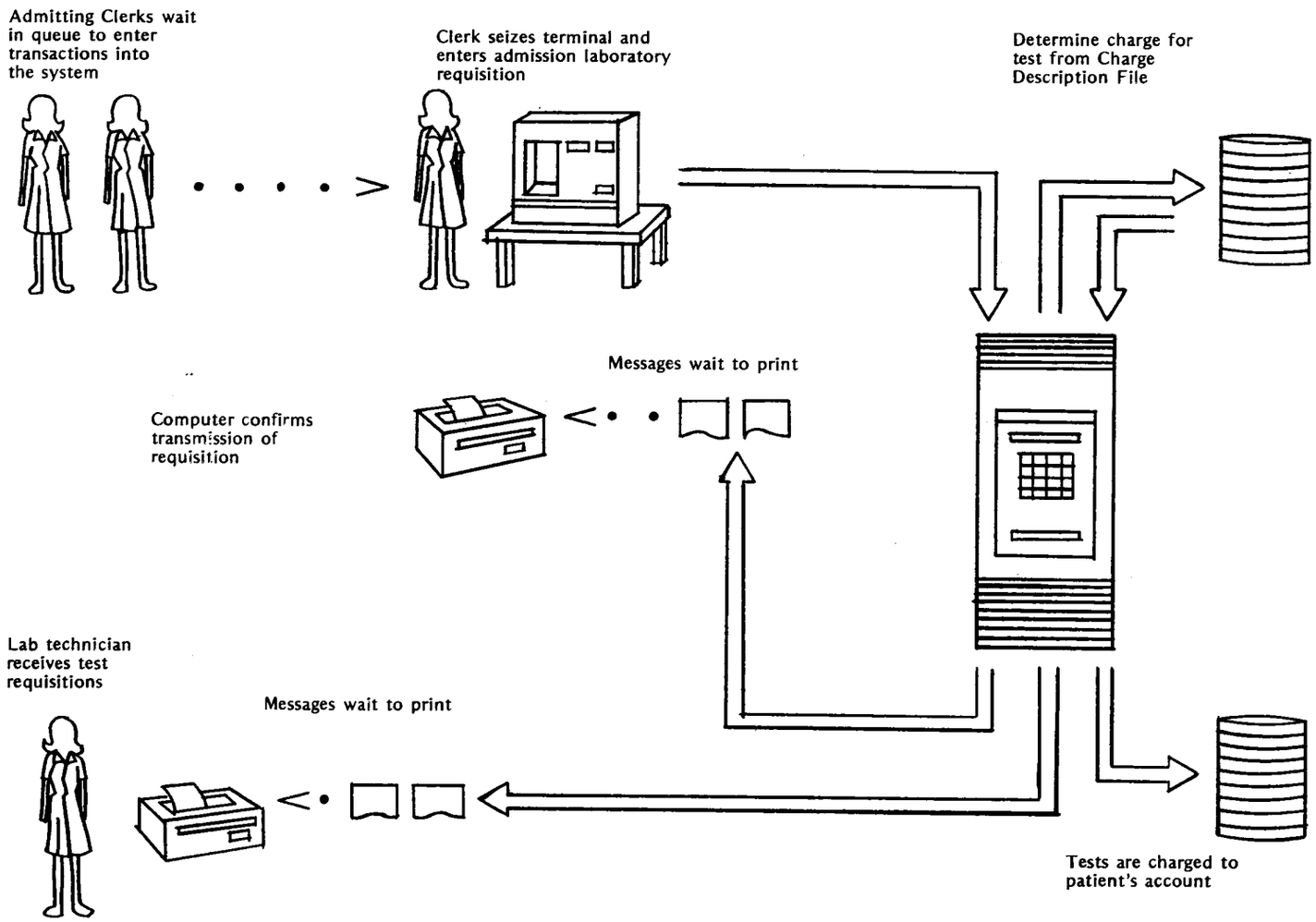

Figure 3. Pictorial representation of activities resulting from a transaction entry.

Priorities

A priority scale of one to three has been defined as follows. Priority class one refers to any transaction that updates some internal data file only. Priority two is assigned to an inquiry transaction in which the operator is waiting at a terminal for a response. Priority three is specified for STAT orders going to the Laboratory or Radiology.

Data Base Files

In studying computer based information systems, it is desirable to have some estimate of the number of times the various data files are accessed. The activity with these files consists of reading from or writing records to disk. GPSS SAVEVALUE entities will be used to count the transactions requiring access to stored information. Table I below identifies each data file and specifies its SAVEVALUE identification number.

Functional Description of the System

After the departments to be included in the information system have been identified, the functions of each department and the activities therein with respect to the system must be specified. During this phase of model construction, each type of transaction to enter the system can be identified.

TABLE I

IDENTIFICATION OF MODELED DATA FILES

File Description	SAVEVALUE Identification Number
Hospital Bed Master File	50
Inpatient Billing Master File	51
Outpatient Billing Master File	52
Charge Description Master File	53
Preadmission Status File	54
Inpatient Billing Number File	55
Hospital Department Charge File	56

Tables listing transactions with priority, input and output times, and destinations are included in the description of each department. These tables are used as input parameters in the simulation program. Data must be collected in order to quantitatively describe input to and output from the system. The data, such as transaction interarrival times and mean interarrival time by hour of the day can be obtained from department log books and direct observation of daily activities. The data characteristic of the system hardware can be obtained from vendor estimates or direct observation of similar systems installed in other hospitals or businesses.

Admitting Office

The purpose of the admission function is to control room occupancy of persons entering the hospital as patients.

This includes the collection and distribution of patient identification information, admission test orders, insurance verification, and control of transfers between rooms.

The following activities in the department result in the generation of information input or inquiries to the system. Every patient to enter the hospital will be entered into a preadmission file. This action will result from a doctor's telephone call notifying the office that a patient is to be hospitalized. A clerk will go to a CRT terminal and type a code requesting entry of preadmission data. A format will appear on the screen and the clerk will enter the patient's name, address, phone number, admission date, diagnosis, and room type desired.

During the day, calls from doctors' offices will be received requesting verification that a patient has been preadmitted, changes in admission information, or cancellation of an admission. In dealing with these functions, the clerk will enter a function code and type information onto a CRT format.

When a patient arrives at the hospital for admission, the clerk will have all patient data displayed on the screen, verify with the patient that it is correct, obtain a billing number, inquire into the bed occupancy file, assign patient a bed, and order four standard lab tests. The system will automatically print a message at the

assigned nursing station notifying staff that a new patient will be sent to them. Simultaneously, a laboratory work form will be produced in the lab for each test ordered. The clerk will then punch a plastic card for the patient. This card will be sent with the patient to the nursing unit.

In order to determine which nursing unit a patient entering the hospital from the Admitting Office or Emergency Room is assigned, Table II must be constructed. This information is easily obtained as the percent of all patients on admission assigned to the respective nursing unit. An acceptable method for calculating these data is to determine the total admissions to each unit over some period of time and divide each by the total admissions.

Table III describes each transaction, specifies its priority, its mean input time, its mean print time, and its destinations. The priority parameter was defined earlier in the chapter.

The mean input time can be considered the service time at an input facility. In studying this time for different individual transactions the distribution of this service time was found to be exponential. The mean print time is almost constant since the transaction prints the same message with each occurrence and the speed of the printers are constant. It was found that the printout does vary by plus or minus one second depending upon the length of the

TABLE II

PROBABILITY OF ADMISSION TO NURSING UNITS

Nursing Unit	Probability of Patient Admission
Three West (3W)	0.099
Four East (4E)	0.079
Four West (4W)	0.065
Four North (4N)	0.020
Five East (5E)	0.079
Five West (5W)	0.089
Six East (6E)	0.079
Six West (6W)	0.089
Seven East (7E)	0.079
Seven West (7W)	0.069
Eight East (8E)	0.079
Eight West (8W)	0.065
Intermediate Care (IMCU)	0.058
Intensive and Coronary Care (ICU)	0.051

patient's name. The destinations to which each transaction is sent or the files that each transaction accesses are identified in the last four columns of the specification table. Refer to the transaction "Check Patient In" for example. Destination one indicates that facility 46, Dietary, is notified that a new patient is to be admitted and another meal prepared. Destination two causes the status of a bed in the "Hospital Bed Master File" to be changed from vacant to occupied and the patient's identifying information written to the record. Destination three establishes a file in which charges will be accumulated. Destination four erases the patient from the "Preadmission Status File."

TABLE III

ADMITTING OFFICE INPUT TRANSACTION SPECIFICATIONS

Description	Priority	Mean Input Time (Sec.)	Mean Print Time (Sec.)	Number of Destinations	Destination Files or Facilities				
					1	2	3	4	5
1. Enter Preadmission Reservation Data	1	47	0	1	54				
2. Verify Entry of Preadmission Data	2	12	0	1	54				
3. Enter Change in Preadmission Data	2	56	0	1	54				
4. Enter Insurance Information	2	38	0	1	54				
5. Enter Preadmission Cancellation	1	17	0	1	54				
6. Obtain Billing Number	2	22	0	2	54	55			
7. Verify Information Completeness	2	72	0	1	54				
8. Verify Bed Vacancy	2	26	0	1	50				
9. Check Patient In	2	12	11	5	46	50	51	54	99
10. Order CBC Test	2	15	13	4	6	50	51	53	
11. Order Serology Test	2	15	13	4	6	50	51	53	
12. Order Urinalysis Test	2	15	13	4	6	50	51	53	
13. Order SMA-12 Test	2	15	13	4	6	50	51	53	

Destination five contains a code 99. This code is used throughout the model to indicate that a copy of the current transaction should be sent to the nursing unit specified in its number 3 parameter.

From direct observations in the Admitting Office, information was obtained to statistically describe the anticipated load input to the system. Table IV shows the distribution of admission function types. Each function represents one transaction that would possibly enter the system except the function "Admit a Patient." In this case, a clerk would seize and hold the terminal to (1) obtain billing number, (2) verify information completeness, (3) verify bed vacancy, (4) check patient in, and (5) order four standard lab tests.

Figure 4 shows the overall distribution of interarrival times between functions, and Figure 5 shows the mean interarrival times during each hour of the day. In order to determine whether or not the interarrival data of the Figure 4 histogram could be described by one of the familiar theoretical distributions, a computer program written by Don T. Phillips of Purdue University was used (40). The program showed that the distribution could be defined by a gamma function having an alpha parameter equal to 2.837 and a beta parameter equal to 2.369. The results of three goodness of fit tests are shown in Table V.

TABLE IV

DISTRIBUTION OF ADMITTING OFFICE TRANSACTION TYPES

Functions	Probability of Occurrence
Entry of Preadmission Reservation Data	0.221
Verify Entry of Preadmission Data	0.048
Enter Change in Preadmission Data	0.253
Enter Insurance Information	0.247
Enter Preadmission Cancellation	0.011
Admit a Patient	0.220

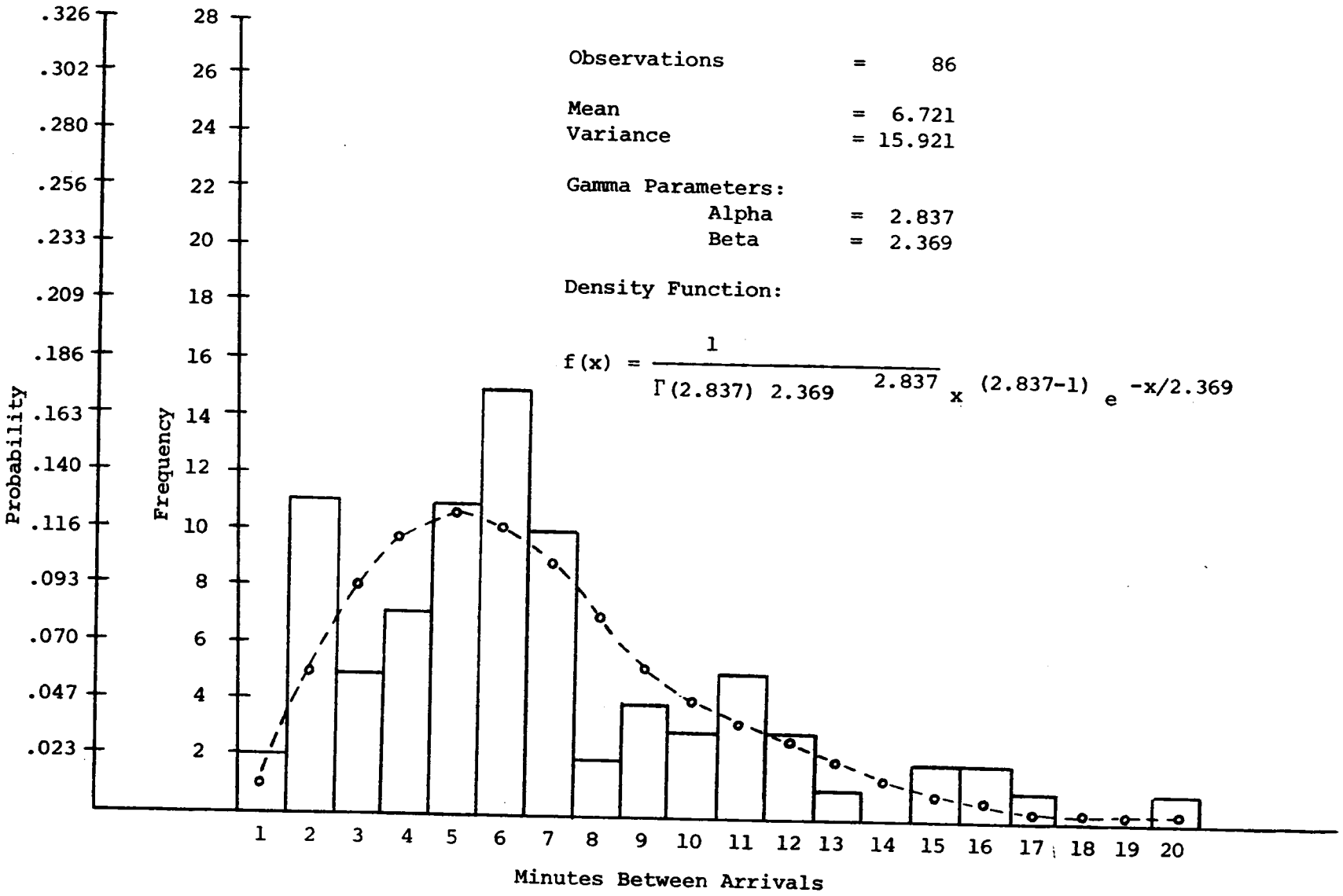

Figure 4. Frequency distribution of Admitting Office Transaction interarrival times.

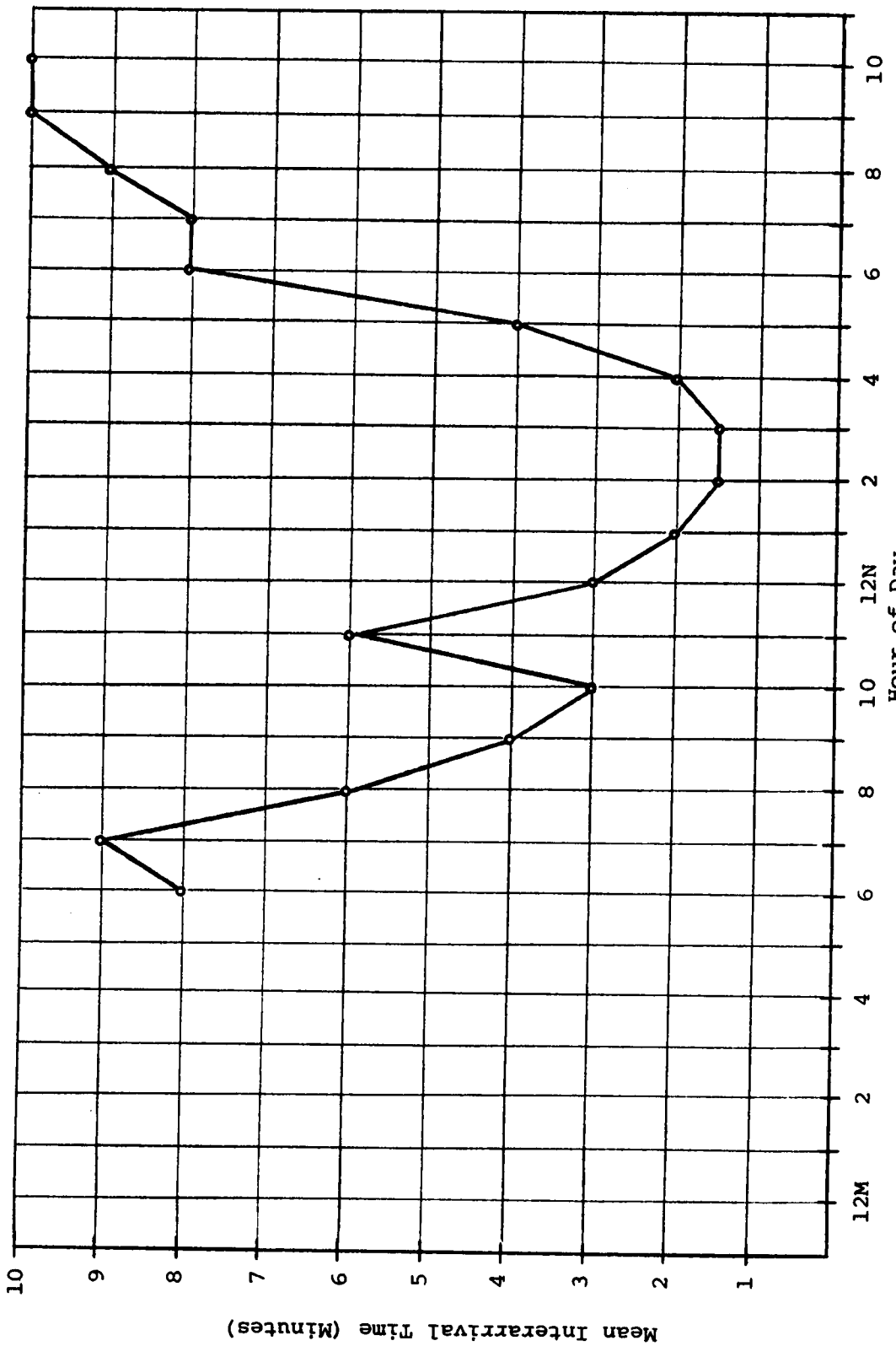

Figure 5. Profile of mean interarrival times for Admitting Office transactions.

TABLE V

GOODNESS OF FIT TESTS FOR ADMITTING TRANSACTION INTERARRIVALS

Test	Calculated Statistic	Critical Value	Significance Level	Decision
Kolmogorov-Smirnov (d.f. = 20)	0.079	0.231	0.200	Accept H_o
Cramer-Von Mises	0.529	0.743	0.010	Accept H_o
		0.620	0.020	Accept H_o
		0.461	0.050	Reject H_o
Chi-Square (d.f. = 7)	12.313	16.013	0.025	Accept H_o
		14.067	0.050	Accept H_o
		12.017	0.100	Reject H_o

H_o: The distribution is gamma with true mean equal to 6.72
H_1: The distribution is not gamma with true mean equal to 6.72

Since all three tests allowed acceptance of the null hypothesis to at least the 0.020 level of significance, the gamma distribution can be used to model the interarrivals in the Admitting Office. The density function is:

$$f(x) = \frac{1}{\Gamma(2.837)\,2.369^{2.837}} \; x^{(2.837-1)} \; e^{-x/2.369} \qquad \text{for } x \geq o$$

The curve plotted on the histogram in Figure 4 was obtained as $P\{o \leq t \leq 1\}$, $P\{1 \leq t \leq 2\}$, and so on. This was obtained by integrating the function over each of the intervals, for example:

$$P\{1 \leq t \leq 2\} = F(2) - F(1) = \int_0^2 f(x)\,dx - \int_0^1 f(x)\,dx.$$

Each department included in the system is modeled in the same manner as described here for the Admitting Office. A computer program was written to perform the complex integration required in the equations above. The trapezoidal method of numerical analysis was used.

Emergency Room

The Emergency Room is included in the system in order that identification information, charges, and treatment requests to other departments can be captured or transmitted for outpatients. The capability to admit emergency cases to the hospital at the doctor's request is required.

Upon entrance of an emergency case, the following will occur. First, the patient will give identifying information, service requested, and method of payment. A clerk will punch a set of cards containing patient identification data. These cards will be read into a reader one at a time. A charge for Emergency Room utilization will automatically be made. If the staff doctor examines the patient rather than his own physician, a doctor charge will be made. This is

accomplished by reading the patient's name card into the system followed by a prepunched doctor card located in a card file beside the terminal. Next, the patient is examined by the doctor. It was found that the examinations take from six to eighteen minutes with a mean of twelve minutes. They are uniformly distributed. After the doctor's exam, various tests are ordered, medications given, or supplies used. Table VI summarizes the number of orders or charges generated for each case.

TABLE VI

PROBABILITY OF TRANSACTION OCCURRENCE IN EMERGENCY ROOM

Transaction Type	Occurrence per case				
	0	1	2	3	4
Emergency Room Physician Charge	0.128	0.872			
Laboratory Test Requisitions	0.729	0.105	0.023	0.015	0.128
X-Ray Procedure Requisitions	0.639	0.293	0.060	0.008	0.000
Pharmacy Medication Charges	0.624	0.286	0.053	0.015	0.022
Medical Supply Charges (CSR)	0.662	0.316	0.022	0.000	0.000
Admission of a Patient	0.872	0.128			

If a laboratory test or x-ray procedure is requested, another delay will occur until notification is sent back over the Emergency Room printer that reports are ready. The time for processing laboratory and x-ray tests are discussed in the respective descriptions of these departments.

After the physician has reviewed the tests, he will either admit or discharge the patient. If the patient is admitted, a bed assignment will be entered into the system along with a request for four standard laboratory tests. After the patient leaves, either through admission or discharge, pharmacy and supply charges will be made from orders written on the medical record by the doctor and notes made by nurses.

Data describing the activities were obtained from the Emergency Room log book. Note that in the simulation model, the parent transaction is the patient or Emergency Room case. From the parent, other transactions are split to represent the traffic into the computer. These offspring become the test orders and charges. Table VII describes each type of transaction split from the parent.

Figure 6 shows a histogram of interarrival times between cases, and Figure 7 shows the mean interarrival time by hour of the day. It was found through goodness of fit testing that the Emergency Room transaction interarrival times were exponentially distributed. The parameter theta was found to be 37.79. Table VIII summarizes the decisions made from three goodness of fit tests. The extremely high frequency of arrivals at the lower end of the scale appears to have greatly influenced the Cramer-Von Mises test. The

TABLE VII

EMERGENCY ROOM INPUT TRANSACTION SPECIFICATIONS

Description	Priority	Mean Input Time (Sec.)	Mean Print Time (Sec.)	Number of Destinations	Destination Files or Facilities 1	2	3	4	5
1. Entry of Outpatient Admission Data	1	72	13	1	52				
2. Physician Charge	1	6	10	1	52				
3. X-Ray Order	3	15	13	3	12	52	53		
4. Lab Test Order	3	15	13	3	6	52	53		
5. Admit Patient	1	56	15	5	2	46	50	51	99
6. Pharmacy Charge	1	27	12	3	10	52	53		
7. Medical Supply Charge	1	27	12	3	8	52	53		

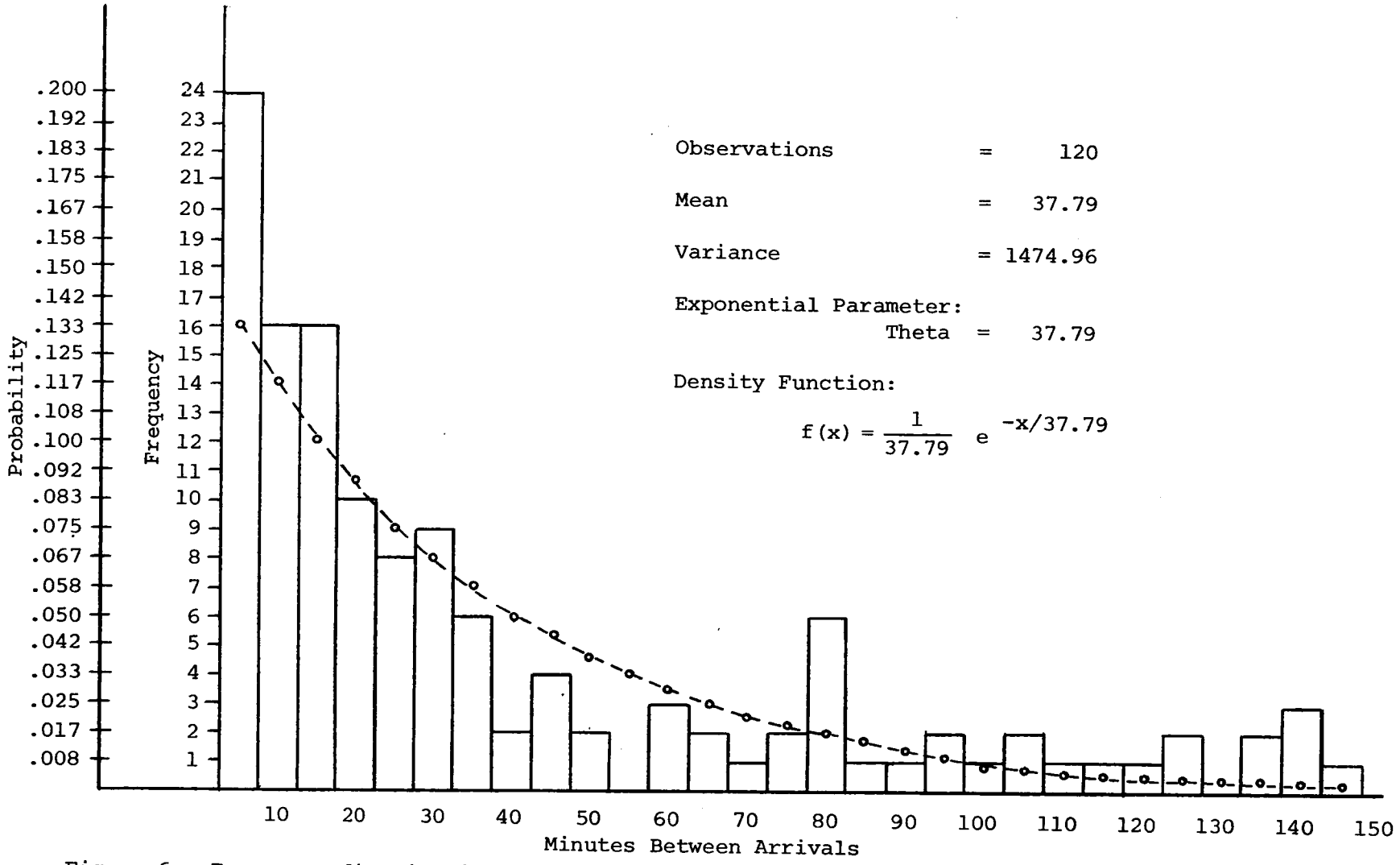

Figure 6. Frequency distribution of Emergency Room case interarrival times.

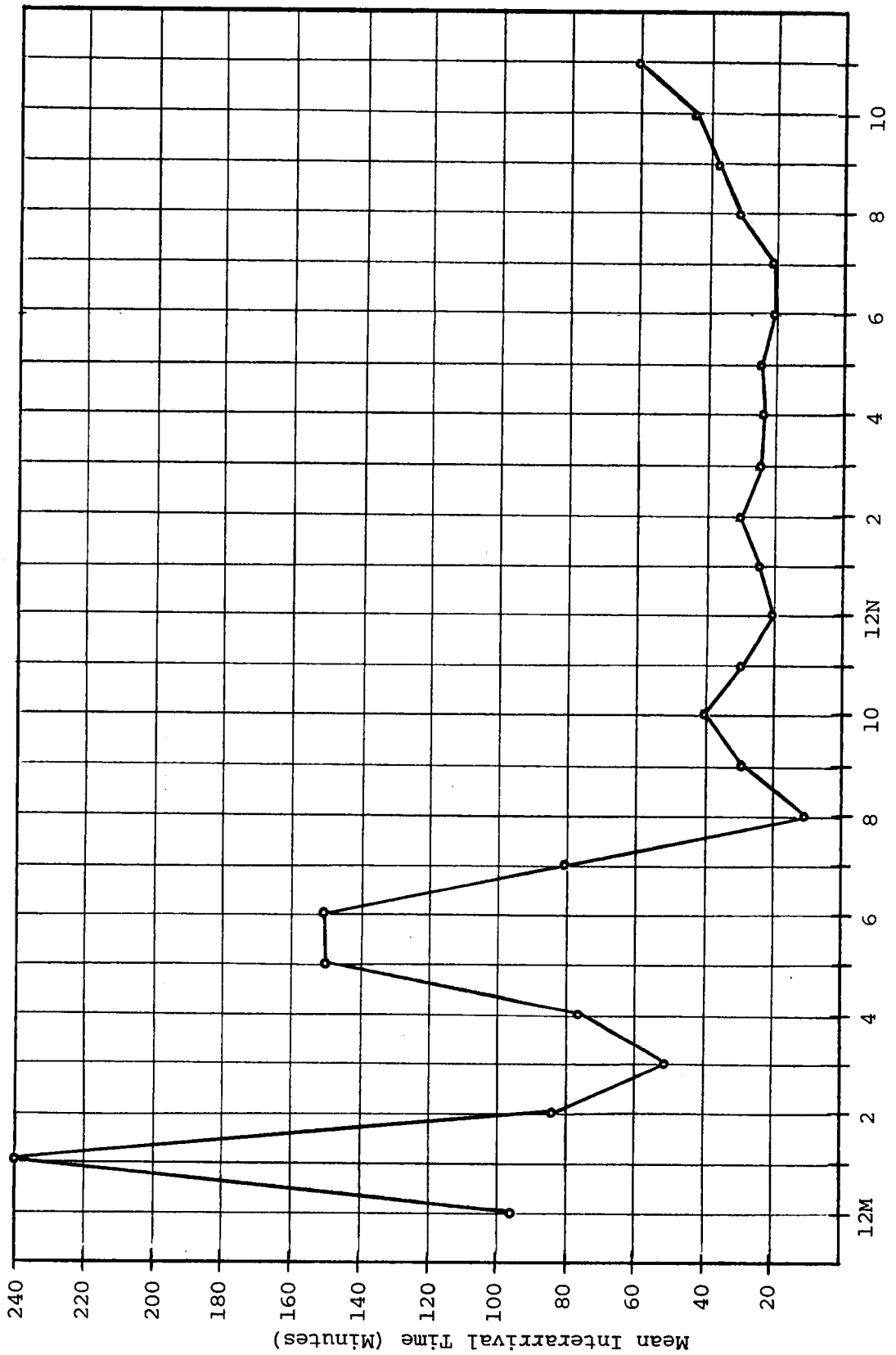

Figure 7. Profile of mean interarrival times for Emergency Room cases.

TABLE VIII

GOODNESS OF FIT TESTS FOR EMERGENCY ROOM TRANSACTION INTERARRIVALS

Test	Calculated Statistic	Critical Value	Significance Level	Decision
Kolmogorov-Smirnov (d.f. = 29)	0.057	0.220	0.100	Accept H_o
		0.190	0.200	Accept H_o
Cramer-Von Mises	0.700	0.743	0.010	Accept H_o
		0.620	0.020	Reject H_o
Chi-Square (d.f. = 12)	15.739	18.549	0.100	Accept H_o
		15.812	0.200	Accept H_o

H_o: The distribution is exponential with the mean equal to 37.79
H_1: The distribution is not exponential with mean equal to 37.79

Kolmogorov-Smirnov and the Chi-Square tests to allow the use of an exponential function with a good degree of confidence.

Laboratory

The laboratory will receive tests through a character printer from Nursing Stations, Emergency Room, and the Admitting Office. The laboratory will be modeled as receiving orders, performing tests, and transmitting results. The area will not generate transactions itself as other departments.

When a test is ordered, each request will be printed on a three copy form. One copy can be used by laboratory aides who go to the nursing units to collect specimens. The form

will have a dry gum back which when moistened can be attached to the specimen container. The second copy can be used as an assignment sheet for medical technicians who perform tests. The third copy will not be removed from the printer but will serve as a log of all orders received. The terminal will be located in a specimen coordinating center. From this area aides can be dispatched, tests scheduled, and results reported.

When the test has been performed, the technician will code patient number, nursing station, and results onto a mark sense work form. This form will be returned to the specimen coordinating area and read into the system. The data will be transmitted and printed at the appropriate nursing station or Emergency Room. The technician's signed mark sense form can later be attached to the patient's chart as a legal record.

The average time to perform a lab test from the time of receipt until completion was found to be 38.3 minutes. The distribution of completion times was furthermore found to be normally distributed as shown in Table IX. Figure 8 shows a frequency distribution of the test duration times. The theoretical probability of test times occurring within the various two minute intervals is plotted over the histogram.

TABLE IX

GOODNESS OF FIT TESTS FOR LABORATORY ORDER PROCESSING TIMES

Test	Calculated Statistic	Critical Value	Significance Level	Decision
Kolmogorov-Smirnov (d.f. = 19)	0.019	0.252	0.150	Accept H_o
		0.237	0.200	Accept H_o
Cramer-Von Mises	0.524	0.620	0.020	Accept H_o
		0.461	0.050	Reject H_o
Chi-Square (d.f. = 11)	4.393	21.920	0.025	Accept H_o
		19.675	0.050	Accept H_o

H_o: The distribution is normal with mean equal to 38.32
H_1: The distribution is not normal with mean equal to 38.32

Central Supply

The function of the Central Supply Room is to distribute sterile supplies to nursing stations and other departments upon request. A character printer and input card reader will be located in the department. A two part roll of paper can be placed in the printer. The top copy may have a dry gum backing. When an order is received, the top copy can be torn from the printer, moistened, and attached to the item ordered. Three types of orders will come to CSR. First, requests will be received for equipment or supplies charged to a patient. When this occurs, CSR aides will fill the order and send the item or items to the nursing unit by

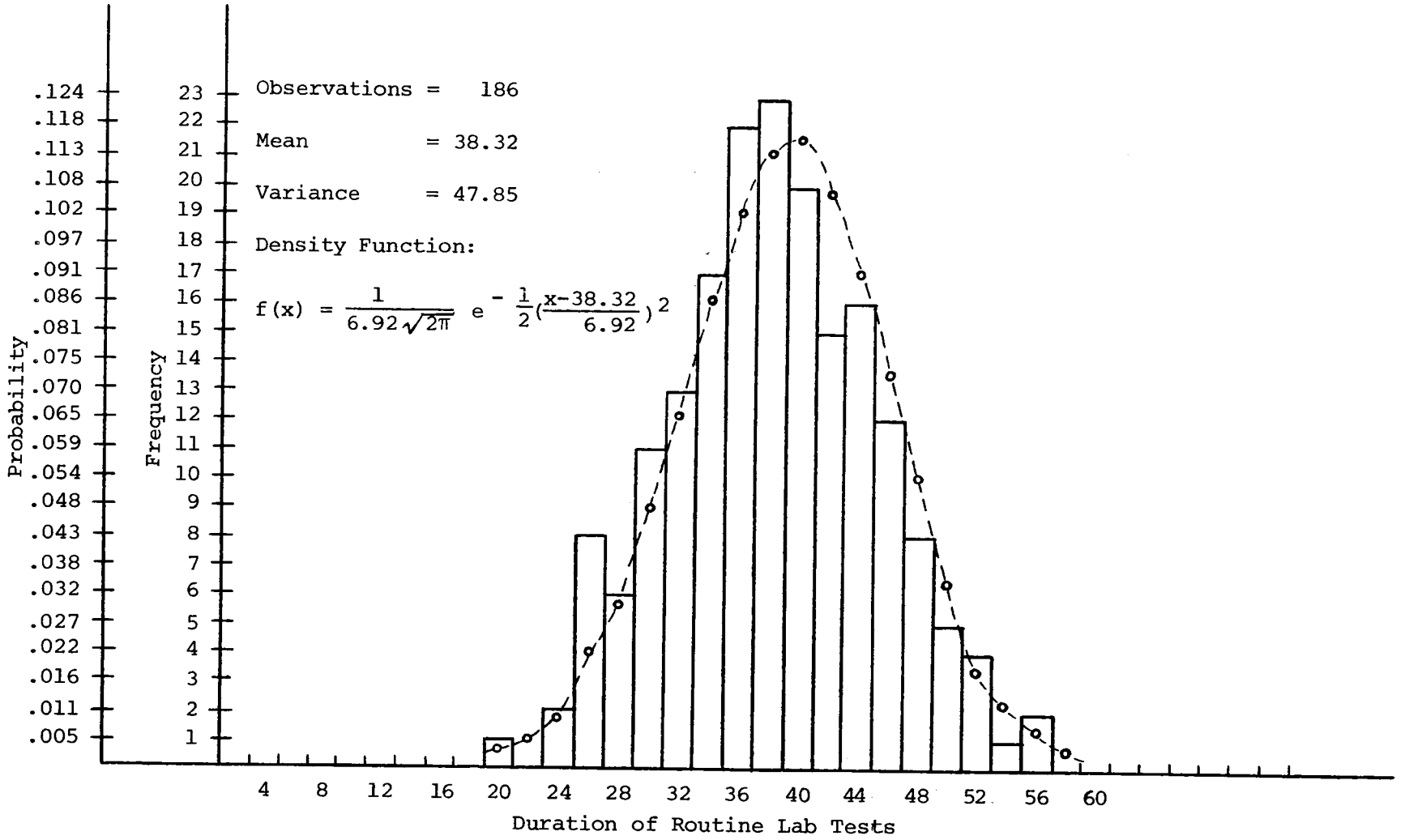

Figure 8. Frequency distribution of Laboratory test completion times.

courier. Next, requests will be received for replacement of supplies used from floor stock. This order may be either charged to the patient or to the nursing unit as operating expense depending upon the item. For example, syringes would be charged to the nursing unit rather than to the patient. Finally, special requests for supplies may come from any hospital department and charged to the department. These requests will usually be submitted in person.

In order to handle credits for orders that could not be filled, credits for items returned, or departmental charges, an input terminal and prepunched card file must be provided. The card file will contain a card for each item carried in inventory. To make a credit for a stockout, a patient's accounting number would be keyed into the terminal and a card identifying the item read in. A message would automatically be returned to the nursing station indicating that the item was out of stock and a credit was made. The same message would be printed on the CSR terminal as verification of acceptance by the system. From observations in Central Supply, 2.1 percent of the time items will not be found in stock.

Another situation as follows would result in a patient credit entered into the system. Nurses frequently order Intravenous Solutions for a continuous twenty-four hour period. If these are discontinued, they can be returned for

credit. It is estimated that 17 percent of the transactions generated in CSR are of this type. Departmental miscellaneous charges for supplies are the only other transactions generated. Note that the credit for returns and the department charges are actually generated in CSR whereas stock-out credits result from transactions generated elsewhere. Table X provides the specifications required for simulation.

The observed distribution of interarrival times is presented in Figure 9. The variation in mean by hour of the day is shown in Figure 10. Three goodness of fit tests were performed in order to see if the hypothesis of a uniform distribution could be rejected. Table XI summarizes the results of the tests. From the computer program output, the unusually high values in the middle of the distribution, and the low values in the upper range affected the Cramer-Von Mises and Chi-Square tests significantly.

Pharmacy

The Pharmacy functions much like Central Supply with respect to the system. Drugs and medications are distributed and accounted for as are sterile supplies in CSR. One additional provision is made for the pharmacist. A profile of all drugs ordered for a patient may be called from disk storage. Requests for the profiles occur as the pharmacist or physician needs them.

TABLE X

CENTRAL SUPPLY TRANSACTION SPECIFICATIONS

Description	Priority	Mean Input Time (Sec.)	Mean Output Time (Sec.)	Destinations	Destination Files or Facilities				
					1	2	3	4	5
1. Credits for Stock-Outs	1	15	13	3	51	53	99		
2. Credits for Returns	1	15	13	2	51	53			
3. Charges to Departments	1	15	13	2	53	56			

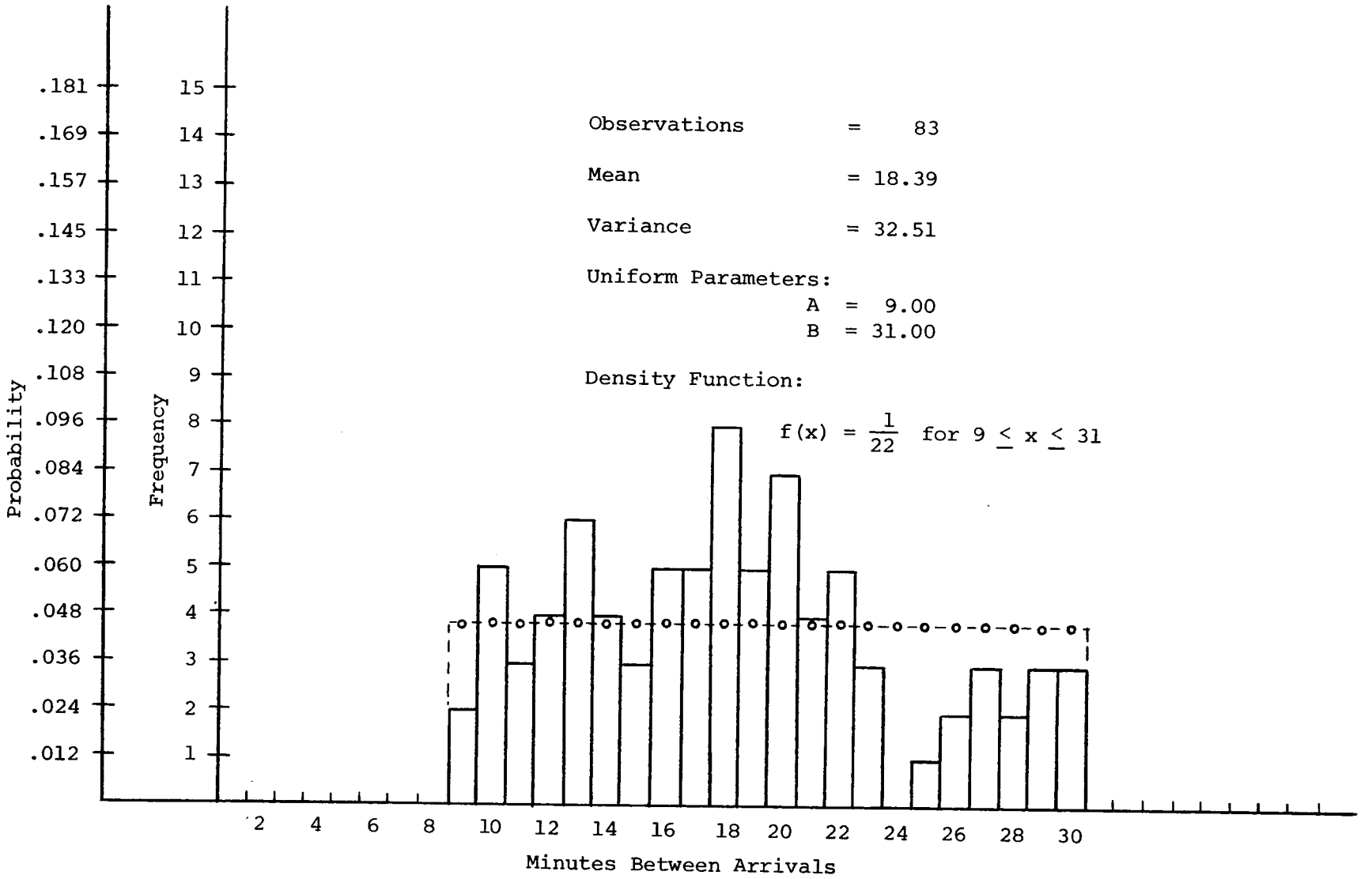

Figure 9. Frequency distribution of CSR transaction interarrival times.

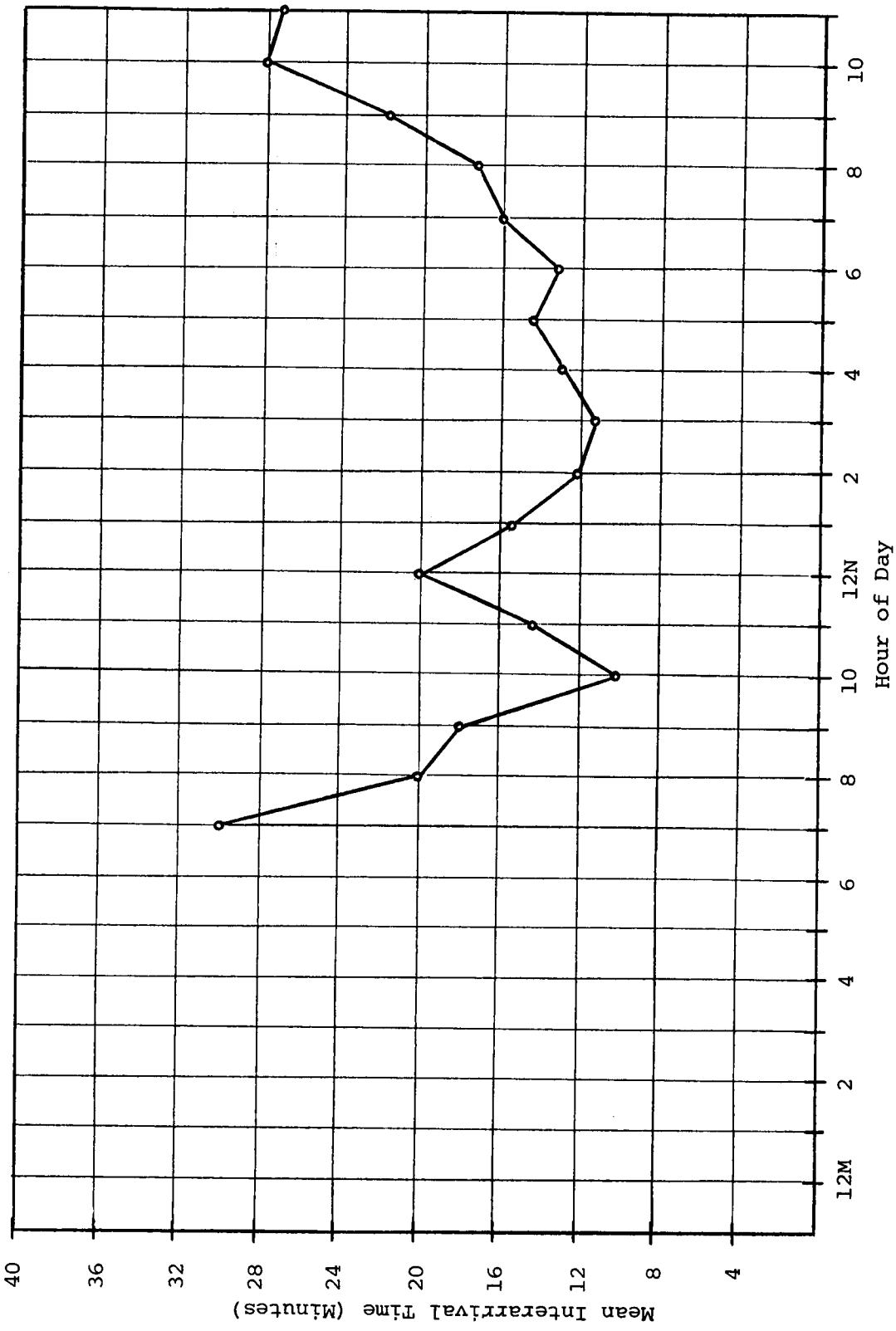

Figure 10. Profile of mean interarrival times for Central Supply transactions.

TABLE XI

GOODNESS OF FIT TESTS FOR CENTRAL SUPPLY TRANSACTION INTERARRIVALS

Test	Calculated Statistic	Critical Statistic	Significance Level	Decision
Kolmogorov-Smirnov (d.f. = 22)	0.159	0.236	0.150	Accept H_o
		0.223	0.200	Accept H_o
Cramer-Von Mises	0.398	0.461	0.050	Accept H_o
		0.347	0.100	Reject H_o
Chi-Square (d.f. = 8)	14.410	15.507	0.050	Accept H_o
		13.362	0.100	Reject H_o

H_o: The distribution is uniform with true mean = 18.39
H_1: The distribution is not uniform with true mean = 18.39

The same type of equipment is used in the Pharmacy as in CSR; a printer and prepunched card reader. The pharmacist has a punch card file of every drug in his inventory. The reader has a set of ten numeric keys and a six digit visual display. This type of terminal is needed for two purposes. First, it is used for requesting drug profiles and second, it is used for credits to patients' accounts if a drug is returned.

All requests for drugs will be printed at a printer terminal. Two copies of each request will be made. Copy one may have a gum back and can be attached to medicine boxes. Copy two will remain on the printer as a log of all transactions.

Departmental requests for medication supplies used as floor stock may arrive through the system from Nursing, Radiology, Surgery, Emergency Room, and Physical Therapy. Charges to these departments will be captured by the system when ordered. All other departments must hand carry requests to the pharmacy and charges entered into the system by the pharmacist.

Table XII provides the specifications for the transactions generated within the pharmacy. It has been observed that 30 percent of all entries will be department charges, 47 percent will be profile requests, and 23 percent will be credits for returned drugs. Figure 11 presents the observed interarrival time frequency histogram and Figure 12 shows how the mean interarrival time changes under existing conditions. The interarrival distribution was tested for its goodness of fit to a gamma function. The tests are summarized in Table XIII. It was found that the hypothesis of a gamma distribution with mean of 13.43 could be accepted at the $\alpha = 0.20$ confidence level with the Kolmogorov-Smirnov and the Cramer-Von Mises tests. The level of significance was not as high for the Chi-Square test. This may have been due to a need for more observations.

TABLE XII

PHARMACY INPUT TRANSACTION SPECIFICATIONS

Description	Priority	Mean Input Time (Sec.)	Mean Print Time (Sec.)	Number of Destinations	Destination Files or Facilities 1	2	3	4	5
1. Departmental Charges	1	15	13	2	53	56			
2. Profile Requests	2	17	45	2	10	51			
3. Returned Drug Credits	1	15	13	2	51	53			

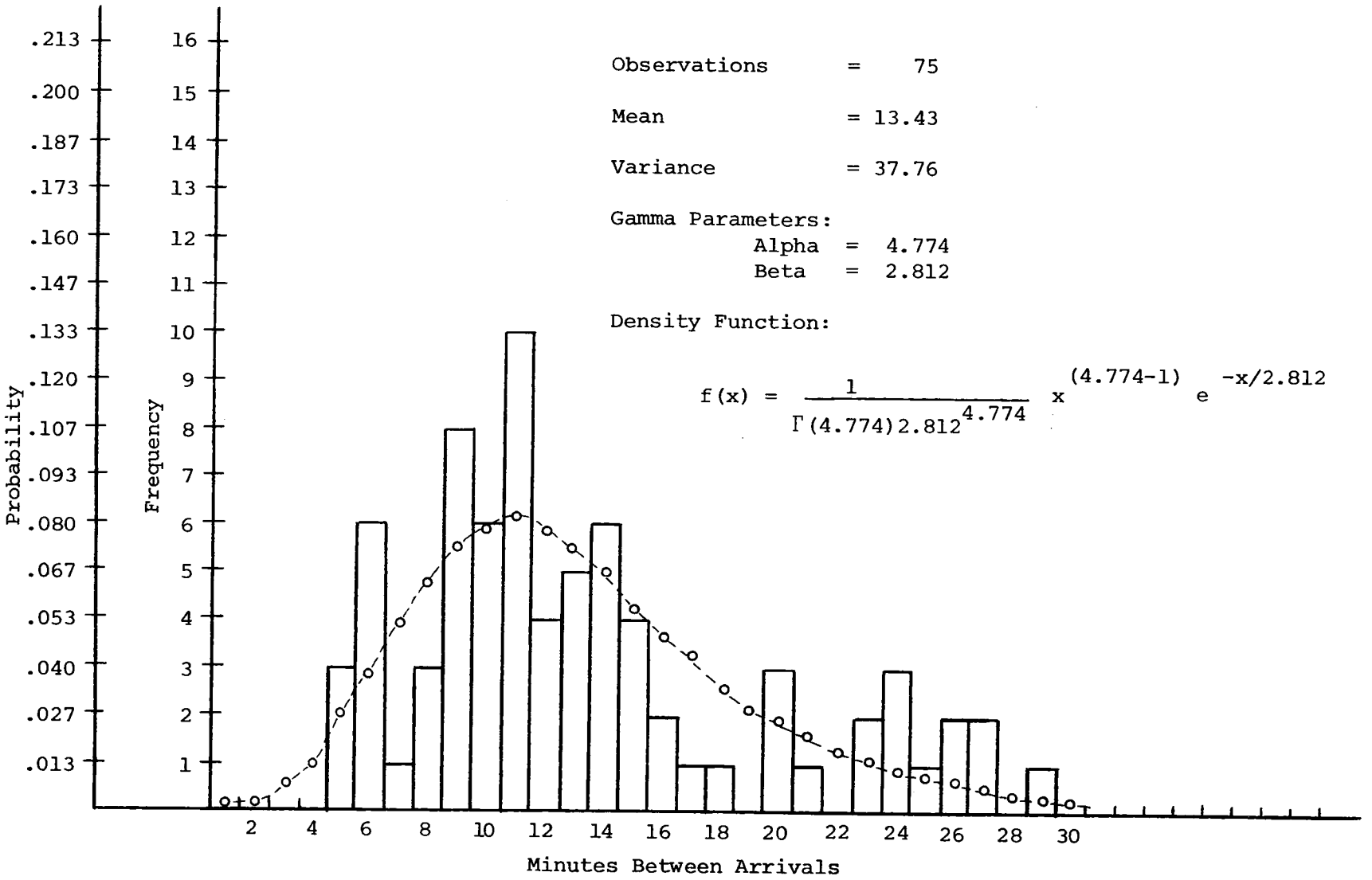

Figure 11. Frequency distribution of Pharmacy transaction interarrival times.

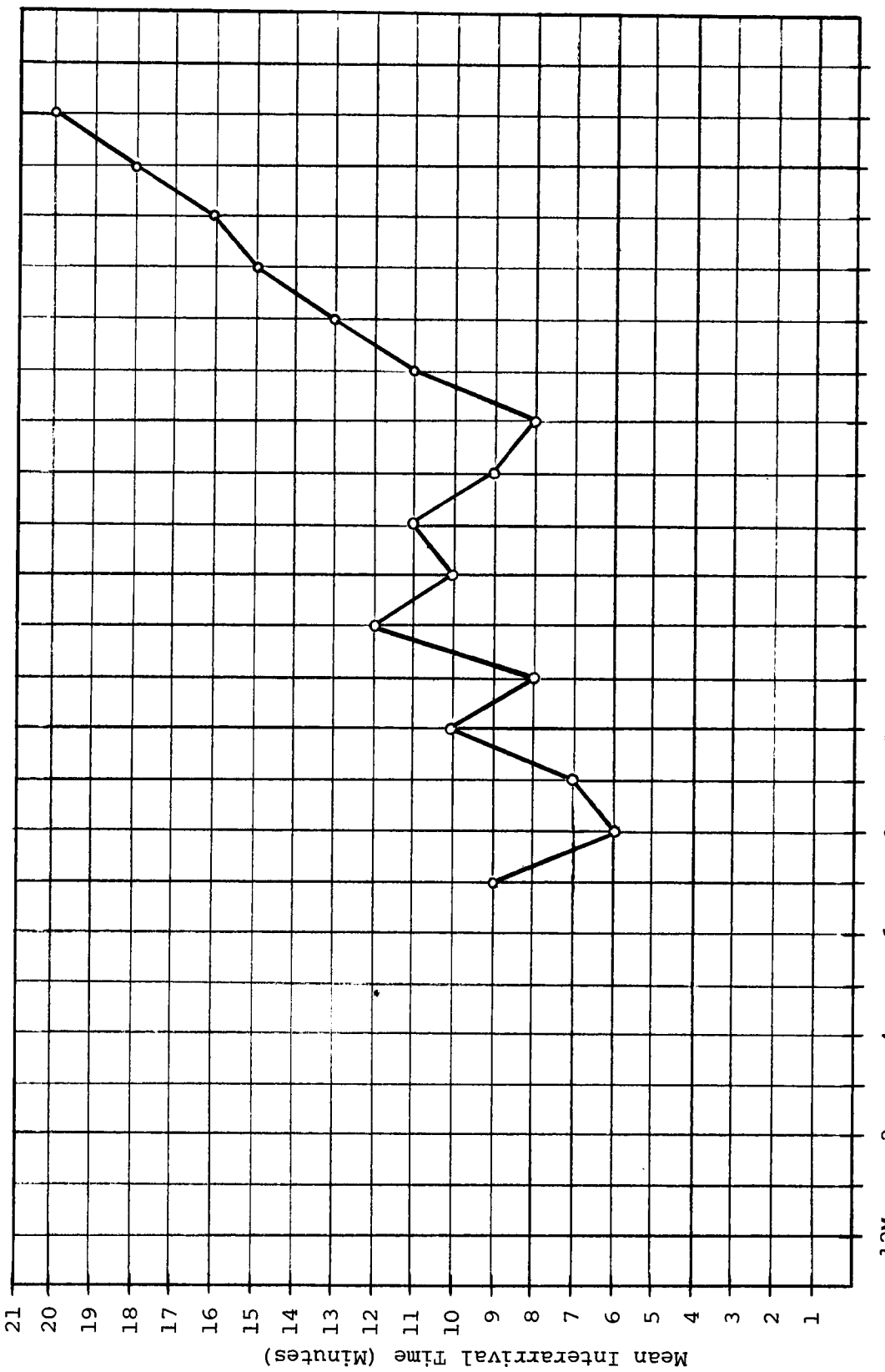

Figure 12. Profile of mean interarrival times for Pharmacy transactions.

TABLE XIII

GOODNESS OF FIT TESTS FOR PHARMACY TRANSACTION INTERARRIVALS

Test	Calculated Statistic	Critical Statistic	Significance Level	Decision
Kolmogorov-Smirnov (d.f. = 25)	0.070	0.220	0.150	Accept H_o
		0.210	0.200	Accept H_o
Cramer-Von Mises	0.175	0.284	0.150	Accept H_o
		0.241	0.200	Accept H_o
Chi-Square (d.f. = 7)	17.820	18.475	0.010	Accept H_o
		16.013	0.025	Accept H_o
		14.067	0.050	Reject H_o

H_o: The distribution is gamma with true mean = 13.43
H_1: The distribution is not gamma with true mean = 13.43

Radiology

The function of the system in Radiology will be to receive requests for tests, order stock supplies from Pharmacy or CSR, and to charge patients for special procedures.

Requests for tests will be received from nursing units and the Emergency Room through a printer terminal. Three copies of each request can be printed on multicopy paper. Copy one will have a dry gum backing and can be attached to the radiologist's report form when moistened. This will eliminate the need to type header information on the report. Copy two will be given to couriers as an assignment to

transport a patient to the Radiology Department for treatment. Copy three can remain on the terminal as a log of all requests received.

A prepunched card reader will be used to input requests for Pharmacy and CSR stock replacements. Cards will be provided in a file at the terminal for each drug or supply usually ordered.

When a patient arrives at the Radiology Department, additional x-rays may be required based on results of those initially ordered. In these cases, the radiology clerk can read the patient's card which is found attached to his medical record and a test order card into the system. This action will charge the patient for the additional test.

Table XIV shows the specifications for the transactions generated in Radiology including; priority, mean input time, mean print time, and destinations. From observations, it is estimated that 43 percent of the transactions will be pharmacy orders, 37 percent will be CSR orders, and 23 percent will be additional procedure inputs. Figure 13 shows the histogram of interarrival times for the generated transactions and Figure 14 describes the expected variation in mean interarrival time by hour of the day.

Goodness of fit tests were again performed in order to find the theoretical function that best described the arrival pattern. The gamma function with parameters

TABLE XIV

RADIOLOGY INPUT TRANSACTION SPECIFICATIONS

Description	Priority	Mean Input Time (Sec.)	Mean Print Time (Sec.)	Number of Destinations	Destination Files or Facilities				
					1	2	3	4	5
1. Pharmacy Orders	1	15	13	3	10	51	53		
2. CSR Orders	1	15	13	3	8	51	53		
3. Additional Patient Charges (X-Ray)	1	15	13	2	51	53			
4. Radiology Test Results	1	23	15	1	99				

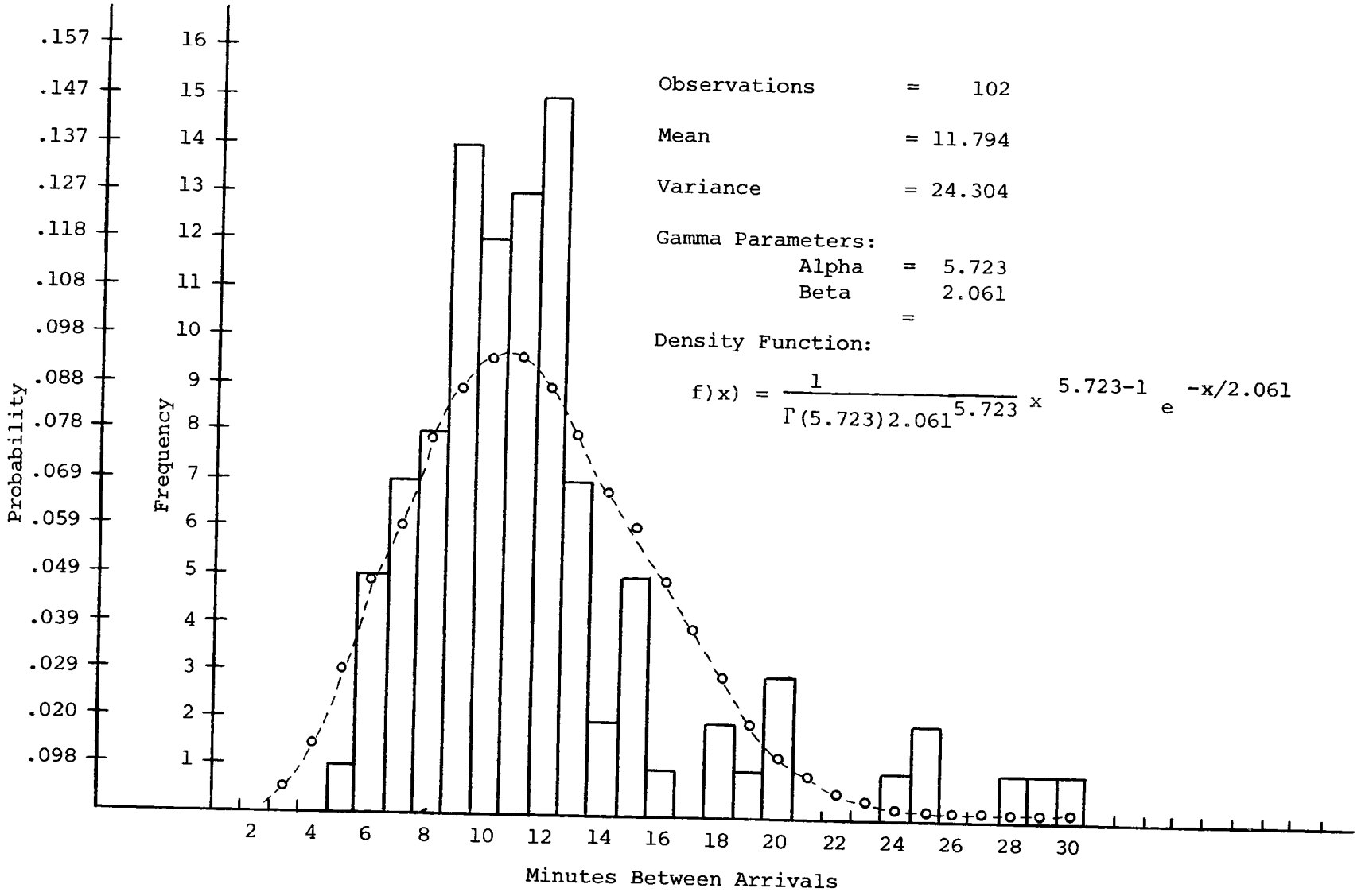

Figure 13. Frequency distribution of Radiology transaction interarrival times.

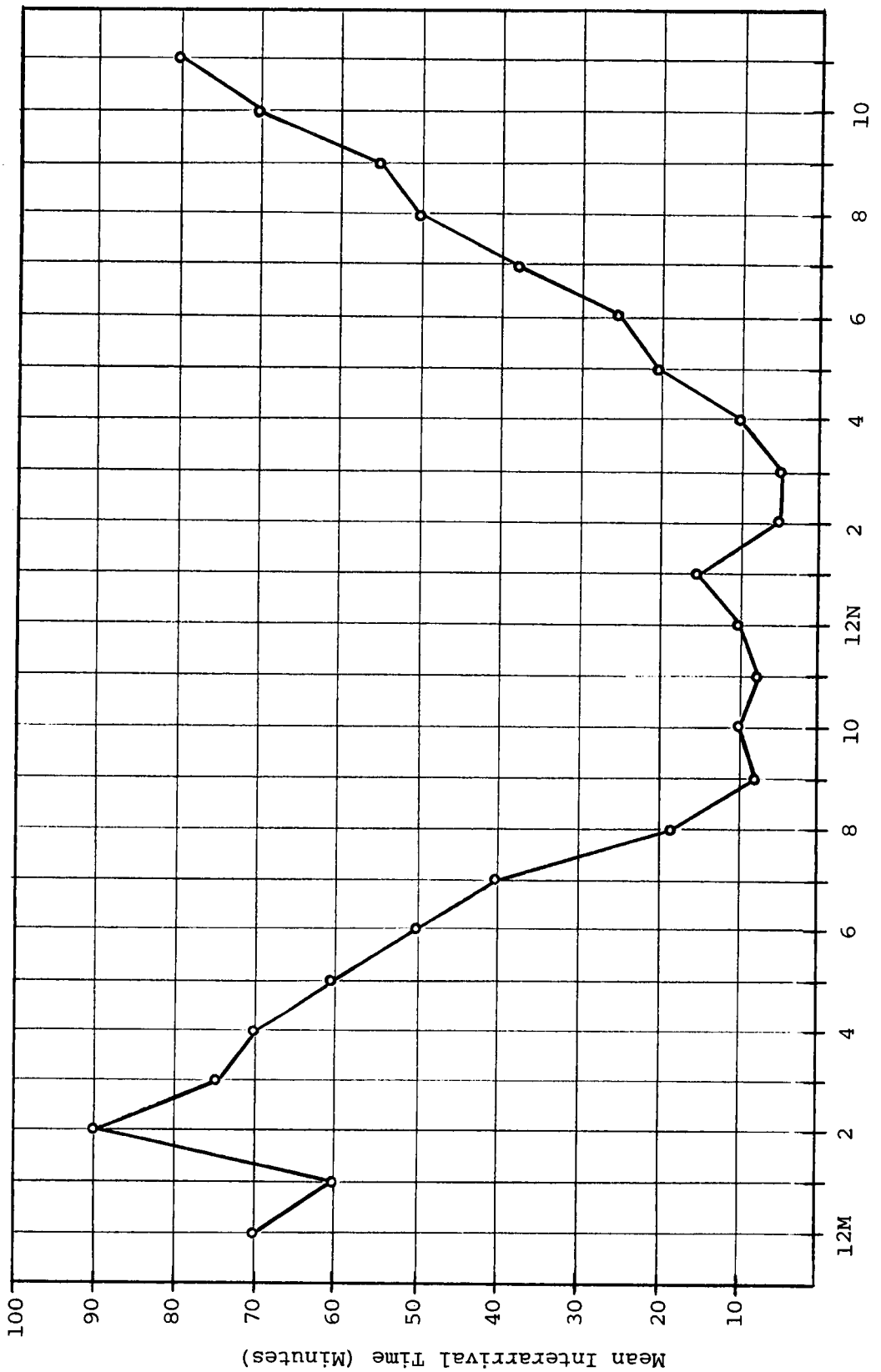

Figure 14. Profile of mean interarrival times for Radiology transactions.

α = 5.723, β = 2.061, and a mean of 11.794 was found to provide an acceptable fit to the data. In Table XV the Kolmogorov-Smirnov test allowed acceptance of the gamma hypothesis with a high level of confidence but the Cramer-Von Mises and Chi-Square tests did not provide such. The unusually high frequency of arrivals with nine to twelve minute intervals seemed to have affected the distribution significantly. Also, the low frequency of interarrivals between fourteen and nineteen minutes affected the tests. In such cases, it is up to the experimenter to decide whether or not to use the function or collect more data.

TABLE XV

GOODNESS OF FIT TESTS FOR RADIOLOGY TRANSACTION INTERARRIVALS

Test	Calculated Statistic	Critical Statistic	Significance Level	Decision
Kolmogorov-Smirnov	0.117	0.230	0.150	Accept H_o
(d.f. = 23)		0.218	0.200	Accept H_o
Cramer-Von Mises	1.367	0.743	0.010	Reject H_o
Chi-Square	18.274	19.023	0.025	Accept H_o
(d.f. = 9)		16.919	0.050	Reject H_o

H_o: The distribution is gamma with true mean = 11.79
H_1: The distribution is not gamma with true mean = 11.79

Physical Therapy

Physical Therapy will function in a manner similar to Radiology and Dietary with respect to the system. Therapy treatments are ordered one time for patients from nursing stations but may continue for several days. For example, a certain treatment may be ordered to continue twice a day for seven days. Two copies of each order are printed. The first copy is torn from the printer and placed in a cardex file. The second copy is left on the printer as a log of all transactions coming through the system. From the cardex file daily treatment schedules may be manually prepared.

Since several treatments will usually result from a single order or prescription sent by nursing, charges for each procedure must be made in the therapy department. This is accomplished as follows. After each treatment is performed, a clerk will key the patient's number into the terminal, pull a card from a prepunched card file identifying the treatment, and read the card into the terminal.

Occasionally, orders for floor stock supplies will be transmitted to Pharmacy and CSR. Charges may also be made to patients for chargeable items used. This is accomplished in the same way as treatment charges described above. It is estimated that 75 percent of all transactions generated will be treatment charges, 7 percent will be pharmacy stock orders, 10 percent will be CSR stock orders, and 8 percent will be patient

supply charges. Table XVI contains the specifications for the transactions required in the simulation.

The observed distribution of interarrival times for these transactions is shown in Figure 15 with the variation in mean by hour of the day in Figure 16. From goodness of fit testing as seen on Table XVII, the gamma function can be used to model the random process.

Surgery

The system will allow online entry of all charges occurring for a patient during each surgical procedure. A single-card reader and a character printer will be located at the surgical office. The reader will have ten numeric keys and a six digit visual display.

During surgery, a record of the operation is filled out by a technician containing the names of staff assisting, length of time in the operating room, anesthesia used, name of the procedure, and a list of every medication, solution, or supply used. Immediately after the operation, the operative record is taken to a secretary in the surgery office. The arrival of these forms can be presented as transactions generated for entry into the computer. The distribution describing these random arrivals is shown in Figure 17. The distribution was constructed from the surgical log book. Variation in the mean interarrival time is shown in Figure 18 for each hour of the day.

TABLE XVI

PHYSICAL THERAPY INPUT TRANSACTION SPECIFICATIONS

Description	Priority	Mean Input Time (Sec.)	Mean Print Time (Sec.)	Number of Destinations	Destination Files or Facilities				
					1	2	3	4	5
1. Physical Therapy Treatment Charge	1	15	13	2	51	53			
2. Pharmacy Order (Floor Stock)	1	15	13	3	10	53	56		
3. CSR Order (Floor Stock)	1	15	13	3	8	53	56		
4. CSR Order (Patient Charge)	1	15	13	3	8	51	53		

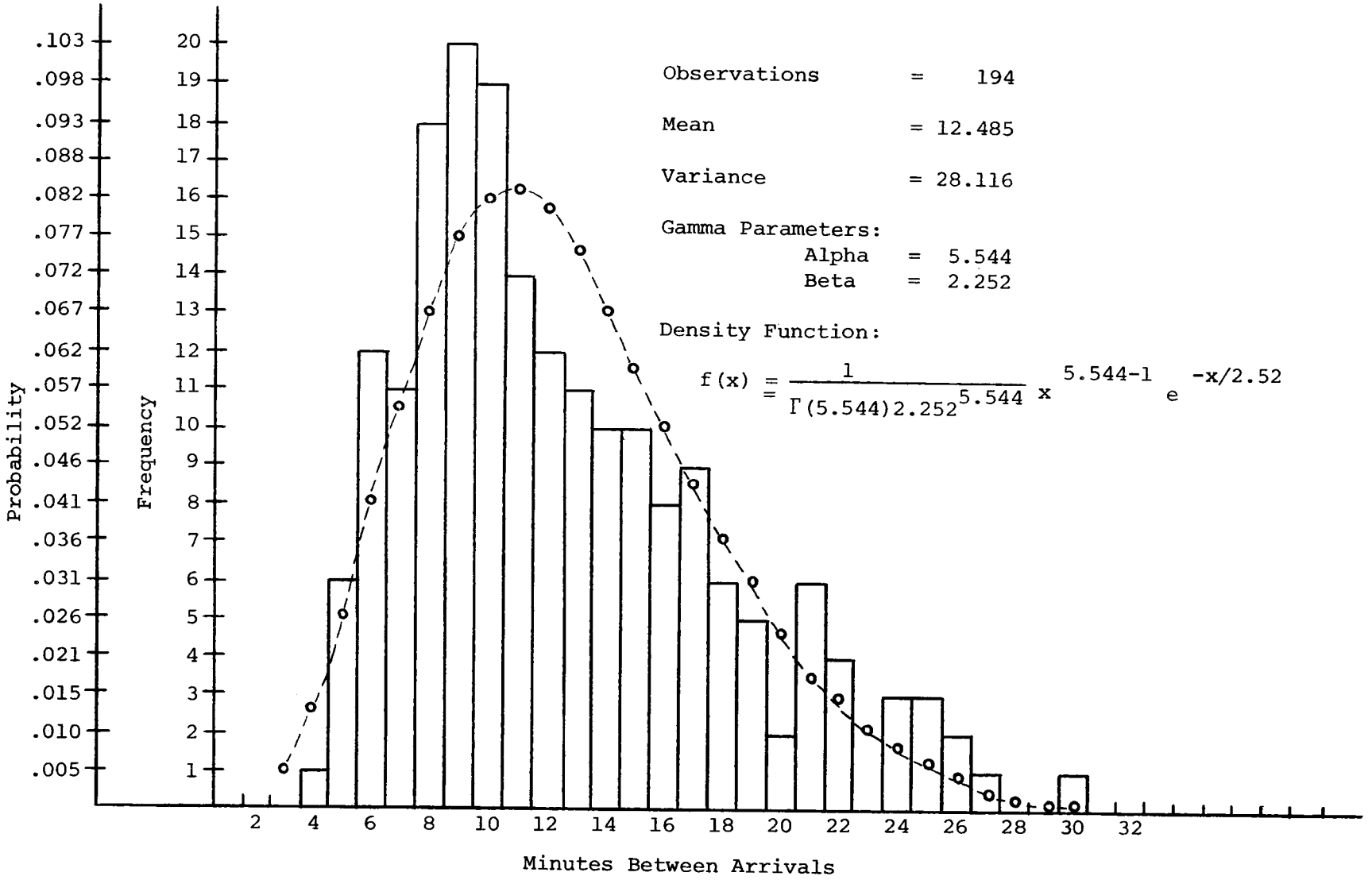

Figure 15. Frequency distribution of Physical Therapy transaction interarrival times.

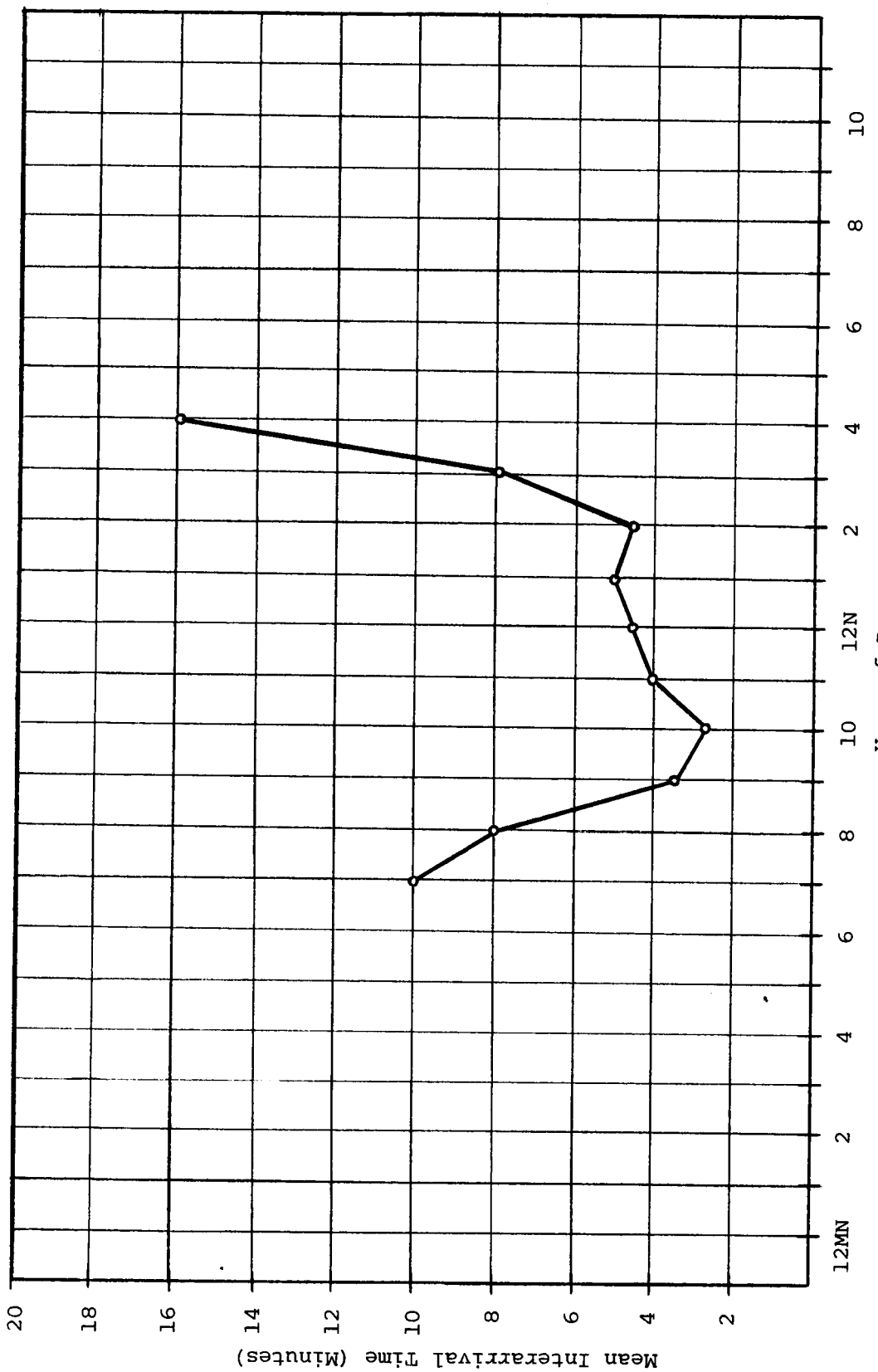

Figure 16. Profile of mean interarrival times for Physical Therapy transactions.

TABLE XVII

GOODNESS OF FIT TESTS FOR PHYSICAL THERAPY TRANSACTION INTERARRIVALS

Test	Calculated Statistic	Critical Value	Significance Level	Decision
Kolmogorov-Smirnov (d.f. = 27)	0.043	0.212	0.150	Accept H_o
		0.198	0.200	Accept H_o
Cramer-Von Mises	0.374	0.461	0.050	Accept H_o
		0.347	0.100	Reject H_o
Chi-Square (d.f. = 15)	10.623	30.578	0.010	Accept H_o
		27.488	0.025	Accept H_o
		24.996	0.050	Accept H_o

H_o: The distribution is gamma with true mean = 12.485
H_1: The distribution is not gamma with true mean = 12.485

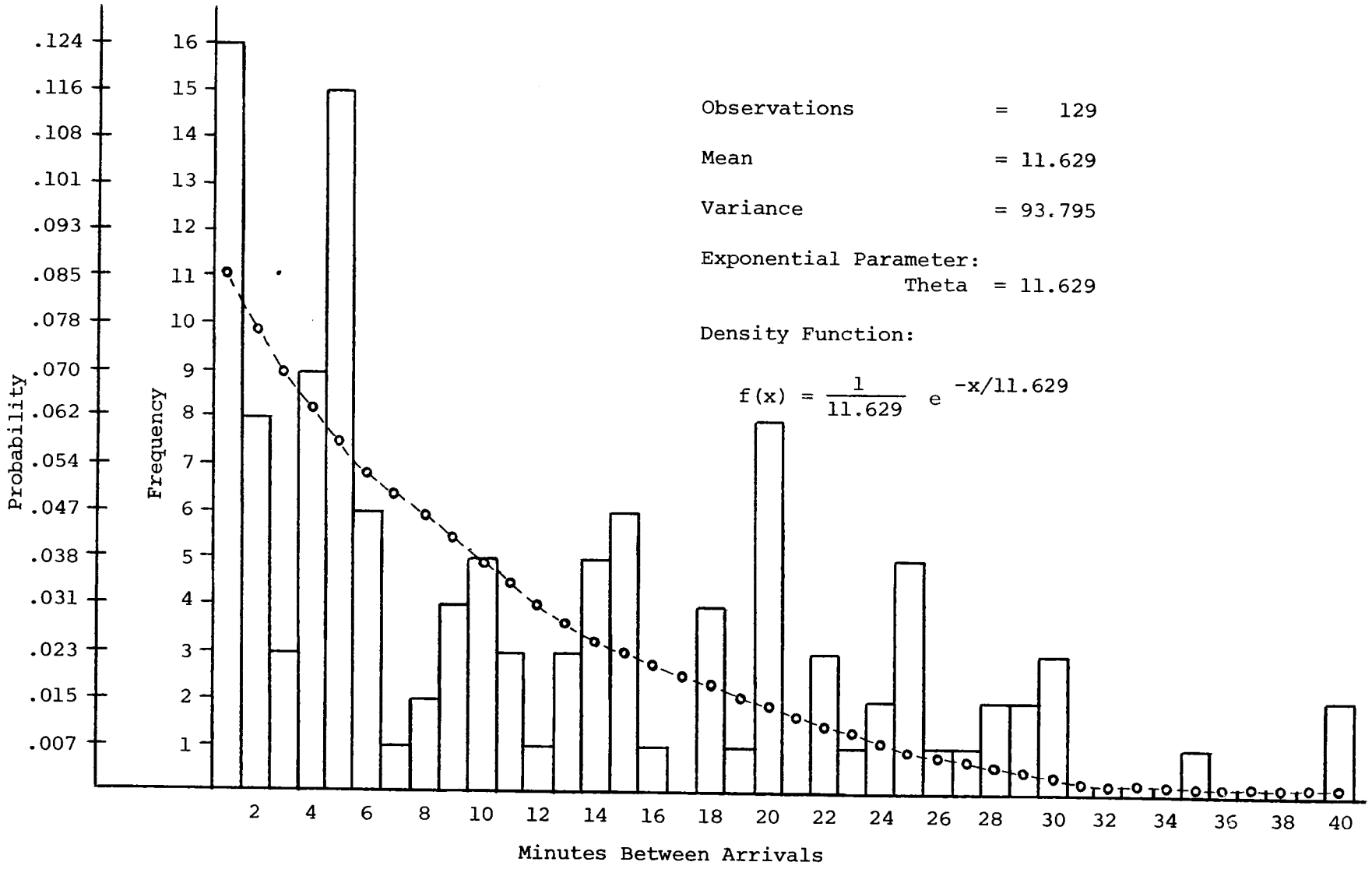

Figure 17. Frequency distribution of Surgery case completion interarrival times.

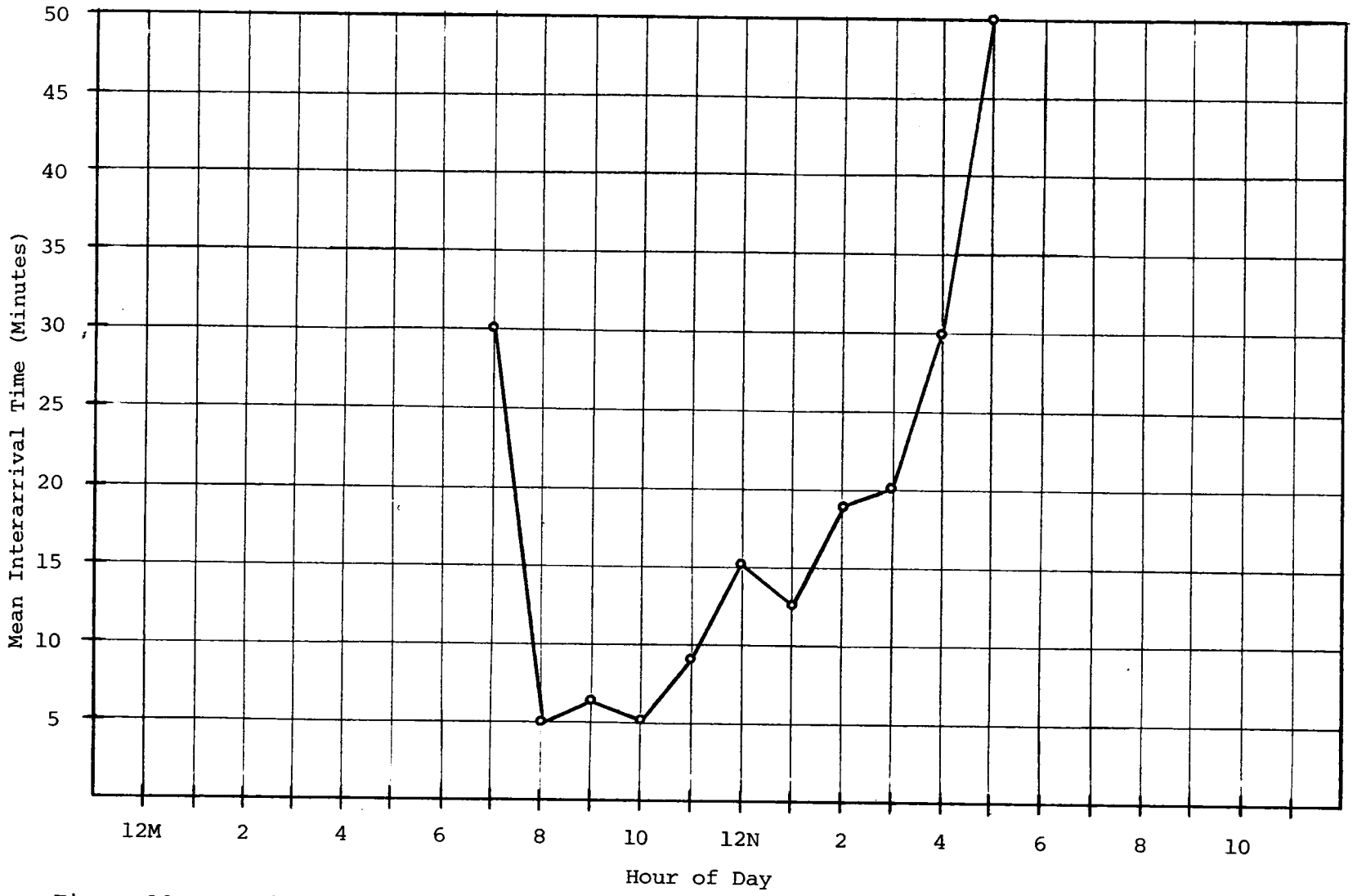

Figure 18. Profile of mean interarrival times for Surgery cases.

The data was tested against several of the familiar functions in order to identify the appropriate theoretical arrival process. Three goodness of fit tests produced the results shown in Table XVIII. These tests allow the use of the exponential function with mean and parameter theta equal to 11.629.

TABLE XVIII

GOODNESS OF FIT TESTS FOR SURGERY CASE INTERARRIVALS

Test	Calculated Statistic	Critical Value	Significance Level	Decision
Kolmogorov-Smirnov (d.f. = 40)	0.079	0.180	0.150	Accept H_o
		0.169	0.200	Accept H_o
Cramer-Von Mises	0.549	0.743	0.010	Accept H_o
		0.620	0.020	Accept H_o
		0.461	0.050	Reject H_o
Chi-Square (d.f. = 15)	37.660	37.697	0.001	Accept H_o
		32.801	0.005	Reject H_o

H_o: The distribution is exponential with true mean = 11.63
H_1: The distribution is not exponential with true mean = 11.63

Upon receipt of the operative record, the secretary will key the patient's identification number into the terminal. She will search for and enter the following types of pre-punched data cards: (1) name of the surgical procedure, (2) a charge for the surgical procedure, (3) a charge for each medication given, (4) a charge for anesthesia, (5) a charge for each surgical supply, (6) a charge for each intravenous solution. The name of the surgical procedure and

a charge must be input for every operation. A charge for anesthesia is made for 97.9 percent of the procedures. Table XIX shows the probability of n medications, supplies, and intravenous solutions used in each procedure.

The average time required to locate prepunched cards, read them into the terminal, and replace them in a card rack is shown as the "mean input time" in Table XX. Also shown is the mean print time since acceptance of each entry is verified with a printed message.

Nursing Units

An input terminal and printer will be located at each nursing unit included in the model. Thirteen different types of transactions will be generated at nursing units as specified in Table XXI. The distribution of these transaction types is shown in Table XXII.

The modeling of activities at the nursing units is simple. As transactions are generated, they will either join a queue or enter the system through a card reader immediately. Two or three cards are read into the terminal for each transaction. Card one identifies the patient and card two identifies the item or service required. A third copy may optionally be included to specify time of day for a test order or dosage of a medication. A message is printed at both the sending and receiving terminals. The message at the sending terminal serves as verification and log of its transmission.

The distribution of interarrival times at a typical nursing station is shown in Figure 19. The same distribution is used in the model for each nursing unit. It should be noted that this may in reality not be true. If this

TABLE XIX

PROBABILITY OF TRANSACTION OCCURRENCE IN SURGERY

Transaction Type	Occurrence per Case													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
Pharmacy Requisition	.695	.192	.071	.042	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
Anesthesia Charges	.021	.979	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
Surgical Supply Charges	.135	.206	.184	.106	.135	.043	.036	.078	.043	.021	.000	.007	.000	.007
IV Solution Charges	.404	.567	.028	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

TABLE XX

SURGERY INPUT TRANSACTION SPECIFICATIONS

Description	Priority	Mean Input Time (Sec.)	Mean Print Time (Sec.)	Number of Destinations	Destination Files or Facility 1	2	3	4	5
1. Operative Record Entry (Procedure Name)	1	15	13	3	51	53			
2. Procedure Charge	1	15	13	3	51	53			
3. Medication Charge	1	15	13	3	51	53			
4. Anesthesia Charge	1	15	13	3	51	53			
5. Supply Charge	1	15	13	3	51	53			
6. IV/Solution Charge	1	15	13	3	51	53			

TABLE XXI

NURSING INPUT TRANSACTION SPECIFICATIONS

Description	Priority	Mean Input Time (Sec.)	Mean Print Time (Sec.)	Number of Destinations	Destination Files or Facility 1	2	3	4	5
1. STAT Laboratory Order	3	15	14	3	6	51	53		
2. Routine Lab Order	1	15	13	3	6	51	53		
3. X-ray Order	1	15	13	3	12	51	53		
4. Physical Therapy Order	1	15	13	3	14	51	53		
5. Supply Order (from CSR)	1	17	10	3	8	51	53		
6. Supply Charge (from stock)	1	17	10	3	8	51	53		
7. Pharmacy Order (floor stock replacement)	1	15	12	3	10	51	53		
8. Pharmacy Order (chargeable to patient)	1	15	12	3	10	51	53		
9. Narcotic Charge (from floor stock)	1	15	12	3	10	51	53		
10. Request for Transfer	1	9	12	1	2				
11. Notice of Discharge	1	8	10	2	2	46			
12. Diet Order or Change	1	13	12	1	46				
13. Miscellaneous Charge	1	15	13	3	51	53			

TABLE XXII

DISTRIBUTION OF TRANSACTION TYPES FROM NURSING

Transaction	Probability of Occurrence
1. STAT Laboratory Order	.038
2. Routine Laboratory Order	.210
3. X-Ray Order	.038
4. Physical Therapy Order	.025
5. Central Supply Order (nonstock item)	.151
6. Central Supply Order (floor stock replacement)	.091
7. Pharmacy Order (floor stock replacement)	.027
8. Pharmacy Order (chargeable to patient)	.221
9. Narcotic Charge (from floor stock)	.025
10. Request for Transfer	.025
11. Notice of Discharge	.051
12. Diet Order or Change	.070
13. Miscellaneous Charge	.025

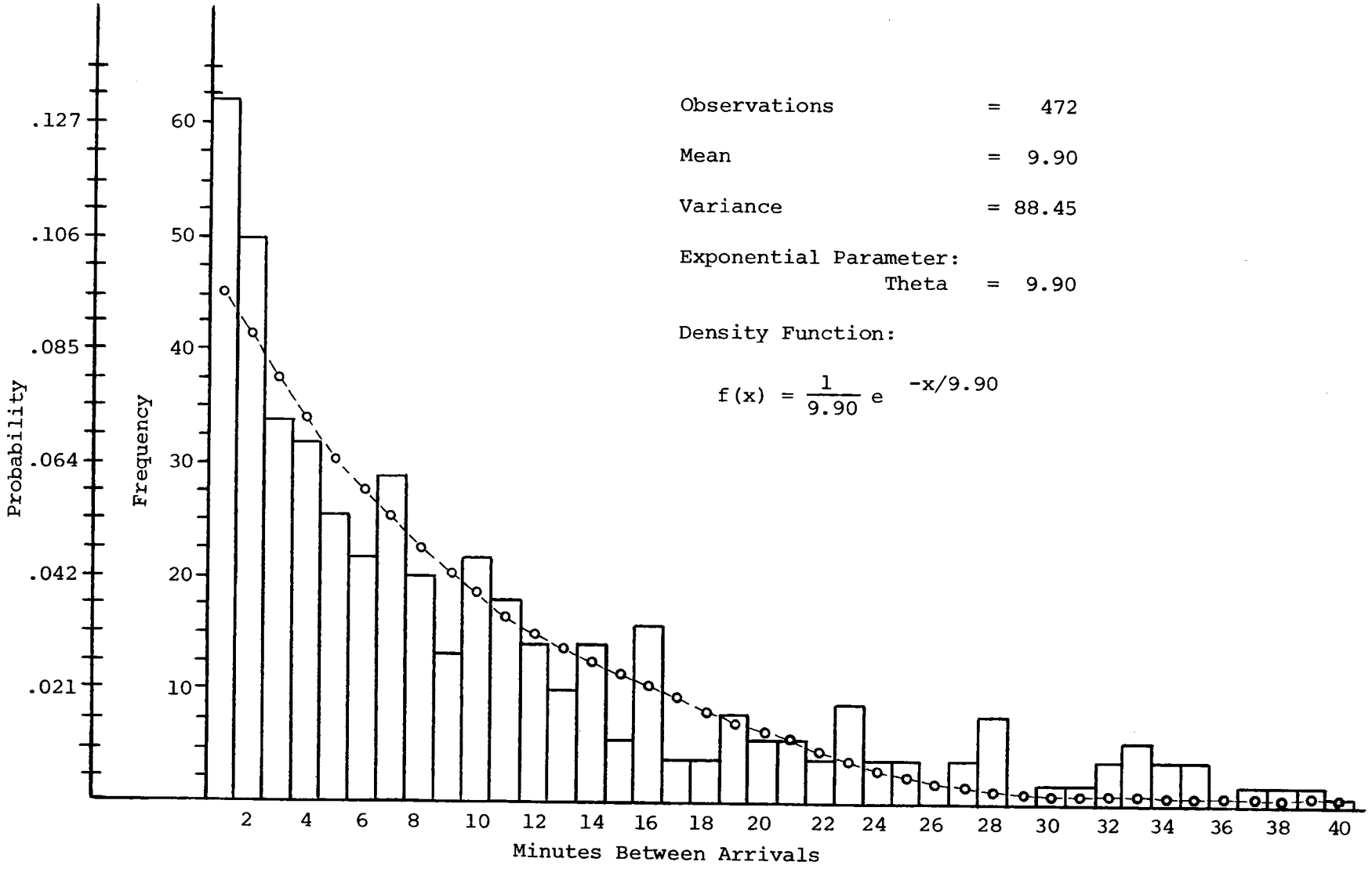

Figure 19. Frequency distribution of Nursing transaction interarrival times.

simplification had not been made, thirteen more distributions would be required for the simulation. Since the mean transaction interarrival time by hour of the day will obviously vary depending upon the size of the unit, Table XXIII was constructed.

A theoretical distribution describing the interarrival process could not be found which passed the three different goodness of fit tests. The best fit obtained was with an exponential distribution. The Kolmogorov-Smirnov test as shown in Table XXIV, allowed acceptance of the exponential distribution to the $\alpha = 0.20$ level of significance. Neither the Cramer-Von Mises nor the Chi-Square test allowed acceptance at any level. The experimenter has three alternatives under this situation: (1) use the exponential distribution, (2) use the empirical data as a discrete distribution, or (3) collect more data.

Dietary

A character printer and patient cardex file will be the only pieces of equipment used in Dietary. Since no input to the system will be made from this area, there will be no need for an input terminal.

Three different types of messages will be received by Dietary. First, requests for meals will be printed at the terminal. These will be torn from the printer and placed in the cardex file, ordered by room number. The orders can either be a change in meal type or notice of meal type for a new patient. The second type of request will be a hold on

TABLE XXIII

MEAN INTERARRIVAL TIME FOR TRANSACTIONS BY HOUR OF DAY AT NURSING UNITS

UNIT	8AM	9	10	11	12N	1	2	3	4	5	6	7	8	9	10	11	12M
3-West (min.)	7	4	7	10	8	4	5	9	8	9	8	10	12	10	16	15	14
4-East	8	5	7	10	9	4	4	8	8	9	9	9	13	10	17	13	14
4-West	9	6	8	11	11	6	8	11	10	10	12	11	14	10	18	17	17
4-North	30	21	28	50	35	15	22	38	30	33	36	29	37	40	48	38	50
5-East	8	5	8	12	9	4	6	10	8	10	10	9	12	12	17	14	15
5-West	7	5	7	11	9	5	6	9	8	9	9	10	12	12	18	15	16
6-East	8	6	8	12	10	5	7	9	9	10	9	11	13	11	17	16	16
6-West	6	5	7	10	8	5	6	9	6	8	9	10	11	10	15	14	14
7-East	8	5	7	10	8	5	6	10	8	6	8	9	9	10	15	13	12
7-West	8	6	7	11	9	6	5	8	7	8	8	10	12	12	16	16	13
8-East	4	5	7	6	8	4	4	8	10	10	9	9	6	9	16	13	7
8-West	10	7	7	11	10	7	4	7	7	10	8	13	11	13	15	16	13
IMCU	10	7	8	10	11	4	8	11	8	10	9	9	14	10	18	17	14
ICU-CCU	9	8	8	11	9	6	4	8	10	9	12	11	13	13	17	13	17

TABLE XXIV

GOODNESS OF FIT TESTS FOR NURSING UNIT
TRANSACTION INTERARRIVALS

Test	Calculated Statistic	Critical Value	Significance Level	Decision
Kolmogorov-Smirnov (d.f. = 40)	0.049	0.180	0.150	Accept H_o
		0.169	0.200	Accept H_o
Cramer-Von Mises	1.672	0.743	0.010	Reject H_o
Chi-Square (d.f. = 27)	81.854	49.645	0.005	Reject H_o

H_o: The distribution is exponential with true mean = 9.90
H_1: The distribution is not exponential with true mean = 9.90

meals for patients receiving nothing by mouth or those on tube feeding. These requests will be placed on file until subsequently changed. Finally, Dietary will be notified to stop all meals upon discharge of a patient. At this time, the patient's file is manually cleared of all diet orders.

Assumptions

Three assumptions are made in the model with respect to its functional behavior. It is assumed that the computer hardware is running properly throughout the period being simulated. In other words, there is no downtime. In reality the system could go down from hardware malfunction, changing of tape or disk devices, or preventive maintenance. If this were to happen, transactions would queue indefinitely. If the system was expected to be down for an extended period of time, some alternate manual system of placing orders and collecting charges would have to be used.

The second assumption concerns system overload. In order to observe maximum queueing which might occur, the system will not shut itself off if queues exceed some point. Some systems will not handle internal printer queues greater than a known number. Two things may be done to prevent overload. Transactions may be temporarily stored on disk or several printers may be located in the problem area. The latter alternative would be the easier of the two solutions to implement. The former would require systems reprogramming.

Finally, it is assumed that all operators are well trained and are not practicing or learning how to use the facilities.

It is believed these assumptions will not invalidate the model but will represent a stable situation without hardware limitations. Thus, the extreme loads expected for the proposed system can be studied.

Two assumptions have been made with respect to the random processes describing the system loading. first, the arrivals of the various transactions are assumed to be independent of each other. Secondly, the fundamental distribution of interarrival times is assumed to remain unchanged even though the mean interarrival time by hour of the day varies.

Chapter Summary

For each information input station, the distribution of interarrival times has been identified, the transaction specifications defined, the distribution of transaction types presented, and the mean interarrival times by hour of day shown. Three goodness of fit tests were performed on time distributions in order to find the theoretical density functions which best described the data.

A functional description as well as the quantitative description was made in defining the system model. All of the information presented in this chapter was required for preparation of the computer simulation program. The application of the data and descriptions is documented in the following chapter.

CHAPTER IV

SIMULATION OF THE SYSTEM

Introduction

A GPSS computer program was used to simulate the system. This chapter contains a description of the program. The code can be divided into thirteen sections for discussion purposes. Section one defines functions, macros, matrices, variables, and initial conditions. Section two is a module for changing the mean interarrival times of transactions each hour. Sections three through twelve simulate the activities in each hospital department on the network. Finally, section thirteen simulates the central processor unit (CPU). The coded GPSS program is included in the Appendix. The comments beside each block help explain the code.

Description of Input Parameters

Transaction Parameters

Up to 100 parameters may be associated with each transaction entering the model. In the simulation presented, there are only two parameters used with transactions passing through the mean interarrival time switch section of code. Parameter number one (P1) contains the number of input

terminal facilities for which the mean time between arrivals is changed each hour of the simulation. The current hour is calculated from variable number two (V2) and placed in parameter two (P2). The V2 value represents the column of matrix ten that contains the interarrival times.

All other transactions in the model have associated with them the standard twelve fullword parameters. The uses of these parameters are defined in Table XXV. Fullword parameters are required since the clock times placed in parameter nine exceed the allowable magnitude of halfword parameters.

Function Definitions

The program requires probability functions for the transaction types, number of orders generated by patients, transaction interarrival times, nursing unit assignments, and transaction input times. These functions must be represented in the program as inverse cumulative probability functions. That is, the dependent variables become the random values of $\underline{x}$ and the independent variables become the F(x) probabilities between zero and one.

Transaction types are assigned based on discrete probability functions. For example, let the probability that a transaction is type $\underline{1}$ be 0.50 and the probability that it is type $\underline{2}$ be 0.50. Type 1 is assigned if $0 \leq RN \leq 0.50$ and type $\underline{2}$ is assigned if $0.50 \leq RN \leq 1.0$ where RN is a random number.

TABLE XXV

DEFINITION OF TRANSACTION PARAMETERS

Parameter Number	Definition and Description of Use
1	Transaction type
2	Matrix that contains the input, output, and destination information
3	Nursing unit assigned from the Admitting Office or the Emergency Room
4	Area Station number of the transaction's origin
5	A counter for the number of transactions to be ASSEMBLED in the Emergency Room to represent test reports
6	A sequence number for transactions split in the CPU section of code for required distribution--Used as a looping index for Emergency Room and Surgery sections of code
7	Destination facility code obtained from the specification matrix identified in P2
8	CRT indicator used in the Admitting Office section of code 1 = Request for data format 2 = Data submission for acknowledgment
9	Relative clock time at which terminal operator initiates a data entry
10	Not used
11	Not used
12	Number of the shortest CRT terminal queue in the Admitting Office--Assigned via a SELECTMIN block

Functions specifying the number of orders generated by patients are needed in the Emergency Room and Surgery sections of the model. This is because the parent transaction is a patient instead of an order, charge, or message. From the parent transaction, offspring are produced. The parent transactions pass through blocks which call discrete probability functions to determine the number of tests, treatments, drugs, or supplies ordered. The number of transactions obtained from the functions are split from the parent and input to the system.

Interarrival time distribution functions must be defined for each input station in the model. The functions are continuous but are approximated in GPSS by straight line segments as shown in Figure 20. The curve shows the actual representation in the simulation program for interarrivals in the Admitting Office as previously described in Figure 4 on page 30. Since the mean of the distribution will change depending upon the hour of the day, the distribution is scaled to a mean of one by dividing each random value $\underline{x}$ by the observed mean of the data. During the simulation, the time lapse between the arrival of two transactions is calculated as follows. A random number between zero and one is generated. The interarrival time, $\underline{x}$, is obtained from the function definition. This value is multiplied by the current mean to get the time lapse.

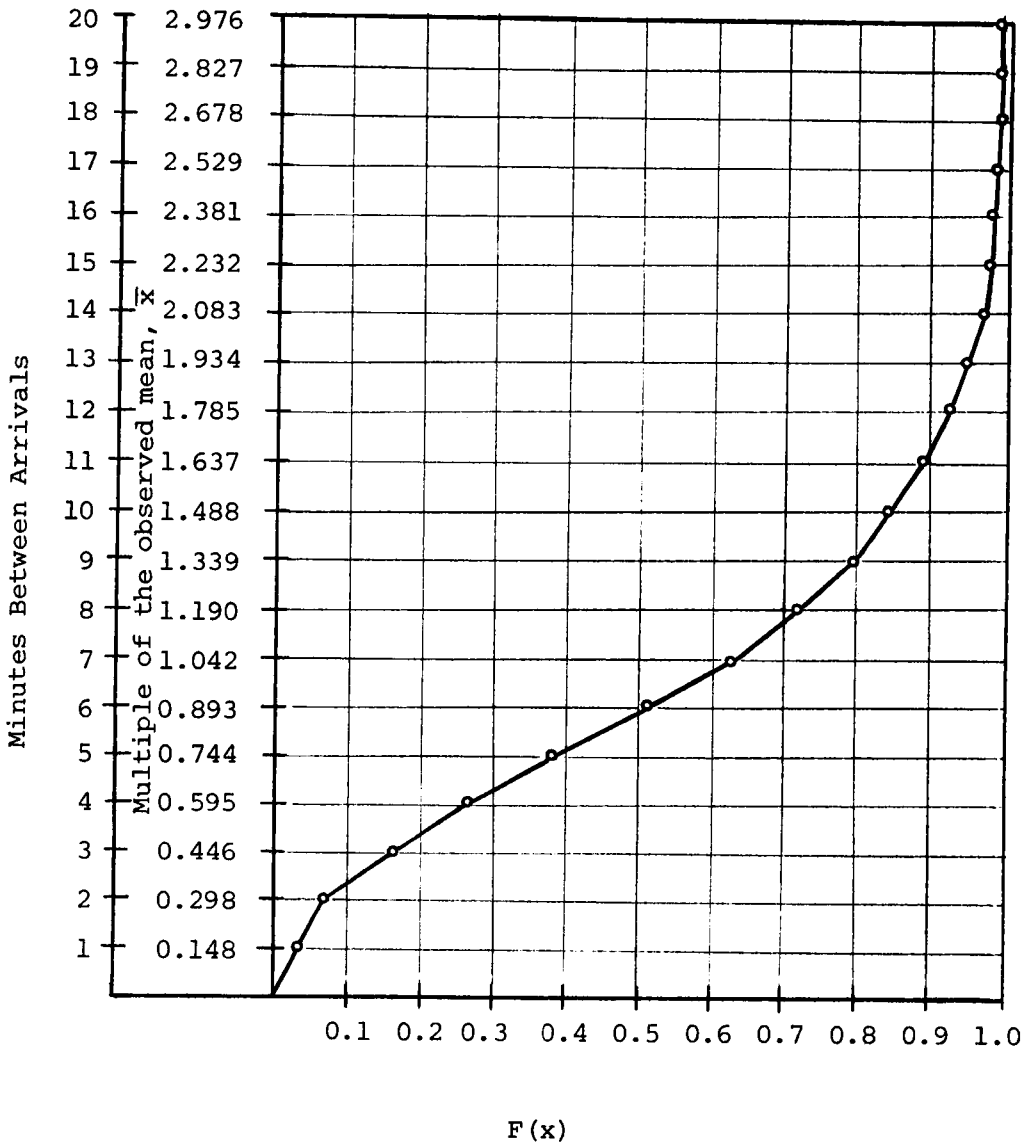

Figure 20. GPSS representation of the Admitting Office interarrival time distribution.

A function for assignment of patients to nursing units is defined for the model from the data in Table II on page 26. In the function, each nursing unit is assigned a discrete number between nine and twenty-two. The function is constructed similar to that described above for assignment of transaction types.

Service times at input facilities are included in a GPSS function statement. These service times are for finding the desired input card, reading the card into the terminal, and replacing it in its file. From observation of a similar system, it was found that the overall distribution of the service times was exponential. The mean varied depending upon the transaction type. The variation is explained by the differences in complexity of drug, lab test, and supply names, or by the higher usage of certain cards. This function is continuous and constructed as those for inter-arrival times described above.

Matrix Definitions

Matrices are used in three ways in the simulation program. They contain (1) the specifications associated with each transaction type, (2) the mean interarrival time values in one-tenth second units for each input station by hour of the day, and (3) a tabulation of the number of each type of transaction from each input station.

Each transaction has associated with it several characteristics as follows: (1) a priority code, (2) mean input time, (3) mean printing time at its destination, (4) number of destinations or copies, and (5) the identification codes for each destination facility or file. These specifications are contained in halfword matrices. There is a matrix for each input station except Nursing. It was found that similar types of transactions were generated at all nursing units and these could be defined in a single matrix. Each row of the matrix represents a different transaction type and the columns contain the five specifications identified above.

In order to change the mean interarrival times each hour, data are initialized in a matrix before the program begins execution. The rows of the matrix represent the input stations and the columns represent the hours of the day.

The number of transactions generated during each experimental run of the simulation model are added one at a time to a matrix. The columns of the matrix represent the transaction type (as identified in specification tables in Chapter Three). The rows of the matrix represent the number of the input station where the transactions were generated.

The reader can find a detailed listing of the matrices used in the "matrix definition" section of the simulation

program. This information is not presented here as it can be found in the Appendix.

Variable Definitions

The program uses seven arithmetic variable entities. The first variable is used to identify the column number of the specification matrices where the destination facility or file can be found. In the CPU section of the program, a number of copies of each transaction is split from the parent. One copy is transmitted to each predefined destination of the message or order. Copies are automatically given a sequence number in their sixth parameter. The original transaction is terminated. Copy one has a 2 placed in P6, copy two has a 3, and so on. By adding 3 to P6, the parameter can be used to indirectly address columns {j = 5, 6, . . ., n} of the specification matrices.

The second variable determines the hour of the simulation from the relative clock, C1. Since each element of a variable statement is evaluated and truncated, the constant value of 1 must be added to C1 divided by the number of one-tenth second units in an hour. During the first hour of simulation, the expression C1/36000 equals zero. The constant 1 must be added so that V2 is equal to 1 during the first hour.

The third variable is used simply to add 1 to the value of parameter five of the calling transaction. This variable is used in the Emergency Room section to count the number of lab tests and x-rays which must be assembled before the physician can admit or discharge the patient. One is added to P5 so that the original transaction is assembled with the P5 copies.

Variables four and five are used to convert sequential printer numbers to facility numbers. For example, the first printer is facility number 2. The second printer is facility number 4. With reference to variable four, P4 of each transaction calling V4 contains the number of the facility from which it originated. By multiplying P4 by 2, we get the number of the printer to which verification messages are returned. In the event that a transaction, originating at the Admitting Office or Emergency Room, is to be sent to a nursing unit, P3 of the transaction contains the number of the input station (nursing unit number). This number is multiplied by a 2 in order to obtain the printer number corresponding to the input station number. This calculation is made by addressing variable five.

Variable six is used to calculate the time between transaction arrivals at the CPU. As each transaction enters the block labeled "CPU," the difference between the current clock time and the time of the last arrival (saved in X25)

is calculated and tabulated. Then the old time in fullword SAVEVALUE 25 is replaced by the current clock time in preparation for the next tabulation.

Variable seven allows the experimenter to uniformly increase or decrease the mean interarrival times without repeated keypunching of every value in the interarrival time matrix. Two forms of this variable can be used. The arithmetic form is used if the matrix is used without change. The floating-point form must be used if for example a 10 percent decrease in all interarrival times is to be used. This latter form prevents truncation until all calculations have been made.

Mean Interarrival Time Switch

A time switch is included in the model since the mean interarrival times required for field A of GENERATE blocks cannot be matrix savevalues. This section of the program transfers the values from column j of the mean interarrival time matrix to the first twenty-two fullword SAVEVALUES X1-X22 once each hour. It is important that these SAVE-VALUES be loaded in INITIAL blocks before the simulation is executed or the mean interarrival times for the first simulation clock unit will be zero. This will cause the system to instantaneously saturate.

Simulation of Area Stations

A generalized discussion of the simulation logic is presented for several sections of the computer program. The sections were chosen because they are either representative of a group of area stations or their complexity requires explanation. The sections to be discussed are the Admitting Office, Emergency Room, Central Supply, Laboratory, Surgery, and Nursing. The simulation logic of the computer processor is also included.

Admitting Office Simulation Logic

When a transaction is generated in the Admitting Office, it is assigned a type, a specification matrix, a place of origin, and a priority. The transaction either joins a queue or seizes the CRT terminal. The transaction is sent to the computer. Its return represents the displaying of a format. An amount of time advances to represent the entry of data. The transaction then goes back to the computer to be processed and distributed to the required areas. A copy of the transaction comes back to the CRT to represent acceptance by the system. Another copy comes back to the printer facility to represent a written log.

With reference to Table III on page 27, transactions numbered 1 through 5 are each independent activities. But, if a type 6 transaction is generated, it will enter a

looping section of program code representing admission of a patient. In this latter case, simulated entry of transactions numbered 6 through 13 occurs. After each transaction reaches the computer section in the program, it is split into a number of copies which are sent to printers or files specified in Table III (p. 27).

Before laboratory test orders are entered, the number of the nursing unit assigned is placed in the "point of origin" parameter. This will allow a message to be sent to nursing notifying personnel that the test was ordered and results will be returned to Nursing instead of Admitting. Figure 21 shows a generalized block diagram of the simulation logic described above.

Emergency Room Simulation Logic

The simulation logic for modeling the Emergency Room is presented in the block diagrams in Figure 22. Transactions are generated to represent patients' arrival for treatment. The specification matrix and origin parameters are assigned before the transaction enters queue. If the card punch and reader are not in use, the facility is seized. Time elapses to represent preparation and entry of patient socioeconomic data. An "Emergency Room usage charge" transaction type is assigned to a parameter. Time elapses for input of the charge to the system. A percentage of patients have their

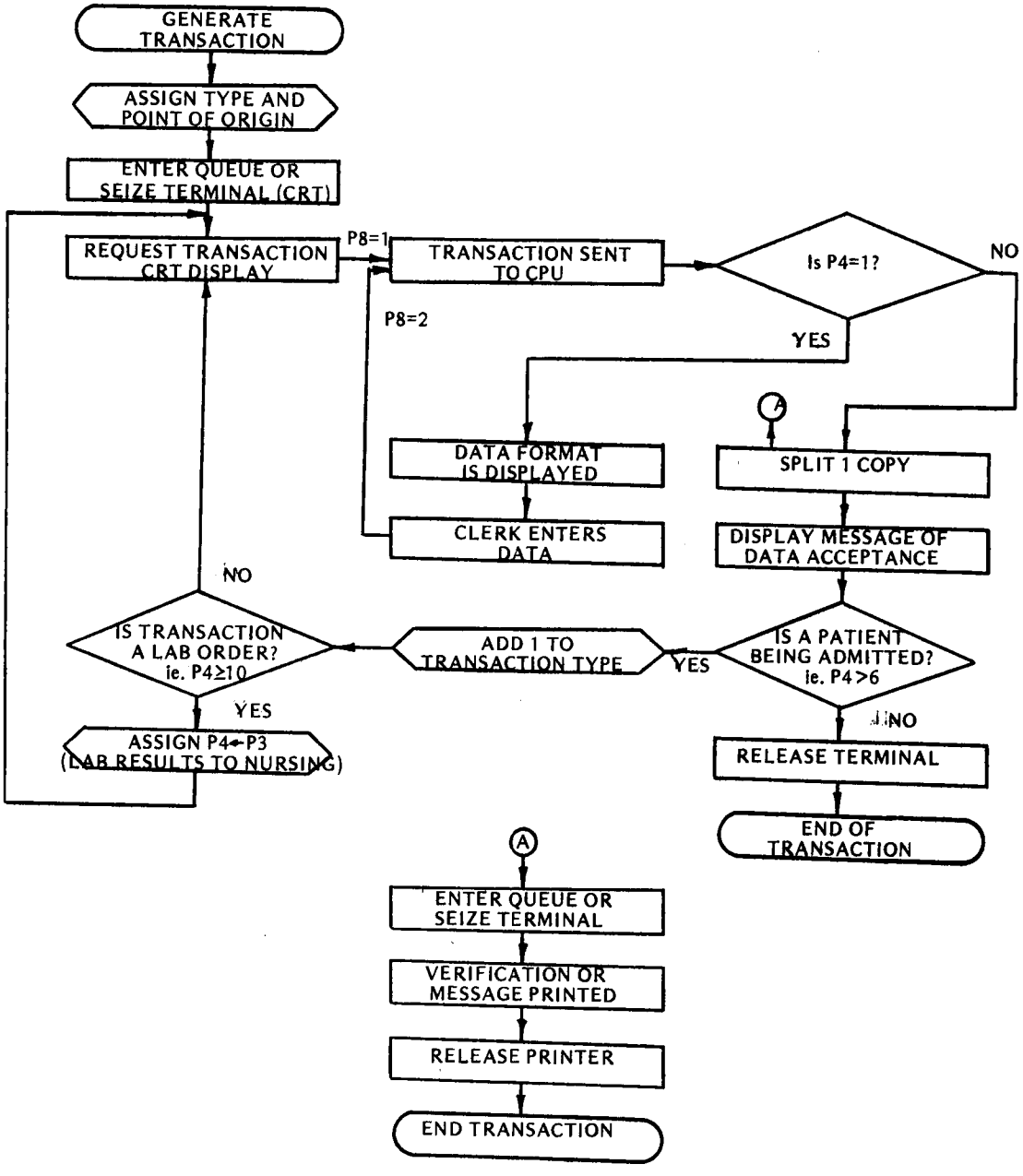

Figure 21. Schematic diagram of the simulation logic for the Admitting Office.

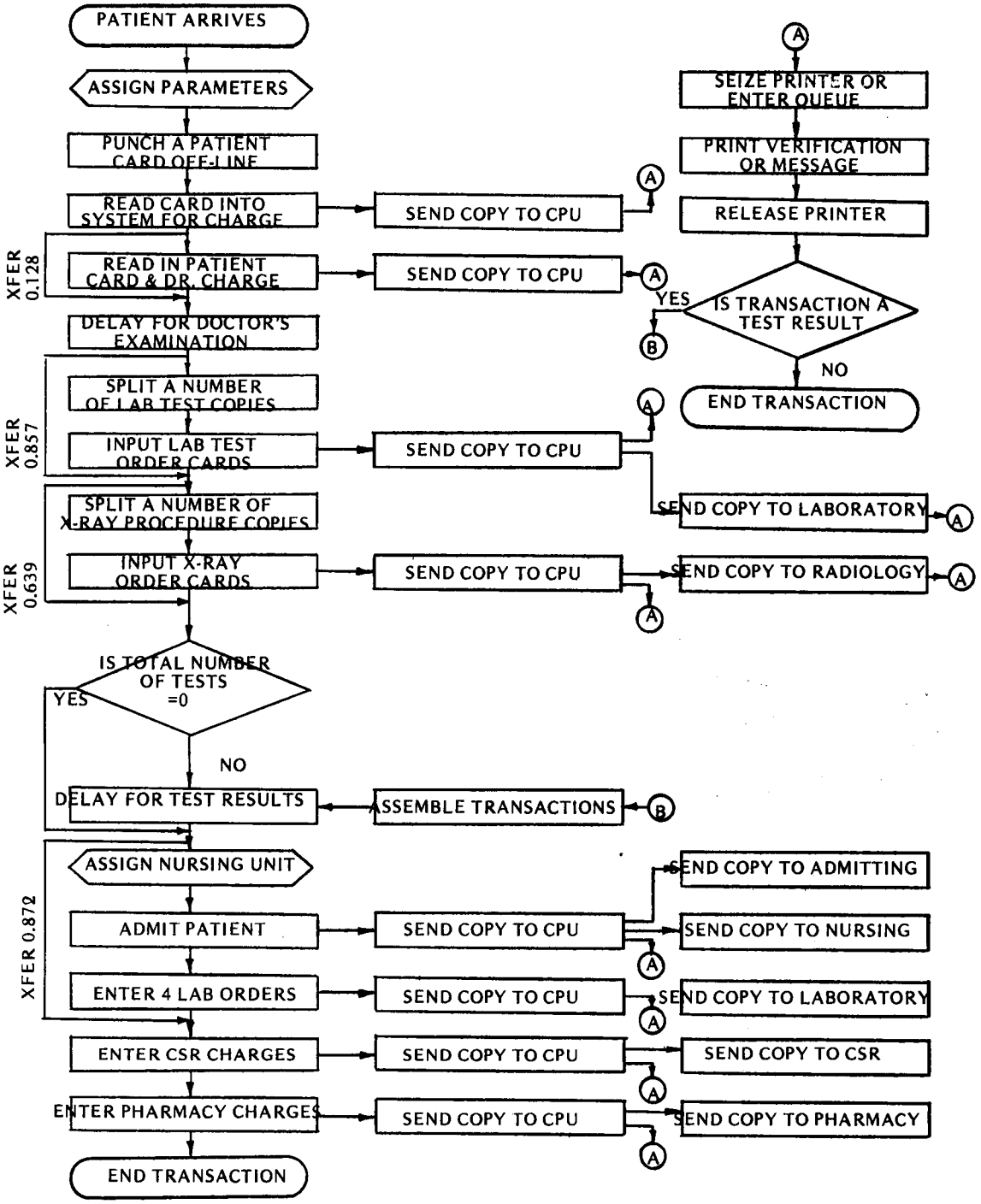

Figure 22. Schematic diagram of the simulation logic for the Emergency Room.

own doctors meet them in the Emergency Room. These transactions bypass the physician's charge. All other transactions are assigned a physician charge parameter and time elapses for their input.

After the doctor's charge is entered, the facility is released. Time is advanced for the physician's examination. The input facility is again seized or a queue is joined after the examination. A parameter type representing lab orders is assigned. The number of tests ordered by the physician are determined from a probability function. Time elapses for the entry of each. The number of x-rays are determined from another function and entered. The terminal is released and the parent transaction waits for lab and x-ray transactions to be assembled. If there are no tests ordered, the parent transaction branches around the assembly area and does not have to wait.

A percentage of patients are admitted to the hospital. This is represented by an assignment of the transaction to a nursing unit. Time is advanced to represent entry of the admission notification. A copy of the parent transaction is split and routed to the assigned nursing unit by way of the computer processor. The parent transaction next enters a loop and cycles through it four times. This represents the entry of four standard laboratory test orders. More than 87 percent of the parent transactions branch around the code

described in this paragraph. This branching represents discharge of the patient from the Emergency Room.

After a transaction has passed through or branched around the admission section, a parameter is assigned to represent drug or medication charges. The number of drugs used is obtained from a probability function. The parent transaction enters a loop and cycles one time for each charge. During each cycle, time advances to represent data entry. A copy of the parent is split and sent to the processor with each cycle. The parent enters a final loop that represents entry of medical supply charges. The transaction then leaves the model.

Laboratory and Radiology Simulation Logic

Three types of transactions will enter the Laboratory and Radiology sections of code as follows: (1) nursing test orders, (2) Emergency Room test orders, and (3) verification from the central processor that test results were transmitted. Upon arrival, a transaction seizes a printer or joins a queue. Time is advanced after a transaction seizes the printer and the printer is then released. If the transaction is a verification that a former transmission of a test result was accepted, the transaction is terminated. Otherwise, time is advanced to represent performance of a test.

Transactions input to the system are of two types, (1) test results, or (2) generated transactions from Radiology only. In the case of test results, the specifications for this type transaction are contained in the Laboratory or Radiology matrices. The station number from which the original order was placed is assigned to parameter number 3 and the station number for Lab or Radiology is placed in parameter 4. The specification matrices show a 99 as the destination of the test results. This code forces transmission of the transaction to the input station whose code is in parameter three.

Transactions generated from Radiology are simply entered into the input terminal and routed to the central processor. There, a copy is produced. The original transaction comes back to Radiology to represent verification of acceptance. The copy goes to CSR or Pharmacy to represent a charge or order. Figure 23 shows a block diagram of the logic described above.

Central Supply Simulation Logic

Two types of transactions will enter the Central Supply section of program code as shown in Figure 24. These types are supply orders and verifications that messages generated in CSR were transmitted. The transactions seize the CSR printer or enter queue. All transactions are terminated

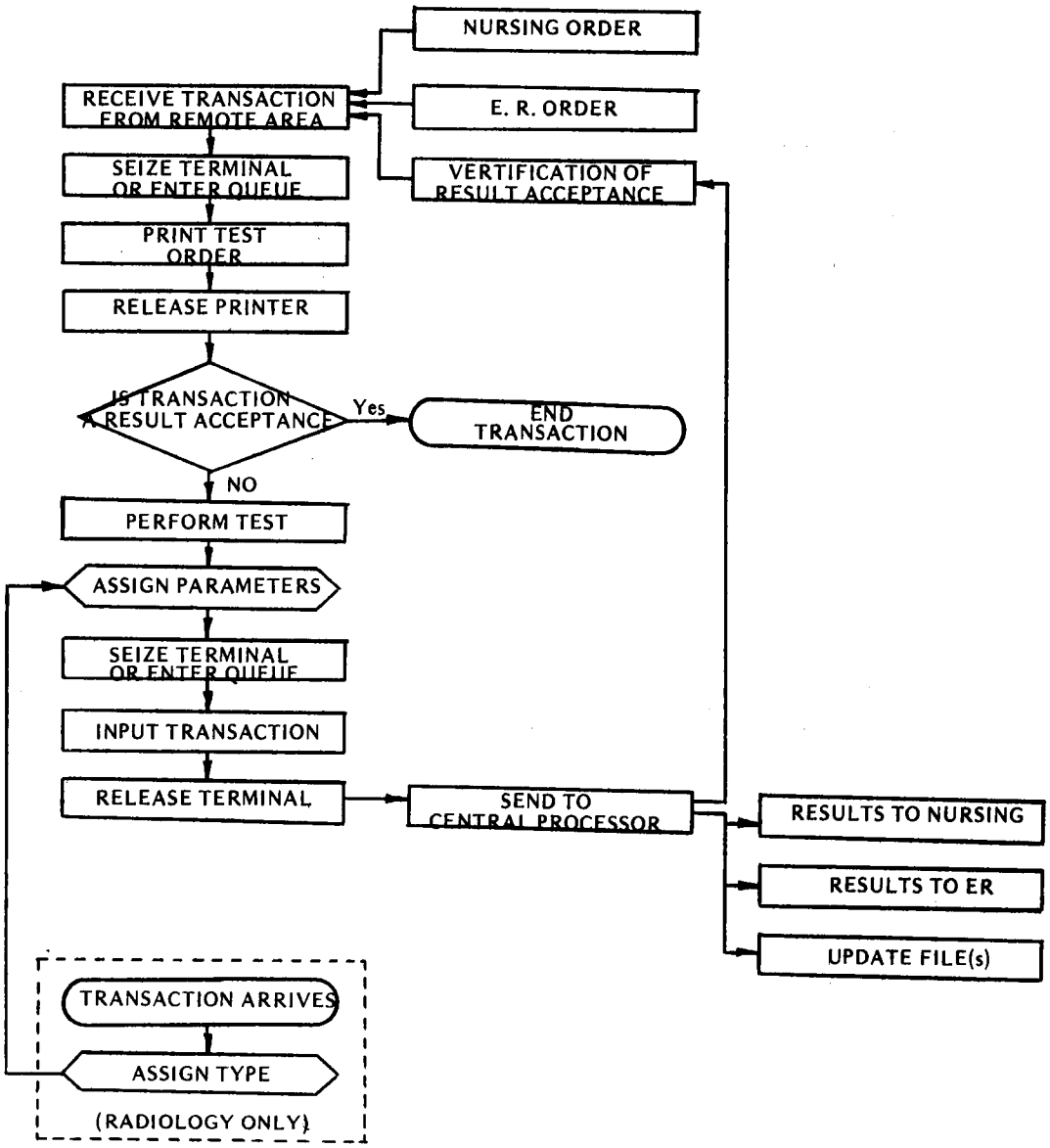

Figure 23. Schematic diagram of the simulation logic for Laboratory and Radiology.

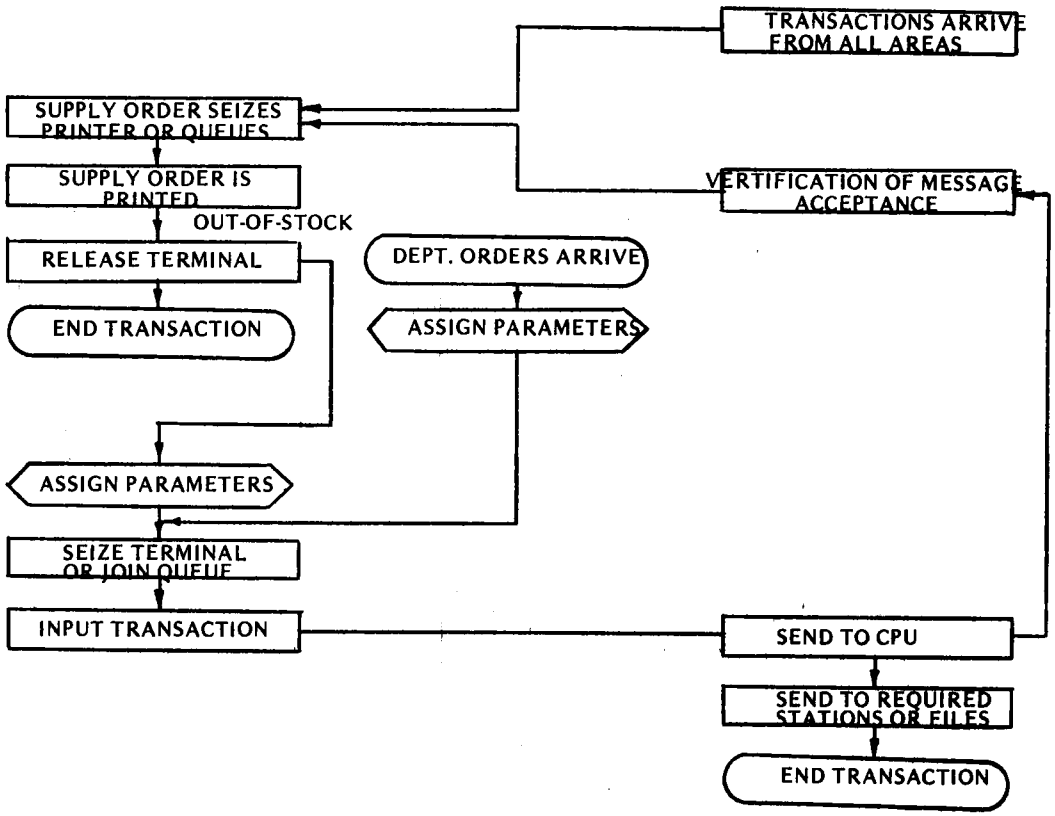

Figure 24. Schematic diagram of the simulation logic for Central Supply.

except those representing orders for supplies out-of-stock. The out-of-stock transactions branch to the section of code representing the input terminal. A parameter type for an out-of-stock transaction is assigned. The terminal is seized or queue joined. When free, the transaction is entered. It is routed to the computer processor where it is split into the required number of copies. These copies either represent files updated or messages returned to the station initially ordering a supply. One copy is routed back to the CSR printer to close the communication loop. This copy represents a message verifying entry of a credit, charge, or out-of-stock transaction.

Surgery Simulation Logic

The transaction flow through the section of code representing surgery is linear in appearance as shown in Figure 25. A transaction is generated to represent the completion of an operative procedure. The transaction either seizes an input terminal or enters a queue. The facility is not released until this parent transaction has completed its pass through the section of code.

When the transaction succeeds in seizing the input facility, time is advanced to represent entry of the operative procedure name. A copy of the parent transaction is sent to the computer processor. The parent proceeds on

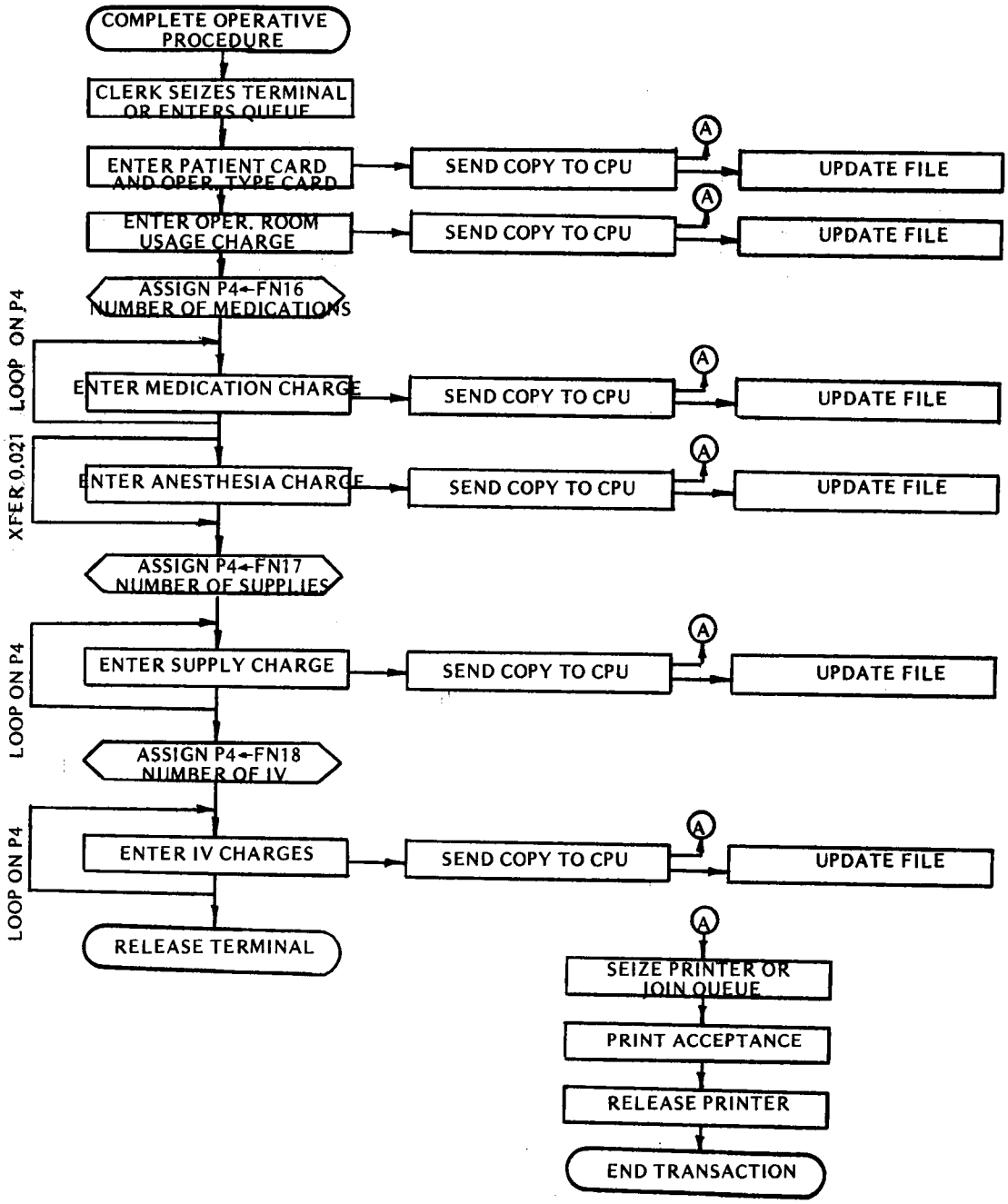

Figure 25. Schematic diagram of the simulation logic for Surgery.

through the code to represent entry of other data. At the processor, the copy is again split. One of the two copies updates the patient's file by writing the name of the operation therein. The other copy is sent back to facility in Surgery representing a character printer. This copy seizes the facility or enters a queue. Time is advanced to model the printing of a message verifying that the computer accepted the transaction.

While the copies are performing their functions, the parent is assigned another transaction type to represent the entry of an operating room usage charge. Again copies are split and proceed to update files and print a verification. This same procedure occurs for the tasks of entering medication charges, anesthesia charge, supply charge, and intravenous solution charges. If the number obtained from the medication function, for example is zero then no medication charges are made and the parent bypasses the time advance block. If the number obtained from the medication function is greater than one, the parent loops through the time advance block for charge entry n times. After the intravenous solution charges have been entered, the parent transaction is terminated and the input facility released.

Nursing Station's Simulation Logic

Using two macro blocks of code, the simulation of Nursing Station activities with respect to the communication

system is not complex. A macro is similar to a subroutine. The difference between the two is that a main program calls a subprogram which is located in core away from the main program. The subroutine usually is inserted at the end of the main program. When a call to the subprogram is made, program control branches to the area of core in which the subroutine is located. In comparison, the statements of a macro are assembled within the body of the main program and no branching or transfer of control is required during program execution.

One of the program macros simulates the input terminal connected with the system. The other macro models the printer. The program logic is simple as shown in Figure 26. Transactions are generated with a mean interarrival time that is updated each hour of simulation clock time. The mean time modifier is obtained by selection of a random deviate from an exponential function. The transaction represents a laboratory test order, a medication order, a diet change order, or other message. Upon generation, the transaction is assigned a type, point of origin code, and a matrix code in which specifications are defined. The transaction then seizes an input terminal or enters a queue. When the transaction is able to seize the facility, time is advanced to represent data entry. The transaction is transmitted to the computer processor. There, a number of

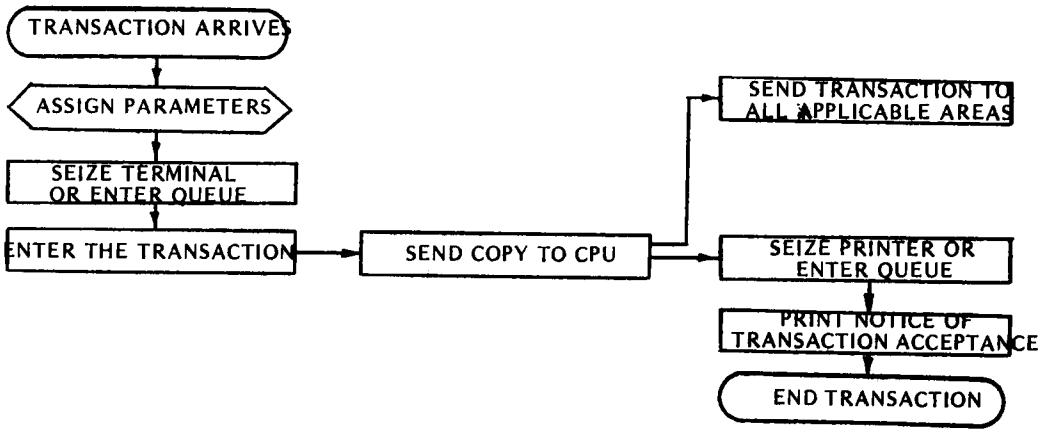

Figure 26. Schematic diagram of the simulation logic for Nursing Stations.

of copies are split from the parent and sent to the destinations specified in the matrix associated with the transaction's origin. The original transaction is routed back to the Nursing Station and enters the second macro representing a printer. The return of this transaction simulates acceptance notification from the system.

Computer Processor Logic

The central computer is modeled as a message processing and switching device. Figure 27 shows the logic used in the simulation program. When a transaction enters the CPU block, the amount of time elapsed since the arrival of the last transaction is tabulated and the current clock time is placed in a SAVEVALUE. The transaction either enters a queue or seizes the computer and is processed. When a transaction succeeds in seizing the computer, the time required to process it is 0.4 seconds. This time is obtained from Figure 28. It can be seen that the constant processing time of 0.4 seconds is valid for $0 \leq \lambda \leq 2$. Lamda is defined as the average number of messages arriving per second. As a result of several initial runs of the simulation program, lamda for the model was found to be 0.064 messages per second or the mean interarrival time was 15.625 seconds per transaction. This arrival rate is well within the applicable limits.

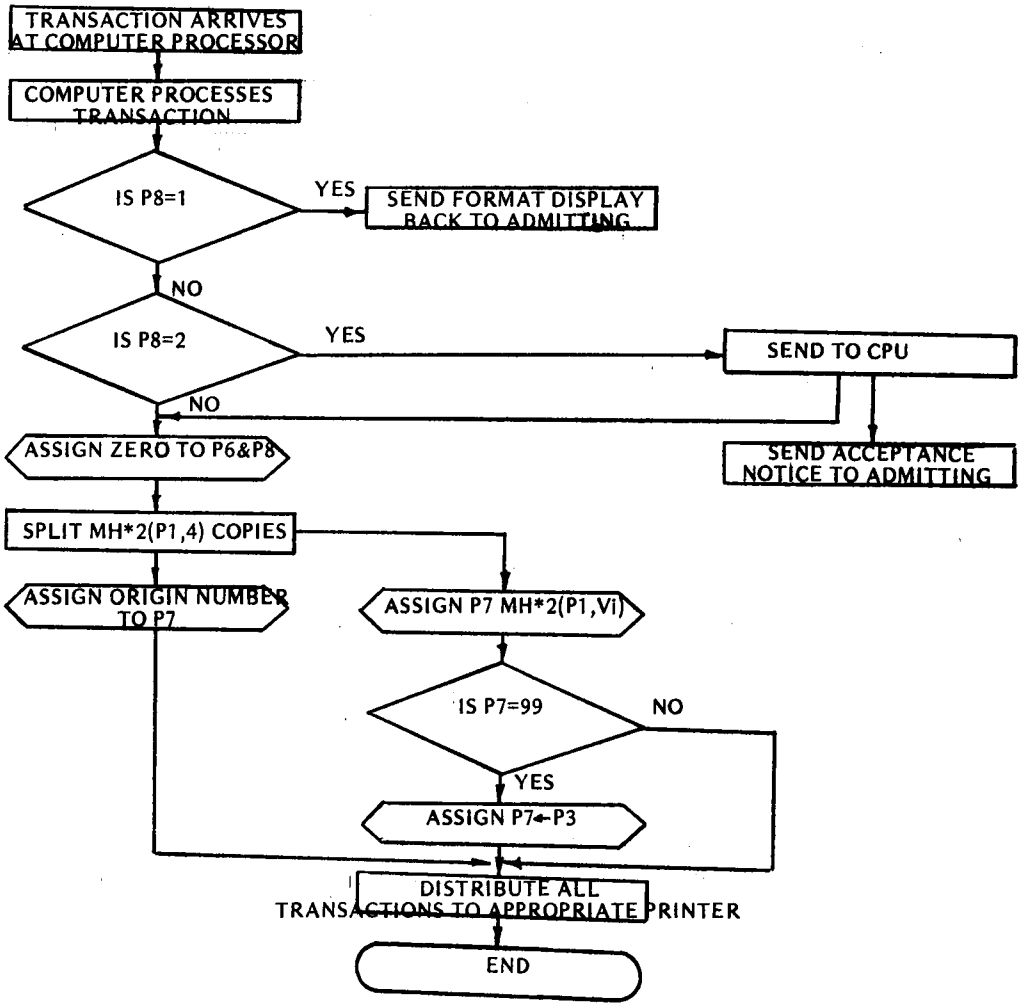

Figure 27. Schematic diagram of the simulation logic for the Computer Processor.

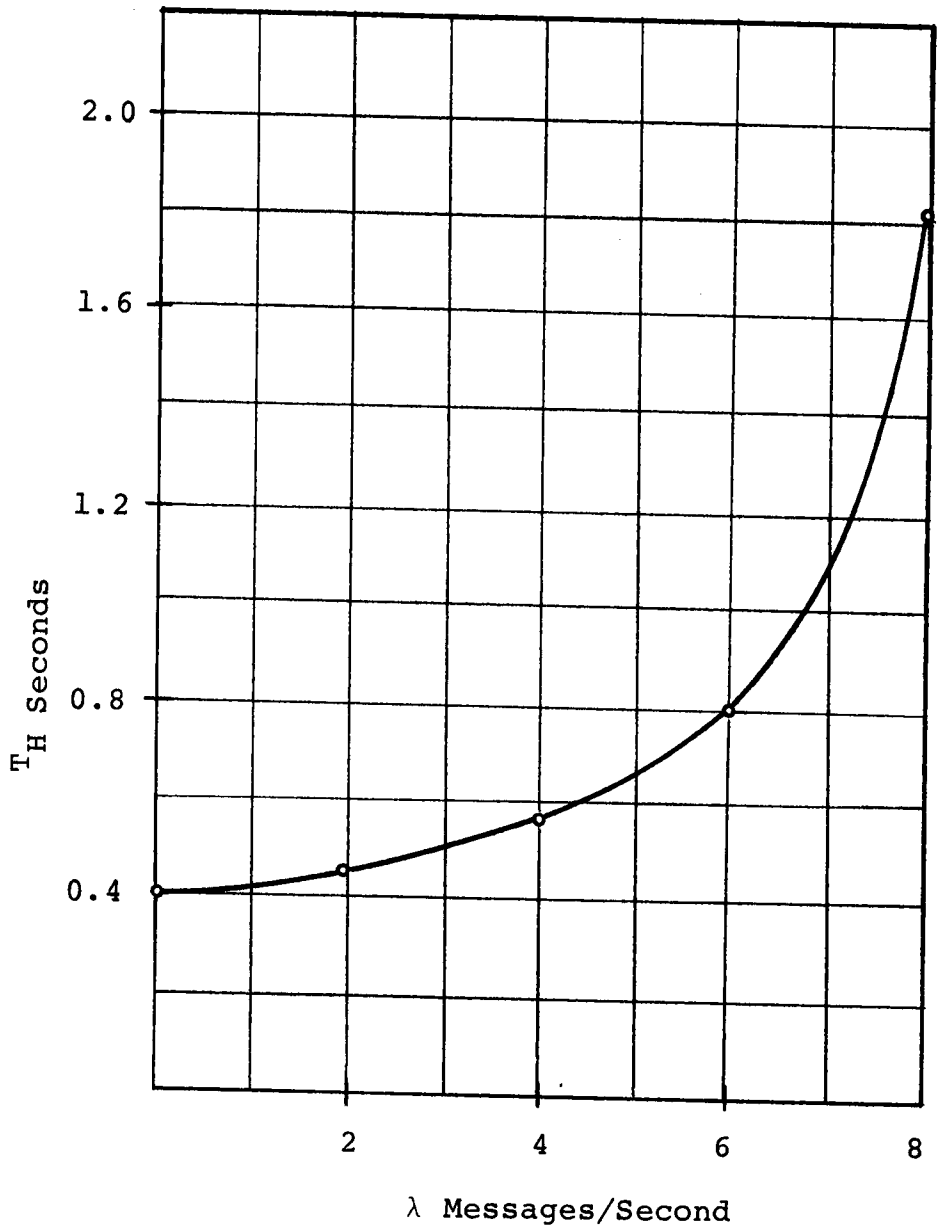

Figure 28. Message processing as a function of throughput.

Source: "Analysis of Some Queueing Models in Real-Time Systems," IBM Publication No. F20-0007-1.

After being processed, transactions are routed to appropriate terminals. Messages from a CRT representing request for a format on the screen are identified with a constant 1 in parameter 8. These are routed immediately back to the CRT. All other messages continue to pass through the program blocks. These transactions are split into the number of copies required. For example, a lab order would be split into three copies. One copy is sent to the laboratory printer. The second and third copies add one to SAVEVALUES representing master charge file inquiry and patient billing file update respectively. The original transaction is sent back to its place of origin to represent printing of a verification that it was sent and accepted by the system.

Note that area stations included within the network are assigned numbers 1 to 23. Input facilities are assigned odd numbers and printer or output facilities are assigned even numbers. In order to send the original transactions back to their originating station, the station identity number is multiplied by 2.

Length of the Simulation Run

A twelve hour period beginning at 8:00 A.M. and ending at 8:00 P.M. was chosen. The foremost reason for the choice was that a majority of hospital activity occurs between

these hours. Some departments such as Nursing and Emergency Room are in operation constantly. Other departments such as Laboratory, Radiology, and Surgery operate constantly but with a reduced staff for emergency as opposed to routine work during the night. The other departments close in the evening and reopen at 7:00 or 8;00 in the morning. For these reasons, any problems such as system overload or queueing should occur during the twelve hour period simulated.

Chapter Summary

A GPSS program is used to simulate the information system. The units of traffic in the system represent messages or patients but the basic unit submitted to the computer is a message. Twelve parameters are associated with each transaction. Fullword parameters are used to accommodate large values anticipated for clock time in parameter 9. Functions are used to assign transaction types, to determine interarrival times, and to calculate service times. Matrices are used to define message specifications, to store the mean interarrival times by hour of the day, and to tabulate the number of transactions by type from each input terminal. The simulation logic for the area stations was shown with the aide of block diagrams. Two MACRO subroutines are used to model areas having identical logic sequences

such as nursing stations. The central processor is modeled as a switching or message distribution facility. The period of interest is 8:00 A.M. to 8:00 P.M. since it is certain that overload problems if any would occur during these hours.

CHAPTER V

VERIFICATION AND STABILITY OF THE MODEL

Introduction

After a simulation program is written, the big question facing the engineer is whether the model is correctly simulating the real world or whether there are some logical or programmed flaws in it. When the model is found to be correct, it must be determined whether statistics should be accumulated from a start up or a steady state condition. The length of simulation time must also be determined at which the model reaches steady state. This chapter deals with a discussion of these two aspects of simulation. The concepts are referred to as verification and stabilization of the model.

Verification of the Model Construction

There are two variables which determine whether or not a model is valid or has been constructed properly. The first variable is the accuracy in which the system was abstractly viewed by the engineer and subsequently programmed. The second variable is the validity of the input parameters. The usual method for verifying that the model does represent

the real world is to examine the simulation program for errors in logic or coding and to compare the simulation results with some actual statistical data.

Simulation Program

The validity of the model depends upon the accuracy of the logic contained in the model's block diagrams. These diagrams are the initial tools used to define expected relationships between the facilities modeled and to identify all the possible movements and delays of the traffic units.

From the block diagrams the simulation program is constructed and debugged. The analyst must look for clues in the simulation statistics that may point out logic errors. The block count, facility utilization, and queueing statistics are particularly useful for this type of search. Examples of several types of errors found in initial runs of the simulation are as follows.

The first observation was found in the simulation of the Emergency Room input terminal. The facility utilization of the terminal was unusually high compared to others in the model. The average time per transaction statistic was equal to approximately two hours. The block count showed that four transactions had been generated and all were still in the system after two hours of simulated time. In analyzing the code, it was found that two SEIZE blocks for the same

facility were included. The first transaction was blocked as it could not seize the same facility twice.

It was found that the utilization of many of the printer terminals was almost zero. The cause of this occurrence was that transactions were not being sent back to the stations where they originated. The return of the transactions was supposed to represent a message verifying their acceptance by the system. The transactions were instead entering a TERMINATE block in the computer processor subsystem. When this error was corrected another error resulted again in the Emergency Room subsystem. The transactions routed back as verification messages were being sent to the ASSEMBLE block where test results should have been put together for each patient as ordered. The verification messages always returned to the assembly block before the test results. Thus, when the test results were returned to the Emergency Room, the required number could not be assembled.

Simulation Parameters

A discussion of the simulation parameters was included in Chapter Three dealing with the definition of the model. The parameters include the distribution of transaction types, the mean interarrival times by hour of the day, the time to enter and print messages, and the overall interarrival of

transactions at input terminals. These latter data were fitted to theoretical statistical distributions. The theoretical distributions were used as the interarrival functions in the model as recommended by Hillier and Lieberman (21, p. 445).

A comparison of the simulation results with actual data representative of the hospital's operation is shown in Table XXVI.

TABLE XXVI

COMPARISON OF SIMULATION VERSUS ACTUAL DATA

Transaction Description	Simulation Results	Actual			Deviation from Maximum (%)
		Min.	Avg.	Max.	
1. Admit Patient	44	18	36	64	-31.3
2. Emergency Room Visits	34	6	29	53	-35.8
3. CSR Charges	382	197	302	478	-20.1
4. Laboratory Tests	492	276	452	643	-23.5
5. Pharmacy Drug	481	281	487	672	-28.4
6. Radiology Procedures	73	37	63	98	-25.5
7. Physical Therapy	77	25	67	118	-34.7
8. Surgery Visits	50	6	34	62	-19.4

The results from the simulation are shown to be within the limits of actual hospital operation for the key transactions in the model. It is seen from Table XXVI that the data were collected during a period of activity above the average in all cases. The deviation from the maximum transaction volumes is shown to range from 19.4 to 35.8 percent low.

The reader should note that this variation does not invalidate the model. The very purpose of simulation is to experiment with a system by looking at certain performance measures obtained at several different levels of activity.

Startup and Stability of the Model

For many types of simulation models, it is desirable that the systems attain a steady state before the accumulation of statistics begins. This state is found by running the simulation program and dumping the block counts at selected intervals of time. The entity of interest is the total number of transactions currently in the system when the internal "snap shot" is taken. The load on the system can be seen to increase and then converge at some point. The reader should note that the term "steady-state" does not mean that the number of transactions converges to a constant but may vary to some degree.

It is not however necessary for all systems to reach steady state. The literature notes that computer installations and power plants are two examples of systems that are not evaluated at steady state (25, p. 204). In the real-time computer model discussed here, it can be seen that the system never approaches a steady state condition. This fact is obvious because the mean interarrival times at each area terminal changes each hour during the day. Figure 29 shows

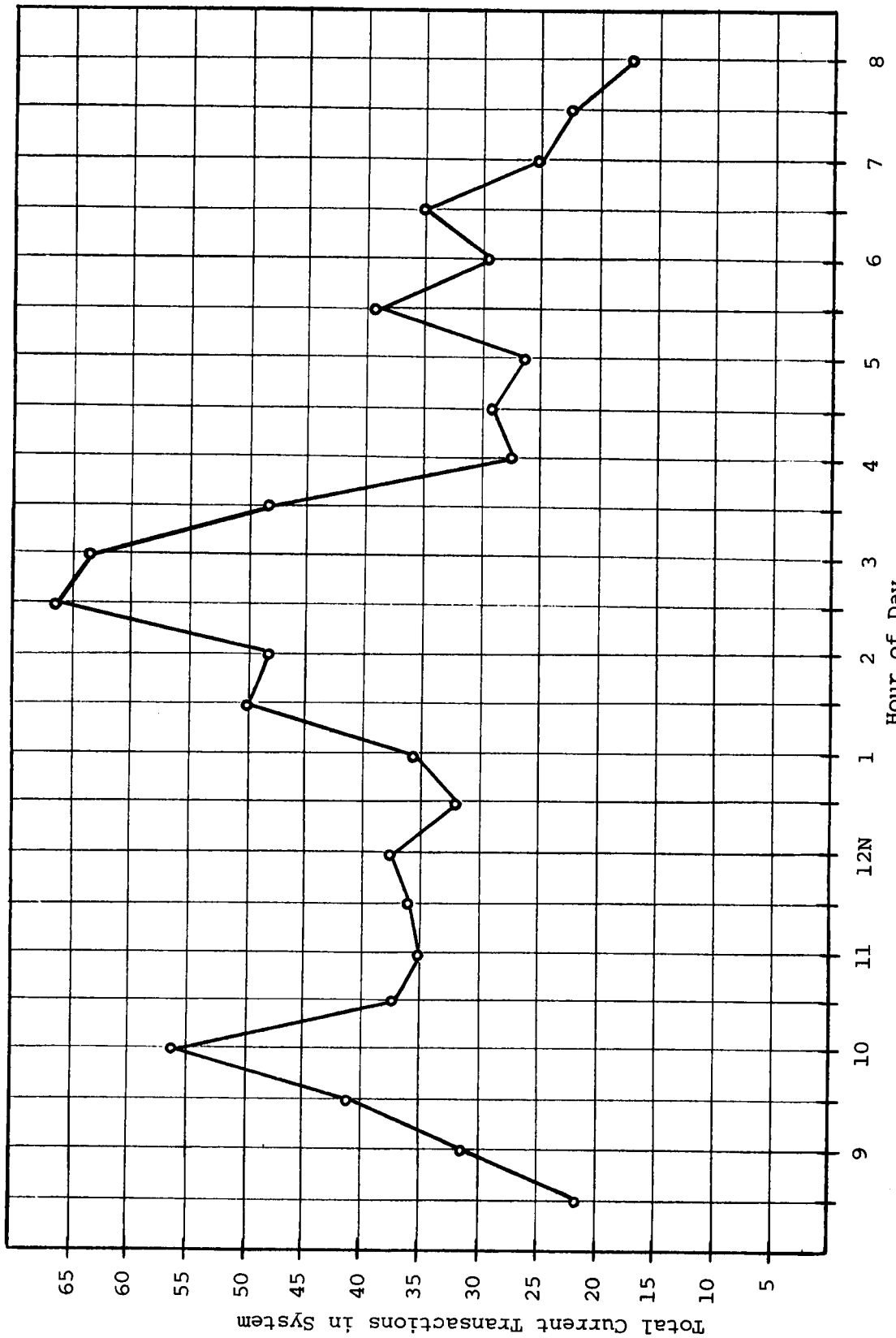

Figure 29. Total current transactions in the system at thirty minute intervals.

the total number of transactions in the system at thirty minute intervals.

Although the system in actuality would run continuously, except for downtime due to daily maintenance, the figure is believed to accurately approximate the morning loading and evening decline in load. As discussed in an earlier chapter, most of the activities within a hospital occur during the twelve hour period simulated. The most important measure to be studied is the peak load periods with overall utilization secondary. It is certain that only emergency activity would occur with respect to the system before 8:00 A.M. All areas of the hospital are closed except the nursing units, Laboratory, Radiology, and the Emergency Room. Note also that only skeleton crews are on duty in all areas to handle emergency situations.

Referring again to Figure 29, the system loads from 8:00 A.M. to 10:00 A.M. at which time incoming lab and x-ray orders decrease. At this point in time, technicians begin to catch up with the work load before lunch. During the hours of 1:00 P.M. to 2:00 P.M. the system begins to load sharply again. Between 2:00 P.M. and 4:00 P.M. the number of laboratory orders reaches its peak. This occurrence is a result of the high number of patient admissions and subsequently four lab tests with each admission. The number of transactions in the model varies between twenty and

thirty-five during the early evening and drops off toward 8:00 P.M.

Chapter Summary

When the debugging process of writing a simulation program is complete, the program's logic must be carefully checked. A close examination of the GPSS standard statistics can often disclose obvious transaction pile-ups or blocked movement. In the model defined here, the program logic was rechecked for proper coding. Various key output statistics were compared with actual data from a 400 bed hospital. The simulation statistics were found to be within the range of the actual data. The data were apparently collected during a period of above average activity. In analyzing the number of transactions in the model at thirty minute intervals, it was found that the system never reaches a steady state. The assumption is made that very little activity occurs with respect to the system during the late night and early morning hours. The peak periods of loading during the daytime hours are of major interest.

CHAPTER VI

RESULTS FROM THE MODEL

Introduction

Numerous experiments were performed with the model after it was constructed. The present chapter reviews the results of several investigations conducted. The interarrival times at input terminals were decreased in steps to determine the sensitivity of the system to increases in input rate. The volumes and types of transactions processed by the system were of interest.

Sensitivity of the Model

The first experiment performed consisted of varying the mean interarrival times for transactions at input terminals. The purpose of the experiment was to observe the sensitivity of the model to increased workload. The measures of interest were the utilization of the equipment, the queueing for data entry, and the distribution of interarrivals at the CPU.

Input Terminals

In theory, a percent decrease in interarrival time of p should result in a percent increase in the number of arrivals

of 1/(1-p). So, a decrease of 20 percent would be expected to cause a 25 percent increase in the number of facility seizures. In Table XXVII, the simulation results were fairly close to those expected. The 20 percent decrease forced 688 more transactions to seize input facilities. These transactions represent a 28.2 percent increase as opposed to the anticipated 25 percent.

Table XXVII shows that the highest utilized terminals were those located in the Admitting Office, Emergency Room, and Surgery. Since the utilization of the Admitting Office terminal was 44.7 percent at the normal arrival rate, the queue formation at that terminal was extremely sensitive to increases in arrival rate. The formation of queues at the various rates of transaction arrival is shown in Table XXVIII. As the utilization of the Admitting Office terminal increased from 0.447 to 0.626, or a percentage increase of 40.0, the maximum queue length ranged from five to forty-two transactions. By dumping the block count statistics at thirty minute intervals, it was found that the maximum queueing occurred during the peak admission hour.

The queue formation at the Emergency Room and Surgery input terminals were completely insensitive to increased arrivals. This result was due to the lower utilization of these facilities compared with that of the Admitting Office

TABLE XXVII

SENSITIVITY OF INPUT TERMINAL UTILIZATION

% Decrease in Interarrival Time	0%			5%			10%			15%			20%		
Total Times Seized	2442			2594			2746			2866			3130		
Terminals	Utl.	Ent.	Avg. Time	Utl.	Ent.	Avg. Time	Utl.	Ent.	Avg. Time	Utl.	Ent.	Avg. Time	Utl.	Ent.	Avg. Time
Admitting	.477	245	78.9	.509	261	84.3	.549	269	88.2	.529	282	81.2	.626	308	87.9
Emergency Room	.127	77	71.4	.120	82	63.7	.110	67	71.3	.135	71	82.6	.171	92	80.4
Laboratory	.054	491	4.8	.060	523	5.0	.069	588	5.1	.067	606	4.8	.082	691	5.1
Central Supply	.019	55	15.0	.020	60	14.9	.021	61	15.0	.021	61	15.0	.021	62	14.9
Pharmacy	.022	70	14.0	.027	76	15.9	.031	81	16.8	.034	83	18.0	.032	88	16.0
Radiology	.046	129	15.7	.058	130	19.5	.069	142	21.3	.064	156	17.9	.077	166	20.2
Physical Therapy	.039	112	15.1	.040	121	14.6	.047	129	15.8	.050	136	16.1	.052	143	15.8
Surgery	.123	52	102.7	.151	59	110.6	.163	64	110.4	.146	57	110.7	.223	82	117.5
3 West	.030	96	13.6	.027	95	12.5	.041	120	15.0	.039	121	14.0	.043	127	14.9
4 East	.036	107	14.7	.037	115	14.1	.039	121	13.9	.039	131	13.2	.047	126	16.4
4 West	.025	72	15.0	.029	84	15.2	.031	85	16.0	.024	77	14.0	.025	79	13.7
4 North	.008	22	16.0	.007	27	12.5	.009	25	16.4	.011	27	18.8	.004	23	9.1
5 East	.037	112	14.6	.027	82	14.4	.030	96	13.8	.047	124	16.4	.037	121	13.4
5 West	.032	83	17.0	.028	96	12.7	.033	91	16.1	.035	100	15.4	.035	118	13.1
6 East	.035	83	18.6	.031	92	15.0	.035	90	17.2	.031	93	14.6	.035	108	14.3
6 West	.027	86	13.9	.031	87	15.5	.043	121	15.5	.027	95	12.7	.031	90	15.2
7 East	.022	89	11.0	.039	104	16.2	.040	107	16.5	.032	100	13.9	.032	110	12.7
7 West	.037	93	17.2	.035	106	14.3	.029	101	12.8	.032	93	15.0	.037	107	15.2
8 East	.043	119	15.6	.036	112	14.2	.038	113	14.5	.047	152	13.4	.049	139	15.3
8 West	.035	96	15.9	.038	109	15.1	.030	97	13.6	.033	109	13.4	.038	117	14.2
IMC	.027	76	15.8	.034	90	16.6	.024	79	14.1	.032	102	13.7	.039	118	14.5
ICU-CCU	.028	77	16.0	.028	83	15.0	.033	99	14.7	.027	90	13.3	.045	115	16.9

TABLE XXVIII

SENSITIVITY OF QUEUE FORMATION AT INPUT TERMINALS

% Decrease in Interarrival Times	0%			5%			10%			15%			20%		
Total Transactions Processed	2442			2594			2746			2866			3130		
Terminals	Max. Queue	% Zeros	Avg. Wait	Max. Queue	% Zeros	Avg. Wait	Max. Queue	% Zeros	Avg. Wait	Max. Queue	% Zeros	Avg. Wait	Max. Queue	% Zeros	Max. Wait
Admitting	5	55.9	131.3	10	50.5	216.5	10	41.2	291.3	26	41.8	776.7	42	25.0	1651.1
Emergency Room	3	89.6	192.9	2	93.9	47.5	1	94.0	162.6	2	92.9	295.8	2	83.6	74.4
Laboratory	3	93.0	6.8	2	93.6	5.8	3	90.6	5.6	2	92.2	5.1	3	88.1	5.4
Central Supply	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0
Pharmacy	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0
Radiology	1	95.3	5.4	1	94.6	22.2	2	95.7	26.7	2	98.0	51.3	1	92.7	21.6
Physical Therapy	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0
Surgery	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0
3 West	1	98.9	0.4	1	98.9	5.4	1	98.3	12.2	1	100.0	0.0	1	97.6	20.9
4 East	1	98.1	13.6	2	97.3	13.5	1	95.8	9.3	2	97.7	15.7	1	95.2	13.9
4 West	1	100.0	0.0	1	97.6	3.7	1	98.8	8.9	1	100.0	0.0	1	100.0	0.0
4 North	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0	1	100.0	0.0
5 East	1	98.2	7.2	1	98.7	7.4	1	100.0	0.0	1	95.9	15.2	1	97.5	6.7
5 West	1	100.0	0.0	1	100.0	0.0	1	97.8	9.1	1	100.0	0.0	1	98.3	14.1
6 East	1	100.0	0.0	1	100.0	0.0	1	98.8	20.6	1	98.9	27.1	1	99.0	0.1
6 West	1	100.0	0.0	1	97.7	20.7	1	95.8	14.1	1	100.0	0.0	1	100.0	0.0
7 East	1	98.8	3.4	1	99.0	11.2	1	98.1	12.8	1	100.0	0.0	1	99.0	13.8
7 West	1	100.0	0.0	1	99.0	4.4	1	100.0	0.0	1	98.9	22.9	1	99.0	19.9
8 East	1	100.0	0.0	1	99.1	1.0	1	97.3	4.3	1	97.3	9.5	1	100.0	0.0
8 West	1	97.9	12.5	1	99.0	6.1	1	98.9	55.1	1	100.0	0.0	1	98.2	24.7
IMCU	1	100.0	0.0	1	98.8	11.0	1	98.7	15.1	1	98.0	20.0	1	100.0	0.0
ICU-CCU	1	98.7	27.8	1	98.7	12.6	1	100.0	0.0	1	100.0	0.0	1	99.1	3.5

terminal. Similarly, the queue formation at nursing units and ancillary departments was found to be insignificant.

Printer Terminals

Table XXIX shows the effects of increased arrival rate at input terminals on the utilization of printer terminals. The printers with the highest utilization were located in the Laboratory, Central Supply, Pharmacy, and Surgery. All other terminals had utilization of 5 percent or less. The Laboratory printer was the only one to show significant sensitivity to increased input.

The nursing units particularly had low utilization factors. The purpose of these printers was to receive test results quicker and obtain verification of orders from the system. The low utilization may cause the analyst to question whether or not this design is worth the cost. An alternative way to report test results would be by telephone with a hard copy report delivered at a future time.

Since significant queueing did result in the Laboratory, Pharmacy, and Surgery, as shown in Table XXX, another design consideration should be made. Buffer space must be provided within the system to accommodate the backup of messages. As an alternative to this, a faster printer could be used or multiple printers could be located in the same area.

TABLE XXIX

SENSITIVITY OF PRINTER TERMINAL UTILIZATION

% Decrease in Interarrival Times	0%			5%			10%			15%			20%		
Total Times Seized	5447			5855			6218			6465			7287		
Terminals	Utl.	Ent.	Avg. Time	Utl.	Ent.	Avg. Time	Utl.	Ent.	Avg. Time	Utl.	Ent.	Avg. Time	Utl.	Ent.	Avg. Time
Admitting	.092	457	8.8	.105	523	8.7	.107	532	8.8	.114	564	8.7	.124	616	8.7
Emergency Room	.044	152	12.7	.042	146	12.6	.034	118	12.6	.042	146	12.5	.056	191	12.9
Laboratory	.325	1002	14.0	.345	1065	14.0	.386	1193	14.0	.397	1226	14.0	.453	1395	14.0
Central Supply	.110	439	10.8	.107	430	10.8	.111	442	10.9	.114	457	10.0	.121	485	10.8
Pharmacy	.187	491	16.5	.217	566	16.6	.223	573	16.9	.224	601	16.1	.239	647	16.0
Radiology	.064	204	13.6	.060	191	13.6	.070	223	13.6	.074	236	13.7	.080	254	13.6
Physical Therapy	.043	143	13.1	.041	140	13.0	.047	157	13.0	.054	181	12.9	.054	181	13.1
Surgery	.109	364	13.0	.131	438	13.0	.131	435	13.0	.125	417	13.1	.191	638	13.0
3 West	.045	153	12.9	.056	190	12.9	.055	189	12.7	.060	200	13.0	.080	268	13.0
4 East	.050	173	12.7	.053	182	12.6	.063	212	12.9	.061	207	12.7	.065	222	12.7
4 West	.032	111	12.5	.036	124	12.7	.036	126	12.6	.042	142	12.8	.043	149	12.7
4 North	.009	30	13.0	.014	50	12.7	.011	39	12.7	.013	46	13.0	.018	61	13.4
5 East	.046	157	12.7	.047	159	12.8	.050	170	12.8	.050	172	12.6	.053	179	12.6
5 West	.040	141	12.4	.045	153	12.7	.048	162	12.9	.059	200	12.8	.064	213	13.0
6 East	.047	162	12.8	.043	146	12.9	.051	171	12.9	.057	189	13.0	.049	168	12.7
6 West	.045	155	12.6	.049	167	12.9	.070	237	12.8	.040	141	12.5	.045	153	12.9
7 East	.049	166	13.0	.048	165	12.6	.068	225	13.1	.062	209	13.0	.050	173	12.5
7 West	.045	156	12.6	.045	155	12.6	.043	151	12.5	.052	176	12.8	.062	209	12.9
8 East	.062	210	12.8	.061	206	12.8	.060	202	12.9	.072	246	12.7	.084	283	12.9
8 West	.042	142	12.8	.048	165	12.7	.039	134	12.7	.043	148	12.6	.058	196	12.8
IMCU	.037	127	12.8	.032	116	12.2	.044	147	13.0	.052	178	12.8	.054	185	12.7
ICU-CCU	.033	115	12.6	.046	158	12.6	.046	159	12.6	.046	157	12.7	.049	168	12.6
Dietary	.051	197	11.3	.056	220	11.1	.057	221	11.3	.058	226	11.1	.066	253	11.3

TABLE XXX

SENSITIVITY OF QUEUE FORMATION AT PRINTER TERMINALS

% Decrease in Interarrival Times	0%			5%			10%			15%			20%		
Total Transactions Processed	5447			5855			6218			6465			7287		
Terminals	Max. Queue	% Zeros	Avg. Wait	Max. Queue	% Zeros	Avg. Wait	Max. Queue	% Zeros	Avg. Wait	Max. Queue	% Zeros	Avg. Wait	Max. Queue	% Zeros	Avg. Wait
Admitting	2	88.8	3.8	2	86.2	3.5	2	87.2	3.0	2	86.8	4.0	2	84.4	3.6
Emergency Room	3	72.3	8.9	2	78.7	8.4	2	79.6	7.6	2	71.2	8.2	3	70.1	10.7
Laboratory	5	58.4	13.5	5	58.4	14.1	6	50.7	15.9	7	53.5	15.2	9	41.7	24.1
Central Supply	2	88.3	6.2	2	88.6	6.3	3	87.7	5.9	2	86.4	5.2	3	88.2	6.9
Pharmacy	4	75.9	25.7	5	72.0	26.9	5	74.5	31.6	4	73.3	27.8	4	71.8	26.7
Radiology	3	87.7	10.8	2	92.1	9.0	3	90.5	10.2	3	87.7	11.8	2	88.5	8.5
Physical Therapy	1	97.9	5.8	1	98.5	5.6	1	96.8	9.1	1	97.7	2.2	1	98.8	9.1
Surgery	6	37.0	18.3	6	32.6	18.9	6	36.3	16.6	6	30.9	20.6	6	30.4	19.4
3 West	3	89.5	11.2	2	88.9	8.1	2	93.6	5.9	3	90.9	10.7	2	83.2	7.8
4 East	3	89.5	12.4	3	86.2	9.7	3	87.7	9.4	4	85.9	15.1	3	83.7	10.1
4 West	1	92.7	4.9	1	94.3	6.2	1	92.8	4.0	3	85.9	9.2	2	88.5	8.1
4 North	1	100.0	0.0	1	95.9	9.0	1	94.8	2.0	1	97.8	3.2	2	86.8	7.1
5 East	1	89.8	6.1	2	88.0	9.1	2	87.6	8.0	1	90.1	6.0	2	86.5	11.5
5 West	3	87.9	12.4	2	94.1	7.9	3	87.6	10.8	3	87.9	9.3	2	87.3	6.2
6 East	3	87.6	9.9	2	91.7	7.5	2	88.3	6.4	4	89.4	15.9	1	94.0	6.7
6 West	1	90.3	5.0	1	89.2	6.9	4	84.8	9.9	1	95.7	4.9	1	93.4	6.2
7 East	1	87.3	6.4	1	92.1	4.0	2	88.4	7.5	2	86.6	7.0	2	93.6	9.5
7 West	2	82.6	6.4	1	92.2	5.4	2	94.0	8.0	2	88.6	6.8	2	83.7	8.7
8 East	2	87.1	9.2	2	85.9	10.1	2	88.6	10.2	2	88.6	10.5	2	86.9	7.8
8 West	3	93.6	12.3	2	92.1	9.4	1	97.7	3.0	1	97.9	3.8	2	86.7	8.7
IMC	2	95.2	10.8	1	93.9	3.3	3	84.3	10.4	2	89.3	10.3	2	90.8	8.0
ICU-CCU	1	90.4	7.5	3	83.5	9.6	1	90.5	6.7	3	89.8	8.8	1	91.0	5.8
Dietary	1	95.4	4.9	2	95.4	7.1	1	91.4	6.3	1	97.3	5.2	1	95.2	5.6

Transaction Arrival at the CPU

The sensitivity of transaction arrival rate at the central processor unit was studied as shown in Figure 30. The increased arrival of transactions was achieved by decreasing the mean interarrival time at input terminals. This was done in increments of 10 percent. As a result of the experiment, the mode of the frequency distribution was at the two second class interval. The same mode occurred for all three levels of activity. The one, two, and three second class intervals were the more sensitive to the increased arrival rate.

There were twenty-five transactions that arrived at the CPU with zero time between arrivals. This meant that two or more tried to seize the CPU at the same time. These occurrences were found to be insensitive to the increased input.

A slight increase in the frequency distribution occurred for the class intervals between four and nine seconds. The right tail of the distribution was almost constant in appearance under the three levels of activity.

Data File Operations

In real-time computer systems, much of the activity concerns the updating of files. As each transaction enters the CPU, it may read or write on one or more files and then be terminated or routed to a remote printer. During the

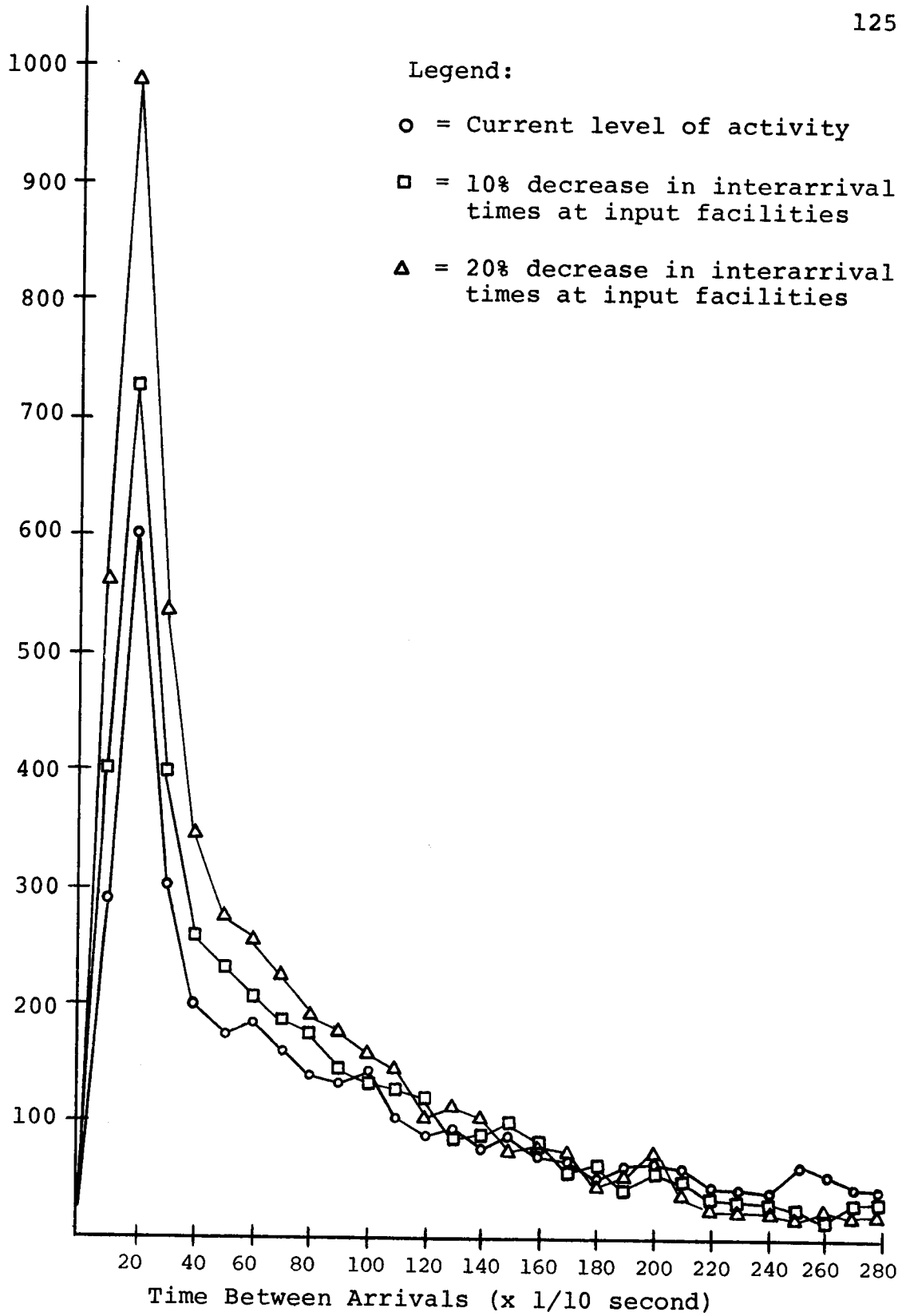

Figure 30. Distribution of CPU transaction interarrivals.

simulation run, the statistics were accumulated showing the number of file operations performed. These data for five experimental program runs are shown in Table XXXI. The ratio of file operations to transaction entries at the CPU was approximately constant at 1.27 for each of the five activity levels.

TABLE XXXI

DATA FILE READ/WRITE OPERATIONS

% Decrease in Interarrival Time at Input Facilities	0%	5%	10%	15%	20%
Total File Operations	4742	5198	5448	5630	6553
Files					
Hospital Bed Master	287	350	378	377	455
Inpatient Billing Master	1888	2084	2183	2238	2618
Outpatient Billing Master	138	122	119	142	164
Charge Description	1964	2125	2226	2311	2689
Preadmission File	339	378	393	406	458
Inpatient Number File	47	59	62	62	75
Hospital Department Charges	79	80	87	94	94

Volume of Transactions

The number of transactions input to the system was easily tabulated by the simulation model. The rows of the matrix shown in Table XXXII represent the point of origin and the columns represent the transaction type. By dumping the volume count matrix at thirty minute intervals, the experimenter can observe the types of transactions processed during different hours of the day. It was found that the Admitting Office places the greatest demand on the system.

Analysis of Queueing in Admitting

The formation of queues within the system could cause significant problems. By placing only one CRT in the Admitting Office, personnel using the system could become totally frustrated as a result of waiting. The queue statistics presented in Table XXVIII on page 120 are unrealistic for the Admitting Office since some alternative procedure would be self-devised by the personnel before queues of such magnitudes formed. The clerks would probably update files at some later time and defeat the real-time nature of the system.

The model allowed experimentation with the original configuration in order to get a better design. Additional CRT terminals were added to the model by constructing the macro ADMIT shown in the Appendix. The queueing discipline

TABLE XXXII

TRANSACTION VOLUMES BY ORIGIN AND TYPE

Transaction Origin	Transaction Type													
	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Admitting	52	6	64	74	2	47	47	47	47	47	47	47	47	574
Emergency Room	31	26	22	29	5	16	14							143
Laboratory	491													491
Central Supply	8	9	38											55
Pharmacy	21	32	17											70
Radiology	28	32	11	58										129
Physical Therapy	82	8	12	10										112
Surgery	52	52	23	52	151	34								364
3 West	6	22	3	5	9	8	2	23	3	0	4	7	4	96
4 East	4	23	6	4	19	12	1	17	5	0	6	10	0	107
4 West	4	16	1	1	18	6	2	11	1	1	8	3	0	72
4 North	1	6	1	0	0	2	0	5	4	1	0	2	0	22
5 East	4	18	7	1	17	8	8	29	6	0	1	11	2	112
5 West	1	12	2	0	24	7	1	19	4	2	4	7	0	83
6 East	4	16	1	1	10	10	4	19	2	1	3	10	2	83
6 West	2	17	5	1	20	7	4	18	2	0	4	5	1	86
7 East	5	22	2	1	10	12	2	16	1	2	1	12	3	89
7 West	4	14	2	5	11	12	3	22	3	1	7	4	5	93
8 East	5	32	2	4	18	15	2	23	5	0	4	5	4	119
8 West	5	22	5	2	14	9	4	20	5	1	4	4	1	96
IMC	2	22	4	5	7	10	1	10	3	1	6	4	1	76
ICU-CCU	5	8	5	1	13	8	3	23	2	0	4	5	0	77
Total														3149

was used to seize the first terminal not being utilized. If all were in use, the shortest queue was entered. The GPSS SELECT block was used to determine the choice of terminals.

Table XXXIII shows that the best configuration would consist of two cathode ray tubes. At the seventy patient per day admission level, the minor benefits of a third terminal could not justify the cost.

After the queueing at the Admitting Office terminal was reduced, a tremendous load was forced on the laboratory printer. Thus, it would be necessary to install a second printer, provide buffer space for up to fifteen test orders, or obtain a higher speed printer.

Response Time for Terminals

Transaction response time was observed to pose no significant problem to users at the Admitting Office cathode ray tubes. The user received a response in less than one second after transmitting data. For a typical simulation run 75 percent of all transactions input received a response within one second. Fifteen percent had response times between one and thirteen seconds. The remaining 10 percent of the transactions showed longer response times for printed messages as a result of queueing.

TABLE XXXIII

ANALYSIS OF QUEUE FORMATION AT ADMITTING CATHODE RAY TUBES--70 PATIENT ADMISSION LEVEL

Statistics	Number of Terminals			
	1	2	3	4
Maximum queue formation	42	2	1	1
		1	1	1
			1	1
				1
Average waiting time in queue excluding zero entries (in seconds)	1651.1	100.4	109.4	206.5
		96.9	97.2	0.0
			0.0	0.0
				0.0
Number of entries	308	207	197	190
		98	80	83
			30	26
				6
Percent of entries without wait	25.0	82.1	95.9	99.4
		84.6	96.2	100.0
			100.0	100.0
				100.0
Facility utilization	0.626	0.482	0.472	0.463
		0.218	0.173	0.181
			0.069	0.061
				0.023
Monthly cost	$300	600	900	1200

Chapter Summary

As a result of conducting various experiments with the simulation model, it was found that the system is generally insensitive to increased workload. One exception to this observation was found in the Admitting Office. Since the utilization of the terminal was approximately 50 percent and the high peaking volume during admission hours, the formation of queues was very sensitive. With respect to printers, the laboratory facility appeared to be the more significant problem area. When the queues were shortened in Admitting, the input rate to the laboratory increased and the queue was shifted to that printer.

The simulation model has allowed the analyst to identify the types of transactions entering the system, to design an initial system and experiment with the design, and to observe utilization, queueing, and system response. Finally, a balancing of facilities in Admitting and Laboratory was made possible.

CHAPTER VII

CONCLUSIONS

Construction of the Model

It has been shown that computer simulation can be an effective tool in modeling a hospital information system. The model has provided quantitative operational information on which to base decisions concerning the design of the system's function and configuration. In constructing the model, the analyst was required to plan the operation of the system with respect to each hospital department in great detail. The types of transactions to be input at each terminal and subsequently processed were identified. An initial configuration had to be specified. The model allowed manipulation of this configuration to reduce user queueing where required.

General Purpose Simulation System/360 was found to be a convenient media for modeling the information system. It was especially well suited to the analysis of queue formation. The standard output feature reduced programming time and complications considerably. The fact that GPSS models can be constructed in modules, as exemplified in this study,

made it particularly easy to add terminals or change their operating characteristics.

In this study, it was possible to fit theoretical probability functions to the observed data. Thus, some of the area stations could have been modeled analytically using the well known queueing equations. This would not have been possible if the data had to be used in its empirical form. The inability to fit data to a theoretical curve form causes no problem in simulation modeling. It is desirable to use statistical functions but with simulation, the data can be used validly in its observed form.

There were some disadvantages to simulating the information system. A considerable amount of data must be collected in order to define the interarrival time distributions, the changes in interarrival time by hour of the day, and the transaction type distributions. From experience, it has been found that data are more reliable if collected by the analyst or well-trained assistants. The cost of a simulation study has been found to be another disadvantage. The computer time required for the program construction, debugging, and experimentation was found to be expensive.

Recommendations for Future Research

For the user who finds this model applicable to his needs, it is recommended that a method for controlled data

collection be devised. It is also recommended that the researcher propose some means for statistically validating the acceptability of the data and the model itself to reality. This could be accomplished by comparing the results from a system model with its performance after installation. It was found that the validation of statistical models is an area that has received little attention in the literature.

The researcher may also be interested in inventing a modeling scheme based in some way on number of admissions, number of treatments performed, number of tests completed, or nursing unit percent occupancy. Relationships between the above measures and information system operation could best be observed by studying a system that is already installed.

BIBLIOGRAPHY

BIBLIOGRAPHY

1. Amato, V. V., "Computer Feasibility Studies: the do-it-yourself Approach," Management Review, 59:2-9, February, 1970.

2. Ball, M. J., "EDP Terminals: Speed, Legibility, Control," Modern Hospital, 117:119-122, November, 1971.

3. _____, "HIS: A Status Report," Hospitals, 46:48-52, December 1, 1972.

4. _____, How to Select a Computerized Hospital Information System. Basel, Switzerland: S. Karger AG, 1972.

5. _____, "Overview of Total Medical Information Systems," Methods of Information in Medicine, 10:73-82, April, 1971.

6. Barnett, G. O., "Can Computers Reduce Manpower Needs?--A Total System Viewed," Hospitals, 45:55-57, August 16, 1971.

7. Becher, H., Matt, K. H., and Rettenmaier, G., "Electronic Data Processing of the Recording of Hospital Services, Billing and Discharge of Patient," Methods of Information in Medicine, 11:28-32, January, 1972.

8. Bennet, W. L., Stroebel, C. F., and Gloeck, B. C., "A Patient-Centered Hospital Information System," Office, 69:65-68, May, 1969.

9. _____, "Systems Approach to Hospital Automation," Hospital Financial Management, 23:8-9, January, 1969.

10. Benson, D. R., "Computer Guide for Hospitals," Hospital Progress, 49:63-65, 84, November, 1968.

11. Brooker, W. M. A., "The Total Systems Myth," Systems and Procedures Journal, 16:28-32, July-August, 1965.

12. Dawson, M. G., and Rathbun, P. W., "Teletype Network Monitors Bed Status," Hospitals, 46:69-72, September 1, 1972.

13. Dearden, John, "Myth of Real Time Management Information," Harvard Business Review, 44:123-132, May-June, 1966.

14. Dixon, R. A., "Model of a Patient Medical Information System," Methods of Information in Medicine, 9:88-97, April, 1970.

15. Eckstein, E. F., and Wakefield, L. M., "Using the Computer for Menu Planning," Hospitals, 46:92, March 16, 1972.

16. Falick, J., "Automation Should Not Just Fit Old Forms but Aide New Functions," Modern Hospitals, 113: 96-101, October, 1969.

17. Gabrieli, E. R., "Systems Thinking--New Dimension in Hospital Functions," New York State Journal of Medicine, 69:3121-3127, December 15, 1969.

18. Gall, John E., "Demonstration and Evaluation of a Total Hospital Information System," El Camino Hospital, Mountain View, California (Unpublished paper).

19. Gillette, P. J., and Rathburn, P. W., "Hospital Information Systems," Hospitals, 44:76-78, August 16, 1970 and 44:45-48, 110, September 1, 1970.

20. Highland, H. J. (Ed.), Proceedings of the 1974 Winter Simulation Conference in Washington, D.C. Elmont, N.Y.: Association for Computing Machinery, 1974.

21. Hillier, F. S., and Leiberman, G. J., Introduction to Operations Research. San Francisco, California: Holden-Day, Inc., 1969.

22. Hospital Abstracts. London: Her Majesty's Stationery Office.

23. Hospital Systems Study Group, Hospital Information Study. Saskatchewan: University of Saskatoon, 1966.

24. Hsieh, R. K. C., "Evaluation of Formal Communications Systems in a Hospital," Health Services Research, 1:43-49, Winter 1966.

25. IBM Corporation, General Purpose Simulation System/360, User's Manual GH20-0304-4. White Plains, N. Y., 1969.

26. _____, Principles of Operation IBM System/360, GA22-6821-8. Poughkeepsie, N. Y., 1970.

27. _____, Hospital Data-Communication System Proposal to East Tennessee Baptist Hospital. Knoxville, Tennessee, December, 1971 (Unpublished).

28. Jacobs, S. E., "Your Guide to Hospital Computer Usage," Hospital Financial Management, 26:5+, September, 1972.

29. Keller, T. F., "Hospital Information System," Hospital Administration, 14:40-50, Winter 1969.

30. Kittle, Robert B., "Getting the Facts," Hospitals, 46:102-105, October 1, 1972.

31. Lockheed Missiles and Space Company, Description and Implementation Plan for the Faulkner Hospital Information System, LMSC/694654. August, 1969.

32. _____, El Camino Community Hospital Information System Analysis Report, LMSC/671062. 1965.

33. Martin, James, Design of Real-Time Computer Systems. Englewood Cliffs, N. J.: Prentice-Hall, 1967.

34. McFarlan, F. W., "Problems in Planning the Information System," Harvard Business Review, 49:75-89, March-April, 1971.

35. Meacham, A. D., and Thompson, V. B., Total Systems. Detroit, Michigan: American Data Processing Incorporated, 1962.

36. Murdick, R. G., and Ross, J. E., Information Systems for Modern Management. Englewood Cliffs, N. J.: Prentice-Hall, 1971.

37. Noble, J. H., "Designing Information Systems for Comprehensive Health Planning," Inquiry, 7:34-40, December, 1970.

38. Parreno, J., "Information Systems in Hospitals," Hospitals, 26:8-10, 12, 14, November 5, 1970.

39. Peters, J. R. (principle investigator), Comprehensive Hospital Computer Applications Program, PB-211 690. Rockledge, Florida: Eugene Wuesthoff Memorial Hospital, 1972.

40. Phillips, Don T., Applied Goodness of Fit Testing, AIIE-OR-72-1. Norcross, Georgia: American Institute of Industrial Engineers, 1972.

41. Plasman, F. B., "Medical Record--The Basis for an Integrated Computerized System," Michigan Hospital, 7:2+, August, 1971.

42. Platiau, P. E. B., Gallina, J. N., and Jeffrey, L. P., "Computer Improves Record Keeping," Hospitals, 46:90-95, November 16, 1972 and 46:61-64, December 1, 1972.

43. Polissar, J., "Hospital Computer Applications: Possible and Projected," Hospital Topics, 47:40+, April, 1969.

44. Pomrinse, S. D., "Cost-benefit Analysis of Computer," Hospitals, 46:76-82, March 16, 1972.

45. Pritsker, A. A. B., The GASP IV Simulation Language. New York, N. Y.: John Wiley and Sons, 1974.

46. Reeves, P. N., "Coordinating and Automating the Hospital's Information Planning Systems," Hospital Financial Management, 26:32-35, January, 1972.

47. Schmitz, H. H., "Evaluation of a Modular Hospital Information System," Hospital Progress, 53:70-76, June, 1972.

48. Schriber, Thomas J., Simulation Using GPSS. New York, N. Y.: John Wiley and Sons, 1974.

49. Schwartz, M. D., "Status of Hospital Information Systems," Hospital Progress, 51:52-60, June, 1970.

50. Shieman, B. M., "Medical Information System-El Camino Hospital," Industrial Medicine Surgery, 40:25-26, October, 1971.

51. Smith, L., "REACH System is Here, and Doctors Can Take It or Leave It," Modern Hospital, 114:94-98, February, 1970.

52. Spivey, B. E., and O'Neill, J., "The Use of Optical Scanning as a Means of Computer Input in Medicine," Journal of the American Medical Association, 208: 665-672, April 28, 1969.

53. Stimler, Saul, Real-Time Data Processing Systems. New York, N. Y.: McGraw-Hill Book Company, 1969.

54. Thomas, Kuruz, Smith, and Kelley, A Model of a Hospital Information System, NIH Grant #1306-993-A-50-642B. Buffalo, N. Y.: State University of New York Department of Industrial Engineering and Computer Center, September, 1965.

55. Thorne, Jack F., "Critical Factors in the Implementation of a Real-Time System," Data Management, 27:36-40, January, 1972.

56. Williams, K. G., "Around the World--the Systems Approach," Engineering Medicine, 1:70+, April, 1972.

57. Wilson, H. B., "How the Total Information System is Designed," The Office, 65:53-55, February, 1967.

APPENDIX

```
BLOCK
NUMBER  *LOC    OPERATION  A,B,C,D,E,F,G              COMMENTS
                SIMULATE
        *
        *       A SIMULATION MODEL OF A HOSPITAL INFORMATION SYSTEM
        *                            BY
        *                      DAVID B. KENNAMER
        *                  UNIVERSITY OF TENNESSEE
        *              DEPARTMENT OF INDUSTRIAL ENGINEERING
        *
 TERM   STARTMACRO
        GENERATE    #A,#B,,,,,F TRANSACTION ARRIVES AT INPUT TERMINAL
        ASSIGN      1,#C        ASSIGN P1=TRANSACTION TYPE
        ASSIGN      2,#D        ASSIGN P2=MATRIX TO REFERENCE FOR SPECS
        ASSIGN      4,#E        ASSIGN P4=POINT OF ORIGIN
        MSAVEVALUE  11+,P4,P1,K1,H ADD ONE TO XACT COUNT
        PRIORITY    #F          INITIALIZE PRIORITY
        QUEUE       #G          ENTER QUEUE FOR TERMINAL
        SEIZE       #G          SEIZE FACILITY
        DEPART      #G          LEAVE QUEUE
        ADVANCE     #H,#I       HOLD FACILITY TO ENTER TRANSACTION
        RELEASE     #G          RELEASE FACILITY
        MARK        9           PUT CLOCK TIME IN P9
        TRANSFER    ,CPU        TRANSMIT TRANSACTION TO CPU
        ENDMACRO
 PNTR   STARTMACRO
 #A     QUEUE       #B          ENTER QUEUE FOR PRINTER
        SEIZE       #B          SEIZE PRINTER
        DEPART      #B          LEAVE QUEUE
        TABULATE    2           TABULATE RESPONSE TIME
        ADVANCE     MH*2(P1,3),#C  HOLD FACILITY TO PRINT TRANSACTION
        RELEASE     #B          RELEASE FACILITY
        TERMINATE               DESTROY THE TRANSACTION
        ENDMACRO
 ADMIT  STARTMACRO
 #A     QUEUE       #B          ENTER QUEUE FOR CRT
```

```
          SEIZE       #B              SEIZE CRT FACILITY
          DEPART      #B              LEAVE QUEUE
#C        ADVANCE     50,FN23         HOLD FACILITY TO ENTER FUNCTION CODE
          ASSIGN      8,K1            ASSIGN P8=1 IMPLYS FORMAT REQUEST
          MARK        9               PUT CLOCK TIME IN P9
          TRANSFER    ,CPU            TRANSMIT TRANSACTION TO CPU
#D        TEST NE     P8,K1,#E        IF P8 .EQ. 1 GO TO #E
          TEST NE     P8,K2,#F        IF P8 .EQ. 2 GO TO #F
          TERMINATE                   ENTRY TO THIS BLOCK FLAGS AN ERROR
#E        ADVANCE     10              FORMAT IS DISPLAYED ON CRT
          ADVANCE     MH1(P1,2),FN23 ADVANCE TIME TO ENTER DATA
          ASSIGN      8,K2            ASSIGN P8=2 IMPLYS DATA SUBMISSION
          MARK        9               PUT CURRENT CLOCK TIME IN P9
          TRANSFER    ,CPU            TRANSMIT TRANSACTION TO CPU
#F        ADVANCE     10              DISPLAY ACCEPTANCE NOTICE ON SCREEN
          TEST GE     P1,6,#G         IF P1 .LT. 6 GO TO #G
          ASSIGN      1+,1            ADD 1 TO TRANSACTION TYPE
          ASSIGN      4,K1            ASSIGN P4=POINT OF ORIGIN
          MSAVEVALUE  11+,P4,P1,K1,H ADD ONE TO XACT COUNT
          TEST E      P1,K9,#H        IF P1 .NE. 9 GO TO #H
          ASSIGN      3,FN22          ASSIGN P3=NURSING UNIT FOR ADMISSION
          TRANSFER    ,#C             TRANSFER TO ENTER NEXT TRANSACTION
#H        TEST G      P1,K9,#C        IF P1 .LT. 9 GO TO #C
          TEST L      P1,K14,#G       IF P1 .GE. 14 GO TO #G
          ASSIGN      4,P3            PUT NURSING UNIT ASSIGNED IN P4
          TRANSFER    ,#C             TRANSFER TO ENTER LAB ORDER
#G        RELEASE     #B              RELEASE CRT
          TERMINATE                   DESTROY THE TRANSACTION
          ENDMACRO
*
*         FUNCTION DEFINITIONS
*
     1 FUNCTION   RN1,D6          ADMITTING TRANSACTION TYPES
.221,1/.269,2/.522,3/.769,4/.780,5/1.00,6
     2 FUNCTION   RN1,C20         ADMITTING INTERARRIVAL DISTRIBUTION
.013,.148/.069,.298/.162,.446/.275,.595/.393,.744/.505,.893
```

```
.606,1.042/.691,1.190/.762,1.339/.818,1.488/.863,1.637/.898,1.785
.924,1.934/.944,2.083/.959,2.232/.971,2.381/.979,2.529/.985,2.678
.989,2.827/.992,2.976
     3 FUNCTION   RN1,D5       NUMBER OF ER LABORATORY TESTS
.729,0/.834,1/.857,2/.872,3/1.00,4
     4 FUNCTION   RN1,D4       NUMBER OF XRAYS
.639,0/.932,1/.992,2/1.00,3
     5 FUNCTION   RN1,D5       NUMBER OF ER PHARMACY CHARGES
.624,0/.910,1/.963,2/.978,3/1.00,4
     6 FUNCTION   RN1,D3       NUMBER OF ER SUPPLY CHARGES
.662,0/.978,1/1.00,2
     7 FUNCTION   RN1,C31      ER INTERARRIVAL DISTRIBUTION
.124,.132/.233,.265/.328,.397/.411,.529/.484,.662/.548,.794/.604,.926
.653,1.058/.696,1.191/.734,1.323/.767,1.455/.795,1.588/.821,1.720
.843,1.852/.862,1.985/.879,2.117/.894,2.249/.907,2.382/.919,2.514
.929,2.646/.938,2.779/.946,2.911/.952,3.043/.958,3.175/.963,3.308
.968,3.440/.972,3.572/.975,3.705/.978,3.837/.981,3.969/.999,7
     8 FUNCTION   RN1,D2       C S R  TRANSACTION TYPES
.191,2/1.00,3
     9 FUNCTION   RN1,C22      CSR INTERARRIVAL DISTRIBUTION
.045,.474/.091,.526/.136,.579/.182,.632/.227,.684/.273,.737
.318,.789/.364,.842/.409,.895/.455,.947/.500,1.00/.545,1.053/.591,1.105
.636,1.158/.682,1.211/.727,1.263/.773,1.316/.818,1.368/.864,1.421
.909,1.474/.954,1.526/1.000,1.579
    10 FUNCTION   RN1,D3       PHARMACY TRANSACTION TYPES
.300,1/.770,2/1.00,3
    11 FUNCTION   RN1,C34      PHARMACY INTERARRIVAL DISTRIBUTION
.001,.149/.007,.223/.021,.298/.045,.372/.082,.447/.131,.521/.189,.596
.254,.670/.324,.745/.395,.819/.466,.894/.533,.968/.597,1.042/.655,1.117
.708,1.191/.754,1.266/.795,1.340/.830,1.415/.860,1.489/.886,1.564
.907,1.638/.925,1.713/.940,1.787/.952,1.862/.961,1.936/.969,2.010
.976,2.085/.981,2.159/.985,2.234/.988,2.308/.991,2.383/.996,2.606
.998,2.829/1.000,2.978
    12 FUNCTION   RN1,D3       RADIOLOGY TRANSACTION TYPE
.430,1/.800,2/1.00,3
    13 FUNCTION   RN1,C29      RADIOLOGY INTERARRIVAL DISTRIBUTION
```

```
.006,.254/.021,.339/.050,.424/.096,.509/.158,.594/.233,.678/.317,.763
.404,.848/.490,.933/.572,1.017/.646,1.102/.712,1.187/.769,1.272
.817,1.357/.860,1.441/.889,1.526/.915,1.611/.936,1.696/.951,1.781
.964,1.865/.973,1.950/.980,2.035/.985,2.120/.989,2.205/.992,2.289
.994,2.374/.996,2.459/.998,2.544/1.000,2.628
    14 FUNCTION   RN1,D4       PHYSICAL THERAPY TRANSACTION TYPES
.750,1/.820,2/.920,3/1.00,4
    15 FUNCTION   RN1,C28      PHYSICAL THERAPY INTERARRIVAL DISTRIBUTION
.005,.240/.018,.320/.043,.400/.083,.481/.137,.561/.204,.641
.279,.721/.360,.801/.441,.881/.520,.961/.594,1.041/.661,1.121
.721,1.201/.773,1.282/.817,1.362/.854,1.442/.885,1.522/.910,1.602
.930,1.682/.946,1.762/.959,1.842/.969,1.922/.976,2.002/.982,2.082
.987,2.163/.990,2.243/.993,2.323/.995,2.403
    16 FUNCTION   RN1,D4       NUMBER OF SURGERY DRUG CHARGES
.695,0/.887,1/.958,2/1.00,3
    17 FUNCTION   RN1,D12      NUMBER OF SURGERY SUPPLY CHARGES
.135,0/.341,1/.525,2/.632,3/.767,4/.809,5/.845,6/.923,7/.965,8/.986,9
.993,11/1.00,13
    18 FUNCTION   RN1,D3       NUMBER OF SURGERY IV CHARGES
.404,0/.971,1/1.00,2
    19 FUNCTION   RN1,C42      SURGERY INTERARRIVAL DISTRIBUTION
.082,.086/.158,.172/.227,.258/.291,.344/.350,.430/.403,.516
.452,.602/.497,.688/.539,.774/.577,.860/.612,.946/.644,1.032
.673,1.118/.700,1.204/.725,1.290/.747,1.376/.768,1.462/.787,1.548
.805,1.634/.821,1.720/.836,1.806/.849,1.892/.862,1.978/.873,2.064
.883,2.150/.893,2.236/.902,2.322/.910,2.408/.917,2.494/.924,2.580
.930,2.666/.936,2.752/.941,2.838/.946,2.924/.951,3.010/.955,3.096
.958,3.182/.962,3.268/.965,3.354/.968,3.440/.970,3.526/.999,7
    20 FUNCTION   RN1,D13      NURSING TRANSACTION TYPES
.038,1/.246,2/.286,3/.311,4/.462,5/.553,6/.580,7/.801,8/.839,9/.851,10
.902,11/.972,12/1.00,13
    21 FUNCTION   RN1,C41      NURSING INTERARRIVAL DISTRIBUTION
.096,.101/.183,.202/.261,.303/.332,.404/.396,.505/.454,.606/.507,.707
.554,.808/.597,.909/.636,1.010/.671,1.111/.702,1.212/.731,1.313
.757,1.414/.780,1.515/.801,1.616/.820,1.717/.838,1.818/.853,1.919
.867,2.020/.880,2.121/.892,2.222/.902,2.323/.911,2.424/.920,2.525
```

```
.928,2.626/.935,2.72/.941,2.828/.947,2.929/.952,3.030/.956,3.131
.961,3.232/.964,3.333/.968,3.434/.971,3.535/.974,3.636/.976,3.737
.978,3.838/.981,3.939/.982,4.040/.999,7
    22 FUNCTION   RN1,D14 PROBABILITY OF ADMISSION TO NURSING UNITS
.099,9/.176,10/.243,11/.263,12/.342,13/.431,14/.510,15
.599,16/.678,17/.747,18/.826,19/.891,20/.949,21/1.000,22
    23 FUNCTION   RN1,C24     EXPONENTIAL DISTRIBUTION
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
    24 FUNCTION   RN1,C21     DISTRIBUTION OF LAB AND XRAY TEST TIMES
.004,.522/.009,.574/.019,.626/.038,.678/.068,.731/.115,.783/.181,.835
.268,.887/.367,.939/.480,.992/.595,1.044/.702,1.096/.794,1.148
.867,1.20/.919,1.253/.955,1.305/.976,1.357/.988,1.409/.995,1.461
.998,1.514/.999,1.566
*
*       MATRIX DEFINITIONS
*
     1 MATRIX      H,13,9       ADMITTING TRANSACTION SPECIFICATIONS
     2 MATRIX      H,7,9        E R TRANSACTION SPECIFICATIONS
     3 MATRIX      H,1,8        LABORATORY TRANSACTION SPECIFICATIONS
     4 MATRIX      H,3,8        C S R TRANSACTION SPECIFICATIONS
     5 MATRIX      H,3,8        PHARMACY TRANSACTION SPECIFICATIONS
     6 MATRIX      H,4,8        RADIOLOGY TRANSACTION SPECIFICATIONS
     7 MATRIX      H,4,8        P T TRANSACTION SPECIFICATIONS
     8 MATRIX      H,6,8        SURGERY TRANSACTION SPECIFICATIONS
     9 MATRIX      H,13,8       NURSING TRANSACTION SPECIFICATIONS
    10 MATRIX      X,22,12      MEAN INTERARRIVAL TIME BY HOUR OF DAY
    11 MATRIX      H,22,14      XACT COUNT BY TYPE AND POINT OF ORIGIN
*
*       INITIALIZATION OF PARAMETERS
*
        INITIAL    MH1(1,1),1/MH1(2-4,1),2/MH1(5,1),1/MH1(6-13,1),2
        INITIAL    MH1(1,2),470/MH1(2,2),120/MH1(3,2),560/MH1(4,2),380
        INITIAL    MH1(5,2),170/MH1(6,2),220/MH1(7,2),720/MH1(8,2),260
        INITIAL    MH1(9,2),120/MH1(10-13,2),150/MH1(9,3),110
```

```
INITIAL    MH1(10-13,3),130/MH1(1-5,4),1/MH1(6,4),2/MH1(7-8,4),1
INITIAL    MH1(9,4),5/MH1(10-13,4),4/MH1(1-7,5),54/MH1(8,5),50
INITIAL    MH1(9,5),46/MH1(10-13,5),6/MH1(6,6),55/MH1(9-13,6),50
INITIAL    MH1(9-13,7),51/MH1(9,8),54/MH1(10-13,8),53
INITIAL    MH1(9,9),99/MH2(1-2,1),1/MH2(3-4,1),3/MH2(5-7,1),1
INITIAL    MH1(1-8,3),80
INITIAL    MH2(1,2),80/MH2(2,2),120/MH2(3-4,2),150/MH2(5,2),560
INITIAL    MH2(6-7,2),130/MH2(1,3),130/MH2(2,3),100
INITIAL    MH2(3-4,3),130
INITIAL    MH2(5,3),150/MH2(6-7,3),120/MH2(1-2,4),1/MH2(3-7,4),3
INITIAL    MH2(1-2,5),52/MH2(3,5),6/MH2(4,5),12/MH2(5,5),2
INITIAL    MH2(6,5),10/MH2(7,5),8/MH2(3-4,6),52/MH2(5,6),46
INITIAL    MH2(6,7),52/MH2(3-4,7),53/MH2(5,7),50/MH2(6-7,7),53
INITIAL    MH2(5,8),51/MH2(5,9),99/MH3(1,1),1/MH3(1,2),50
INITIAL    MH2(6-7,6),52
INITIAL    MH2(5,4),5
INITIAL    MH3(1,3),150/MH3(1,4),1/MH3(1,5),99/MH4(1-3,1),1
INITIAL    MH4(1-3,2),150/MH4(1-3,3),130/MH4(1,4),3/MH4(2-3,4),2
INITIAL    MH4(1-2,5),51/MH4(3,5),56/MH4(1-3,6),53/MH4(1,7),99
INITIAL    MH5(1,1),1/MH5(2,1),2/MH5(3,1),1/MH5(1,2),150
INITIAL    MH5(2,2),170/MH5(3,2),150/MH5(1,3),130/MH5(2,3),450
INITIAL    MH5(3,3),130/MH5(1-3,4),2/MH5(1,5),53/MH5(2,5),10
INITIAL    MH5(3,5),51/MH5(1,6),56/MH5(2,6),51/MH5(3,6),53
INITIAL    MH6(1-4,1),1/MH6(1-3,2),150/MH6(1-3,3),130
INITIAL    MH6(1-2,4),3
INITIAL    MH6(3,4),2/MH6(4,2),230/MH6(4,3),150/MH6(4,4),1
INITIAL    MH6(1,5),10/MH6(2,5),8/MH6(3,5),51/MH6(1-3,6),53
INITIAL    MH6(1-2,7),51/MH7(1-4,1),1/MH7(1-4,2),150/MH6(4,5),99
INITIAL    MH7(1-4,3),130/MH7(1,4),2/MH7(2-4,4),3/MH7(1,5),51
INITIAL    MH7(2,5),10/MH7(3-4,5),8/MH7(1-4,6),53/MH7(2-3,7),56
INITIAL    MH7(4,7),51/MH8(1-6,1),1/MH8(1-6,2),150
INITIAL    MH8(1-6,3),130
INITIAL    MH8(1-6,4),2/MH8(1-6,5),51/MH8(1-6,6),53
INITIAL    MH9(1,1),3/MH9(2-13,1),1/MH9(1-4,2),150
INITIAL    MH9(5-6,2),170/MH9(12,2),130/MH9(5-6,3),100
INITIAL    MH9(7-9,2),150/MH9(10,2),90/MH9(11,2),80
```

```
INITIAL    MH9(13,2),150/MH9(1,3),140/MH9(2-4,3),130
INITIAL    MH9(7-10,3),120/MH9(11,3),100/MH9(12,3),120
INITIAL    MH9(13,3),130
INITIAL    MH9(1-6,4),3/MH9(7,4),3/MH9(8-9,4),3/MH9(10,4),1
INITIAL    MH9(11,4),2/MH9(12,4),1/MH9(13,4),2/MH9(1-2,5),6
INITIAL    MH9(3,5),12/MH9(4,5),14/MH9(5-6,5),8/MH9(7-9,5),10
INITIAL    MH9(10-11,5),2/MH9(12,5),46/MH9(13,5),51
INITIAL    MH9(1-9,6),51/MH9(11,6),46/MH9(13,6),53
INITIAL    MH9(1-9,7),53/MX10(1,1),3600/MX10(2,1),9000
INITIAL    MX10(4,1),12000/MX10(5,1),3600/MX10(6,1),11400
INITIAL    MX10(7,1),6000/MX10(8,1),3300/MX10(9,1),4200
INITIAL    MX10(10,1),4800/MX10(11,1),5400/MX10(12,1),18000
INITIAL    MX10(13,1),4800/MX10(14,1),4200/MX10(15,1),4800
INITIAL    MX10(16,1),3600/MX10(17-18,1),4800/MX10(19,1),2400
INITIAL    MX10(20-21,1),6000/MX10(22,1),5400/MX10(1,2),2400
INITIAL    MX10(2,2),16800/MX10(4,2),10800/MX10(5,2),4200
INITIAL    MX10(6-7,2),4800/MX10(8,2),4000/MX10(9,2),2400
INITIAL    MX10(10,2),3000/MX10(11,2),3600/MX10(12,2),12600
INITIAL    MX10(13-14,2),3000/MX10(15,2),3600/MX10(16-17,2),3000
INITIAL    MX10(18,2),3600/MX10(19,2),3000/MX10(20-21,2),4200
INITIAL    MX10(22,2),4800/MX10(1,3),1800/MX10(2,3),24000
INITIAL    MX10(4-6,3),6000/MX10(7,3),2100/MX10(8,3),3000
INITIAL    MX10(9-10,3),4200/MX10(11,3),4800/MX10(12,3),16800
INITIAL    MX10(13,3),4800/MX10(14,3),4200/MX10(15,3),4800
INITIAL    MX10(16-20,3),4200/MX10(21-22,3),4800/MX10(1,4),3600
INITIAL    MX10(2,4),18000/MX10(4,4),8400/MX10(5-6,4),4800
INITIAL    MX10(7,4),1800/MX10(8,4),4800/MX10(9-10,4),6000
INITIAL    MX10(11,4),6600/MX10(12,4),30000/MX10(13,4),7200
INITIAL    MX10(14,4),6600/MX10(15,4),7200/MX10(16-17,4),6000
INITIAL    MX10(18,4),6600/MX10(19,4),3600/MX10(20,4),6600
INITIAL    MX10(21,4),6000/MX10(22,4),6600/MX10(1,5),1800
INITIAL    MX10(2,5),11400/MX10(4,5),12000/MX10(5,5),7200
INITIAL    MX10(6,5),6000/MX10(7,5),2400/MX10(8,5),9000
INITIAL    MX10(9,5),4800/MX10(10,5),5400/MX10(11,5),6600
INITIAL    MX10(12,5),21000/MX10(13-14,5),5400/MX10(15,5),6000
INITIAL    MX10(16-17,5),4800/MX10(18,5),5400/MX10(19,5),4800
INITIAL    MX10(20,5),6000/MX10(21,5),6600/MX10(22,5),5400
```

```
INITIAL    MX10(1,6),1200/MX10(2,6),13200/MX10(4,6),9000
INITIAL    MX10(5,6),6000/MX10(6,6),8400/MX10(7,6),2700
INITIAL    MX10(8,6),7200/MX10(9-10,6),2400/MX10(11,6),3600
INITIAL    MX10(12,6),9000/MX10(13,6),2400/MX10(14-17,6),3000
INITIAL    MX10(18,6),3600/MX10(19,6),2400/MX10(20,6),4200
INITIAL    MX10(21,6),2400/MX10(22,6),3600/MX10(1,7),900
INITIAL    MX10(2,7),18000/MX10(4,7),7200/MX10(5,7),6600
INITIAL    MX10(6,7),3000/MX10(7,7),3000/MX10(8,7),11400
INITIAL    MX10(9,7),3000/MX10(10,7),2400/MX10(11,7),4800
INITIAL    MX10(12,7),13200/MX10(13-14,7),3600/MX10(15,7),4200
INITIAL    MX10(16-17,7),3600/MX10(18,7),3000/MX10(19-20,7),2400
INITIAL    MX10(21,7),4800/MX10(22,7),2400/MX10(1,8),900
INITIAL    MX10(2,8),12600/MX10(4,8),6600/MX10(5,8),5400
INITIAL    MX10(6,8),3000/MX10(7,8),2700/MX10(8,8),12600
INITIAL    MX10(9,8),5400/MX10(10,8),4800/MX10(11,8),6600
INITIAL    MX10(12,8),22800/MX10(13,8),6000/MX10(14-16,8),5400
INITIAL    MX10(17,8),6000/MX10(18-19,8),4800/MX10(20,8),4200
INITIAL    MX10(21,8),6600/MX10(22,8),4800/MX10(1,9),1200
INITIAL    MX10(2,9),12600/MX10(4,9),7800/MX10(5,9),4800
INITIAL    MX10(6,9),7200/MX10(7,9),4800/MX10(8,9),18600
INITIAL    MX10(9-10,9),4800/MX10(11,9),6000/MX10(12,9),18000
INITIAL    MX10(13-14,9),4800/MX10(15,9),5400/MX10(16,9),3600
INITIAL    MX10(17,9),4800/MX10(18,9),4200/MX10(19,9),6000
INITIAL    MX10(20,9),4200/MX10(21,9),4800/MX10(22,9),6000
INITIAL    MX10(1,10),2400/MX10(2,10),12600/MX10(4,10),8400
INITIAL    MX10(5,10),6600/MX10(6,10),12000/MX10(7,10),9600
INITIAL    MX10(8,10),33000/MX10(9-10,10),5400/MX10(11,10),6000
INITIAL    MX10(12,10),19800/MX10(13,10),6000/MX10(14,10),5400
INITIAL    MX10(15,10),6000/MX10(16,10),48000/MX10(17,10),3600
INITIAL    MX10(18,10),4800/MX10(19-21,10),6000/MX10(22,10),5400
INITIAL    MX10(1,11),4800/MX10(2,11),11400/MX10(4-5,11),7800
INITIAL    MX10(6,11),15000/MX10(7-8,11),72000/MX10(9,11),4800
INITIAL    MX10(10,11),5400/MX10(11,11),7200/MX10(12,11),21600
INITIAL    MX10(13,11),6000/MX10(14-16,11),5400
INITIAL    MX10(19,11),5400/MX10(20,11),4800/MX10(21,11),5400
INITIAL    MX10(22,11),7200/MX10(1,12),4800/MX10(4,12),9600
```

```
            INITIAL     MX10(17-18,11),4800/MX10(2,12),11400
            INITIAL     MX10(5,12),9000/MX10(6,12),22200/MX10(7-8,12),72000
            INITIAL     MX10(9,12),6000/MX10(10,12),5400/MX10(11,12),6600
            INITIAL     MX10(12,12),17400/MX10(13,12),5400/MX10(14,12),6000
            INITIAL     MX10(15,12),6600/MX10(16,12),6000/MX10(17,12),5400
            INITIAL     MX10(18,12),6000/MX10(19,12),5400/MX10(20,12),7800
            INITIAL     MX10(21,12),5400/MX10(22,12),6600
            INITIAL     X1,3600/X2,9000/X4,12000/X5,3600/X6,11400/X7,6000
            INITIAL     X8,3300/X9,4200/X10,4800/X11,5400/X12,18000/X13,4800
            INITIAL     X14,4200/X15,4800/X16,3600/X17,4800/X18,4800
            INITIAL     X19,2400/X20,6000/X21,6000/X22,5400
*
*       VARIABLE FUNCTION DEFINITIONS
*
      1 VARIABLE    P6+K3          CALCULATE PARAMETER # TO FIND DESTN'S
      2 VARIABLE    C1/36000+1     CALCULATE SIMULATION HOUR NUMBER
      3 VARIABLE    P5+1           ASSEMBLE P5+1 XACTS (SEE ASMB BLOCK)
      4 VARIABLE    P4*2           CALCULATE PRINTER # OF ORIGIN
      5 VARIABLE    P3*2           CALCULATE PRINTER # OF DESTINATION
      6 VARIABLE    C1-X25         CALCULATE TIME SINCE LAST CPU ARRIVAL
      7 VARIABLE    MX10(P1,P2)
*
*       TABLE DEFINITIONS
*
      1 TABLE       V6,0,10,240    TABULATE CPU INTERARRIVAL TIMES
      2 TABLE       MP9,0,10,300   TABULATE TRANSACTION RESPONSE TIMES
*
*       MEAN INTERARRIVAL TIME SWITCH
*
1           GENERATE    36000,,,,,2,F   GENERATE 1 XACT EACH HOUR
2           ASSIGN      1,K22           LOOP 22 TIMES
3           ASSIGN      2,V2            ASSIGN P2=COLUMN FOR HOUR OF DAY
4           TEST GE     P2,13,MITS      IF P2 .LT. 13 GO TO 'MITS'
5           TERMINATE                    END OF 12 HOUR RUN
6     MITS  SAVEVALUE   P1,V7           PUT MEAN INTERARRIVAL TIME IN X*1
7           LOOP        1,MITS          CONTINUE LOOPING FOR 22 STATIONS
```

```
8                TERMINATE                          END OF PROCESSING FOR ONE HOUR
          *
          *      ADMITTING DEPARTMENT
          *
9                GENERATE    X1,FN2,,,,,F TRANSACTION ARRIVES
10               ASSIGN      1,FN1        P1=TRANSACTION TYPE
11               ASSIGN      2,K1         P2=SPECIFICATION MATRIX
12               ASSIGN      4,K1         P4=PLACE OF ORIGIN
13               PRIORITY    MH1(P1,1)    ASSIGN PRIORITY
14               MSAVEVALUE  11+,P4,P1,K1,H
15               QUEUE       1            F1=CRT IN ADMITTING
16               SEIZE       1
17               DEPART      1
18         STR1  ADVANCE     50,FN23      CLERK ENTERS FUNCTION CODE
19               ASSIGN      8,K1         P8=1 IMPLYS REQUEST FOR CRT FORMAT
20               MARK        9
21               TRANSFER    ,CPU
22         CRT1  TEST NE     P8,K1,INPT1  IF FALSE A FORMAT IS BEING DISPLAYED
23               TEST NE     P8,K2,INPT2  IF FALSE INPUT ACCEPTANCE SPECIFIED
24               TERMINATE
25         INPT1 ADVANCE     10           DISPLAY FORMAT
26               ADVANCE     MH1(P1,2),FN23 ENTER DATA
27               ASSIGN      8,K2         P8=2 INPUT OF DATA
28               MARK        9
29               TRANSFER    ,CPU         SEND XACT TO CPU
30         INPT2 ADVANCE     10           DISPLAY ACCEPTANCE MESSAGE
31               TEST GE     P1,6,END1    IF PATIENT IS NOT ADMT. GO TO END1
32               ASSIGN      1+,1         ADD 1 TO TRANSACTION TYPE
33               ASSIGN      4,K1
34               MSAVEVALUE  11+,P4,P1,K1,H
35               TEST E      P1,K9,LABS   P1=9 IDENTIFYS PATIENT CHECK-IN
36               ASSIGN      3,FN22       ASSIGN A NURSING UNIT TO P3
37               TRANSFER    ,STR1        TRANSFER TO ENTER THE CHECK-IN
38         LABS  TEST G      P1,K9,STR1   IF 9 < P1 < 14 ENTER LAB REQUISITIONS
39               TEST L      P1,K14,END1
40               ASSIGN      4,P3
```

```
41                TRANSFER    ,STR1          TRANSFER TC ENTER REQUISITIONS
42          END1  RELEASE     1              RELEASE CRT
43                TERMINATE
44          PNT1  QUEUE       2              ENTER QUEUE FOR PRINTER
45                SEIZE       2              SEIZE PRINTER
46                DEPART      2              LEAVE PRINT QUEUE
47                TABULATE    2              TABULATE RESPONSE TIME
48                ADVANCE     MH*2(P1,3),10  HOLD FACILITY TO PRINT TRANSACTION
49                RELEASE     2              RELEASE PRINTER
50                TERMINATE                   DESTROY TRANSACTION
                  *
                  *           EMERGENCY ROOM
                  *
51                GENERATE    X2,FN7,,,,,F PATIENT ARRIVES FOR TREATMENT
52                ASSIGN      2,K2           P2=SPECIFICATION MATRIX
53                ASSIGN      4,K2           P4=PLACE OF ORIGIN
54                QUEUE       3              F3=CARD READER AND PUNCH
55                SEIZE       3              SEIZE READER AND PUNCH
56                DEPART      3              DEPART FROM QUEUE
57                ADVANCE     1200,FN23      PUNCH ADMISSION CARD FOR PATIENT
58                ASSIGN      1,K1           P1=1 IMPLYS ER USAGE CHARGE
59                PRIORITY    MH2(P1,1)      INITIALIZE PRIORITY
60                MSAVEVALUE  11+,P4,P1,K1,H ADD ONE TO XACT COUNT
61                ADVANCE     MH2(P1,2),FN23 ENTER ER USAGE CHARGE
62                MARK        9              PUT CLOCK TIME IN P9
63                SPLIT       1,CPU          SEND COPY TO CPU
64                TRANSFER    .128,,EXAM     12.8% DO NOT RECEIVE DR. CHARGE
65                ASSIGN      1,K2           P1=2 IMPLYS DOCTOR CHARGE
66                PRIORITY    MH2(P1,1)      INITIALIZE PRIORITY
67                MSAVEVALUE  11+,P4,P1,K1,H ADD ONE TO XACT COUNT
68                ADVANCE     MH2(P1,2),FN23 ADD ONE TO XACT COUNT
69                MARK        9              PUT CLOCK TIME IN P9
70                SPLIT       1,CPU          SEND COPY TO CPU
71          EXAM  RELEASE     3              RELEASE FACILITY FOR DOCTORS EXAM
72                ADVANCE     6000,FN23      DOCTOR'S EXAM AND TREATMENT
73                QUEUE       3              ENTER QUEUE FOR TERMINAL AGAIN
```

```
74                SEIZE     3                SEIZE TERMINAL
75                DEPART    3                LEAVE QUEUE
76                ASSIGN    1,K3             P3=3 IMPLYS LAB ORDER
77                PRIORITY  MH2(P1,1)        INITIALIZE PRIORITY
78                ASSIGN    6,FN3            P6=NUMBER OF TESTS
79                MSAVEVALUE 11+,P4,P1,P6,H ADD ONE TO XACT COUNT
80                TEST NE   P6,K0,XRAY       IF P6=0 GO TO XRAY
81          LOOP1 ADVANCE   MH2(P1,2),FN23 READ ORDER AND PATIENT CARDS
82                ASSIGN    5+,K1            ADD 1 TO NUMBER OF XACTS
83                MARK      9                PUT CLOCK TIME IN P9
84                SPLIT     1,CPU            SEND COPY TO CPU
85                LOOP      6,LOOP1          GO TO LOOP1 P6 TIMES
86          XRAY  ASSIGN    1,K4             P1=4 IMPLYS XRAY TRANSACTION
87                PRIORITY  MH2(P1,1)        INITIALIZE PRIORITY
88                ASSIGN    6,FN4            P6=NUMBER OF XRAYS ORDERED
89                MSAVEVALUE 11+,P4,P1,P6,H ADD ONE TO XACT COUNT
90                TEST NE   P6,K0,REL3       IF P6=0 GO TO RELEASE 3
91          LOOP2 ADVANCE   MH2(P1,2),FN23 READ ORDER AND PATIENT CARDS
92                ASSIGN    5+,K1            ADD 1 TO NUMBER OF XACTS
93                MARK      9                PUT CLOCK TIME IN P9
94                SPLIT     1,CPU            SEND COPY TO CPU
95                LOOP      6,LOOP2          GO TO LOOP2 P6 TIMES
96          REL3  TEST NE   P5,K0,ADMT       IF P5=0 GO TO ADMT
97                RELEASE   3                RELEASE F3
98          ASMB  ASSEMBLE  V3               ASSEMBLE P5+1 XACTS
99                ASSIGN    5,K0             ZERO TEST COUNT
100               ADVANCE   1200,FN23        DOCTOR REVIEWS RESULTS
101               QUEUE     3                ENTER QUEUE FOR TERMINAL AGAIN
102               SEIZE     3                SEIZE TERMINAL
103               DEPART    3                LEAVE QUEUE
104         ADMT  TRANSFER  .872,,DISC       87.2% OF PATIENTS ARE DISCHARGED
105               ASSIGN    1,K5             P1=5 IMPLYS ADMISSION DATA
106               PRIORITY  MH2(P1,1)        INITIALIZE PRIORITY
107               MSAVEVALUE 11+,P4,P1,K1,H ADD ONE TO XACT COUNT
108               ADVANCE   MH2(P1,2),FN23 PUNCH DATA AND READ INTO SYSTEM
109               ASSIGN    3,FN22           ASSIGN NURSING UNIT
```

```
110             MARK        9               PUT CLOCK TIME IN P9
111             SPLIT       1,CPU           SEND COPY TO CPU
112             ASSIGN      1,K4            P1=4 IMPLYS LAB TESTS
113             PRIORITY    MH2(P1,1)       INITIALIZE PRIORITY
114             ASSIGN      6,K4            P6=4 LAB TESTS ON ALL ADMISSIONS
115             MSAVEVALUE  11+,P4,P1,P6,H ADD ONE TO XACT COUNT
116             ASSIGN      4,P3            RESULTS SHOULD GO TO NURSING UNIT
117     LOOP3   ADVANCE     MH2(P1,2),FN23 ENTER TRANSACTION AT TERMINAL
118             MARK        9               PUT CLOCK TIME IN P9
119             SPLIT       1,CPU           SEND COPY TO CPU
120             LOOP        6,LOOP3         GO TO LOOP3 P6 TIMES
121             ASSIGN      4,K2            P4=PLACE OF ORIGIN
122     DISC    ASSIGN      1,K6            P1=6 IMPLYS PHARMACY CHARGES
123             PRIORITY    MH2(P1,1)       INITIALIZE PRIORITY
124             ASSIGN      6,FN5           P6=NUMBER OF DRUGS USED
125             MSAVEVALUE  11+,P4,P1,P6,H ADD ONE TO XACT COUNT
126             TEST NE     P6,K0,NCSR      IF NO DRUGS USED GO TO NCSR
127     LOOP4   ADVANCE     MH2(P1,2),FN23 FIND AND READ CARDS INTO SYSTEM
128             MARK        9               PUT CLOCK TIME IN P9
129             SPLIT       1,CPU           SEND COPY TO CPU
130             LOOP        6,LOOP4         GO TO LOOP4 P6 TIMES
131     NCSR    ASSIGN      1,K7            P1=7 IMPLYS CSR CHARGE
132             PRIORITY    MH2(P1,1)       INITIALIZE PRIORITY
133             ASSIGN      6,FN6           P6=NUMBER OF SUPPLIES USED
134             MSAVEVALUE  11+,P4,P1,P6,H ADD ONE TO XACT COUNT
135             TEST NE     P6,K0,END2      IF NO SUPPLIES USED,DISCHARGE PATIENT
136     LOOP5   ADVANCE     MH2(P1,2),FN23 FIND AND READ CARDS INTO SYSTEM
137             MARK        9               PUT CLOCK TIME IN P9
138             SPLIT       1,CPU           SEND COPY TO CPU
139             LOOP        6,LOOP5         GO TO LOOP5 P6 TIMES
140     END2    RELEASE     3               RELEASE TERMINAL
141             TERMINATE                    DESTROY THE TRANSACTION
142     PNT2    QUEUE       4               ENTER QUEUE FOR PRINTER
143             SEIZE       4               SEIZE PRINTER
144             DEPART      4               LEAVE QUEUE
145             TABULATE    2               TABULATE TRANSACTION RESPONSE TIME
```

```
146             ADVANCE     MH*2(P1,3),10  PRINT MESSAGE AT TERMINAL
147             RELEASE     4              RELEASE THE PRINTER
148             TEST NE     P4,K2,TMNO     XACT VERIFICATIONS GO TO 'TMNO'
149             TEST E      P5,K0,ASM8     SEND TEST RESULTS TO ASSEMBLE W/ OTHERS
150      TMNO   TERMINATE                  DESTROY THE TRANSACTION
         *
         *      LABORATORY
         *
151      PNT3   QUEUE       6              ENTER Q6 FOR PRINTER #3
152             SEIZE       6              SEIZE PRINTER
153             DEPART      6              LEAVE Q6
154             TABULATE    2              TABULATE TRANSACTION RESPONSE TIMES
155             ADVANCE     MH*2(P1,3),10 PRINT TEST ORDER
156             RELEASE     6              RELEASE PRINTER
157             TEST NE     P4,K3,TMN1     IF XACT IS A VERIFICATION GO TO 'TMN1'
158             ADVANCE     23000,FN24     PERFORM LAB TEST
159             ASSIGN      1,K1           ASSIGN P1=TRANSACTION TYPE
160             ASSIGN      2,K3           ASSIGN P2=SPEC MATRIX
161             ASSIGN      3,P4           XACT RETURNS TO ITS ORIGIN
162             ASSIGN      4,K3           ASSIGN P4=POINT OF ORIGIN
163             PRIORITY    MH3(P1,1)      INITIALIZE PRIORITY
164             QUEUE       5              ENTER Q5
165             SEIZE       5              SEIZE INPUT DEVICE F5
166             DEPART      5              LEAVE Q5
167             ADVANCE     MH3(1,2),FN23 INPUT TEST RESULTS
168             RELEASE     5              RELEASE TERMINAL F5
169             MARK        9              PUT CLOCK TIME IN P9
170             TRANSFER    ,CPU           TRANSMIT XACT TO CPU
171      TMN1   TERMINATE                  DESTROY THE TRANSACTION
         *
         *      CENTRAL SUPPLY
         *
172      PNT4   QUEUE       3              ENTER Q8 FOR PRINTER #4
173             SEIZE       8              SEIZE PRINTER
174             DEPART      3              LEAVE Q8
175             TABULATE    2              TABULATE TRANSACTION RESPONSE TIME
```

```
176                ADVANCE     MH*2(P1,3),10 PRINT ORDER
177                RELEASE     8             RELEASE PRINTER
178                TEST NE     P4,K4,TMN2    IF XACT IS A VERIFICATION GO TO 'TMN2'
179                TRANSFER    .021,,OTSTK    2.1% OF ORDERS OUT-OF-STOCK
180          TMN2  TERMINATE                 ITEMS ARE DELIVERED AS ORDERED
181          OTSTK ASSIGN      1,K1          P1=1 IMPLYS INPUT OF A CREDIT
182                ASSIGN      3,P4          ASSIGN P3=STATION TO RETURN TO
183                ASSIGN      4,K4          ASSIGN P4=POINT OF ORIGIN
184                MSAVEVALUE  11+,P4,P1,K1,H ADD ONE TO XACT COUNT
185          NPUT  ASSIGN      2,K4          P2=MATRIX TO REFERENCE FOR SPECS.
186                PRIORITY    MH4(P1,1)     ASSIGN PRIORITY
187                QUEUE       7             ENTER Q7
188                SEIZE       7             SEIZE INPUT DEVICE F7
189                DEPART      7             LEAVE Q7
190                ADVANCE     MH4(P1,2),10 READ CREDIT INTO SYSTEM
191                RELEASE     7             RELEASE TERMINAL F7
192                MARK        9             PUT CLOCK TIME IN P9
193                TRANSFER    ,CPU          SEND XACT TO CPU
194                GENERATE    X4,FN9,,,,,F GENERATE CREDITS FOR SUPPLY RETURNS
195                ASSIGN      1,FN8         P1=TRANSACTION TYPE
196                ASSIGN      4,K4          P4=ORIGIN OF TRANSACTION
197                MSAVEVALUE  11+,P4,P1,K1,H ADD ONE TO XACT COUNT
198                TRANSFER    ,NPUT         ROUTE ALL TRANSACTIONS TO 'NPUT'
                   *
                   *          PHARMACY
                   *
199                GENERATE    X5,FN11,,,,,F TRANSACTION ARRIVES
200                ASSIGN      1,FN10        ASSIGN TRANSACTIO N TYPE
201                ASSIGN      2,K5          P2=MATRIX REFERENCED FOR SPECIFICATIONS
202                ASSIGN      4,K5          P4=PLACE OF ORIGIN
203                PRIORITY    MH5(P1,1)     INITIALIZE PRIORITY
204                MSAVEVALUE  11+,P4,P1,K1,H ADD ONE TO COUNT
205                QUEUE       9             ENTER QUEUE FOR TERMINAL
206                SEIZE       9             SEIZE FACILITY
207                DEPART      9             LEAVE QUEUE
208                ADVANCE     MH5(P1,2),FN23 ENTER TRANSACTION
```

```
209             RELEASE     9               RELEASE TERMINAL
210             MARK        9               PUT CLOCK TIME IN P9
211             TRANSFER    ,CPU            ROUTE ALL TRANSACTIONS TO 'CPU'
212     PNT5    QUEUE       10              ENTER QUEUE FOR PRINTER
213             SEIZE       10              SEIZE PRINTER
214             DEPART      10              LEAVE QUEUE
215             TABULATE    2               TABULATE RESPONSE TIMES
216             ADVANCE     MH*2(P1,3),10   PRINT MESSAGE
217             RELEASE     10              RELEASE TERMINAL
218             TERMINATE                    DESTROY THE TRANSACTION
        *
        *       RADIOLOGY
        *
219     PNT6    QUEUE       12              ENTER PRINT QUEUE
220             SEIZE       12              SEIZE PRINTER
221             DEPART      12              LEAVE QUEUE
222             TABULATE    2               TABULATE RESPONSE TIMES
223             ADVANCE     MH*2(P1,3),10   PRINT TRANSACTION
224             RELEASE     12              RELEASE TERMINAL
225             TEST NE     P4,K6,TMN3      IF XACT IS A VERIFICATION GO TO  'TMN3'
226             ADVANCE     45000,FN24      PERFORM TEST
227             ASSIGN      1,K4            ASSIGN P1=TRANSACTION TYPE
228     INPT3   ASSIGN      2,K6            ASSIGN P2=SPECIFICATION MATRIX
229             ASSIGN      3,P4            ASSIGN P3=STATION TO RETURN TO
230             ASSIGN      4,K6            ASSIGN P4=POINT OF ORIGIN
231             PRIORITY    MH6(P1,1)       INITIALIZE PRIORITY
232             MSAVEVALUE  11+,P4,P1,K1,H ADD ONE TO XACT COUNT
233             QUEUE       11              ENTER TERMINAL QUEUE
234             SEIZE       11              SEIZE TERMINAL
235             DEPART      11              LEAVE QUEUE
236             ADVANCE     MH6(P1,2),FN23 ENTER TRANSACTION
237             RELEASE     11              RELEASE TERMINAL
238             MARK        9               PUT CLOCK TIME IN P9
239             TRANSFER    ,CPU            TRANSMIT XACT TO CPU
240     TMN3    TERMINATE                   DESTROY THE TRANSACTION
241             GENERATE    X6,FN13,,,,,F   GENERATE A TRANSACTION
```

```
242                ASSIGN      1,FN12          ASSIGN P1=TRANSACTION TYPE
243                TRANSFER    ,INPT3          ROUTE ALL TRANSACTIONS TO 'INPT3'
               *
               *       PHYSICAL THERAPY
               *
                TERM   MACRO       X7,FN15,FN14,K7,K7,MH7(P1,1),13,MH7(P1,2),FN23
244                GENERATE    X7,FN15,,,,,F
245                ASSIGN      1,FN14
246                ASSIGN      2,K7
247                ASSIGN      4,K7
248                MSAVEVALUE  11+,P4,P1,K1,H
249                PRIORITY    MH7(P1,1)
250                QUEUE       13
251                SEIZE       13
252                DEPART      13
253                ADVANCE     MH7(P1,2),FN23
254                RELEASE     13
255                MARK        9
256                TRANSFER    ,CPU
                PNTR   MACRO       PNT7,14,10
257             PNT7   QUEUE       14
258                SEIZE       14
259                DEPART      14
260                TABULATE    2
261                ADVANCE     MH*2(P1,3),10
262                RELEASE     14
263                TERMINATE
               *
               *       SURGERY
               *
264                GENERATE    X8,FN19,,,,,F SURGICAL CASE COMPLETED
265                ASSIGN      2,K8            ASSIGN P2=SPECIFICATION MATRIX
266                ASSIGN      4,K8            ASSIGN P4=POINT OF ORIGIN
267                QUEUE       15              F15=CARD READER
268                DEPART      15              LEAVE QUEUE
269                SEIZE       15              SEIZE FACILITY
```

```
270             ASSIGN      1,K1            P1=1 IMPLYS ENTRY OF OPERATION TYPE
271             PRIORITY    MH8(P1,1)       INITIALIZE PRIORITY
272             MSAVEVALUE  11+,P4,P1,K1,H ADD ONE TO XACT COUNT
273             ADVANCE     MH8(P1,2),FN23 ENTER TRANSACTION
274             MARK        9               PUT CLOCK TIME IN P9
275             SPLIT       1,CPU           SEND TO CPU
276             ASSIGN      1,K2            ASSIGN P1=TRANSACTION TYPE
277             PRIORITY    MH8(P1,1)       INITIALIZE PRIORITY
278             MSAVEVALUE  11+,P4,P1,K1,H ADD ONE TO XACT COUNT
279             ADVANCE     MH8(P1,2),FN23 ENTER TRANSACTION
280             MARK        9               PUT CLOCK TIME IN P9
281             SPLIT       1,CPU           ROUTE ALL TRANSACTIONS TO 'CPU'
282             ASSIGN      1,K3            P1=3 IMPLYS MEDICATION CHARGE
283             PRIORITY    MH8(P1,1)       INITIALIZE PRIORITY
284             ASSIGN      6,FN16          P6=NUMBER OF MEDICATIONS
285             MSAVEVALUE  11+,P4,P1,P6,H ADD ONE TO XACT COUNT
286             TEST NE     P6,K0,ANES      IF P6=0 GO TO ANES
287     MED     ADVANCE     MH8(P1,2),FN23 ENTER TRANSACTION
288             MARK        9               PUT CLOCK TIME IN P9
289             SPLIT       1,CPU           SEND XACT TO CPU
290             LOOP        6,MED           GO TO MED P6 TIMES
291     ANES    TRANSFER    .021,,XANS      2.1% = NO ANESTHESIA
292             ASSIGN      1,K4            P1=4 IMPLYS ANESTHESIA CHARGE
293             PRIORITY    MH8(P1,1)       INITIALIZE PRIORITY
294             MSAVEVALUE  11+,P4,P1,K1,H ADD ONE TO XACT COUNT
295             ADVANCE     MH8(P1,2),FN23 ENTER XACT
296             MARK        9               PUT CLOCK TIME IN P9
297             SPLIT       1,CPU           SEND XACT TO CPU
298     XANS    ASSIGN      1,K5            P1=5 IMPLYS SUPPLY CHARGE
299             PRIORITY    MH8(P1,1)       INITIALIZE PRIORITY
300             ASSIGN      6,FN17          P6=NUMBER OF SUPPLIES
301             MSAVEVALUE  11+,P4,P1,P6,H ADD ONE TO XACT COUNT
302             TEST NE     P6,K0,XSUP      IF P6=0 GO TO XSUP
303     SUPL    ADVANCE     MH8(P1,2),FN23 ENTER XACT
304             MARK        9               PUT CLOCK TIME IN P9
305             SPLIT       1,CPU           SEND COPY TO CPU
```

```
          LOOP       6,SUPL       GO TO SUPL P6 TIMES
XSUP      ASSIGN     1,K6         ASSIGN P1=TRANSACTION TYPE
          PRIORITY   MH8(P1,1)    INITIALIZE PRIORITY
          ASSIGN     6,FN18       P6=NUMBER OF IV SOLUTIONS
          MSAVEVALUE 11+,P4,P1,P6,H ADD ONE TO XACT COUNT
          TEST NE    P6,K0,XIV    ENTER XACT
IVS       ADVANCE    MH8(P1,2),FN23 ENTER XACT
          MARK       9            PUT CLOCK TIME IN P9
          SPLIT      1,CPU        SEND XACT TO CPU
          LOOP       6,IVS        GO TO IVS P6 TIMES
XIV       RELEASE    15           RELEASE TERMINAL
          TERMINATE                DESTROY THE TRANSACTION
PNT8      QUEUE      16           ENTER PRINT QUEUE
          SEIZE      16           SEIZE TERMINAL
          DEPART     16           LEAVE QUEUE
          TABULATE   2            TABULATE RESPONSE TIMES
          ADVANCE    MH*2(P1,3),10  PRINT MESSAGE
          RELEASE    16           RELEASE TERMINAL
          TERMINATE                DESTROY THE TRANSACTION
*
*         NURSING UNIT -3 WEST
*
TERM      MACRO      X9,FN21,FN20,K9,K9,MH9(P1,1),17,MH9(P1,2),FN23
          GENERATE   X9,FN21,,,,,F
          ASSIGN     1,FN20
          ASSIGN     2,K9
          ASSIGN     4,K9
          MSAVEVALUE 11+,P4,P1,K1,H
          PRIORITY   MH9(P1,1)
          QUEUE      17
          SEIZE      17
          DEPART     17
          ADVANCE    MH9(P1,2),FN23
          RELEASE    17
          MARK       9
          TRANSFER   ,CPU
```

```
          PNTR    MACRO       PNT9,18,10
338       PNT9    QUEUE       18
339               SEIZE       18
340               DEPART      18
341               TABULATE    2
342               ADVANCE     MH*2(P1,3),10
343               RELEASE     18
344               TERMINATE
          *
          *       NURSING UNIT - 4 EAST
          *
          TERM    MACRO       X10,FN21,FN20,K9,K10,MH9(P1,1),19,MH9(P1,2),FN23
345               GENERATE    X10,FN21,,,,,F
346               ASSIGN      1,FN20
347               ASSIGN      2,K9
348               ASSIGN      4,K10
349               MSAVEVALUE  11+,P4,P1,K1,H
350               PRIORITY    MH9(P1,1)
351               QUEUE       19
352               SEIZE       19
353               DEPART      19
354               ADVANCE     MH9(P1,2),FN23
355               RELEASE     19
356               MARK        9
357               TRANSFER    ,CPU
          PNTR    MACRO       PNT10,20,10
358       PNT10   QUEUE       20
359               SEIZE       20
360               DEPART      20
361               TABULATE    2
362               ADVANCE     MH*2(P1,3),10
363               RELEASE     20
364               TERMINATE
          *
          *       NURSING UNIT - 4 WEST
          *
```

```
         TERM   MACRO       X11,FN21,FN20,K9,K11,MH9(P1,1),21,MH9(P1,2),FN23
365              GENERATE    X11,FN21,,,,,F
366              ASSIGN      1,FN20
367              ASSIGN      2,K9
368              ASSIGN      4,K11
369              MSAVEVALUE  11+,P4,P1,K1,H
370              PRIORITY    MH9(P1,1)
371              QUEUE       21
372              SEIZE       21
373              DEPART      21
374              ADVANCE     MH9(P1,2),FN23
375              RELEASE     21
376              MARK        9
377              TRANSFER    ,CPU
         PNTR   MACRO       PNT11,22,10
378      PNT11   QUEUE       22
379              SEIZE       22
380              DEPART      22
381              TABULATE    2
382              ADVANCE     MH*2(P1,3),10
383              RELEASE     22
384              TERMINATE
         *
         *       NURSING UNIT - 4 NORTH
         *
         TERM   MACRO       X12,FN21,FN20,K9,K12,MH9(P1,1),23,MH9(P1,2),FN23
385              GENERATE    X12,FN21,,,,,F
386              ASSIGN      1,FN20
387              ASSIGN      2,K9
388              ASSIGN      4,K12
389              MSAVEVALUE  11+,P4,P1,K1,H
390              PRIORITY    MH9(P1,1)
391              QUEUE       23
392              SEIZE       23
393              DEPART      23
394              ADVANCE     MH9(P1,2),FN23
```

```
395             RELEASE     23
396             MARK        9
397             TRANSFER    ,CPU
          PNTR  MACRO       PNT12,24,10
398       PNT12 QUEUE       24
399             SEIZE       24
400             DEPART      24
401             TABULATE    2
402             ADVANCE     MH*2(P1,3),10
403             RELEASE     24
404             TERMINATE
          *
          *     NURSING UNIT - 5 EAST
          *
          TERM  MACRO       X13,FN21,FN20,K9,K13,MH9(P1,1),25,MH9(P1,2),FN23
405             GENERATE    X13,FN21,,,,,F
406             ASSIGN      1,FN20
407             ASSIGN      2,K9
408             ASSIGN      4,K13
409             MSAVEVALUE  11+,P4,P1,K1,H
410             PRIORITY    MH9(P1,1)
411             QUEUE       25
412             SEIZE       25
413             DEPART      25
414             ADVANCE     MH9(P1,2),FN23
415             RELEASE     25
416             MARK        9
417             TRANSFER    ,CPU
          PNTR  MACRO       PNT13,26,10
418       PNT13 QUEUE       26
419             SEIZE       26
420             DEPART      26
421             TABULATE    2
422             ADVANCE     MH*2(P1,3),10
423             RELEASE     26
424             TERMINATE
```

```
                *
                *       NURSING UNIT - 5 WEST
                *
                 TERM   MACRO       X14,FN21,FN20,K9,K14,MH9(P1,1),27,MH9(P1,2),FN23
425                     GENERATE    X14,FN21,,,,,F
426                     ASSIGN      1,FN20
427                     ASSIGN      2,K9
428                     ASSIGN      4,K14
429                     MSAVEVALUE  11+,P4,P1,K1,H
430                     PRIORITY    MH9(P1,1)
431                     QUEUE       27
432                     SEIZE       27
433                     DEPART      27
434                     ADVANCE     MH9(P1,2),FN23
435                     RELEASE     27
436                     MARK        9
437                     TRANSFER    ,CPU
                 PNTR   MACRO       PNT14,28,10
438              PNT14  QUEUE       28
439                     SEIZE       28
440                     DEPART      28
441                     TABULATE    2
442                     ADVANCE     MH*2(P1,3),10
443                     RELEASE     28
444                     TERMINATE
                *
                *       NURSING UNIT - 6 EAST
                *
                 TERM   MACRO       X15,FN21,FN20,K9,K15,MH9(P1,1),29,MH9(P1,2),FN23
445                     GENERATE    X15,FN21,,,,,F
446                     ASSIGN      1,FN20
447                     ASSIGN      2,K9
448                     ASSIGN      4,K15
449                     MSAVEVALUE  11+,P4,P1,K1,H
450                     PRIORITY    MH9(P1,1)
451                     QUEUE       29
```

```
452                SEIZE       29
453                DEPART      29
454                ADVANCE     MH9(P1,2),FN23
455                RELEASE     29
456                MARK        9
457                TRANSFER    ,CPU
            PNTR   MACRO       PNT15,30,10
458         PNT15  QUEUE       30
459                SEIZE       30
460                DEPART      30
461                TABULATE    2
462                ADVANCE     MH*2(P1,3),10
463                RELEASE     30
464                TERMINATE
           *
           *       NURSING UNIT - 6 WEST
           *
            TERM   MACRO       X16,FN21,FN20,K9,K16,MH9(P1,1),31,MH9(P1,2),FN23
465                GENERATE    X16,FN21,,,,,F
466                ASSIGN      1,FN20
467                ASSIGN      2,K9
468                ASSIGN      4,K16
469                MSAVEVALUE  11+,P4,P1,K1,H
470                PRIORITY    MH9(P1,1)
471                QUEUE       31
472                SEIZE       31
473                DEPART      31
474                ADVANCE     MH9(P1,2),FN23
475                RELEASE     31
476                MARK        9
477                TRANSFER    ,CPU
            PNTR   MACRO       PNT16,32,10
478         PNT16  QUEUE       32
479                SEIZE       32
480                DEPART      32
481                TABULATE    2
```

```
482                ADVANCE     MH*2(P1,3),10
483                RELEASE     32
484                TERMINATE
                   *
                   *       NURSING UNIT - 7 EAST
                   *
                    TERM   MACRO       X17,FN21,FN20,K9,K17,MH9(P1,1),33,MH9(P1,2),FN23
485                GENERATE    X17,FN21,,,,,F
486                ASSIGN      1,FN20
487                ASSIGN      2,K9
488                ASSIGN      4,K17
489                MSAVEVALUE  11+,P4,P1,K1,H
490                PRIORITY    MH9(P1,1)
491                QUEUE       33
492                SEIZE       33
493                DEPART      33
494                ADVANCE     MH9(P1,2),FN23
495                RELEASE     33
496                MARK        9
497                TRANSFER    ,CPU
                    PNTR   MACRO       PNT17,34,10
498                 PNT17  QUEUE       34
499                SEIZE       34
500                DEPART      34
501                TABULATE    2
502                ADVANCE     MH*2(P1,3),10
503                RELEASE     34
504                TERMINATE
                   *
                   *       NURSING UNIT - 7 WEST
                   *
                    TERM   MACRO       X18,FN21,FN20,K9,K18,MH9(P1,1),35,MH9(P1,2),FN23
505                GENERATE    X18,FN21,,,,,F
506                ASSIGN      1,FN20
507                ASSIGN      2,K9
508                ASSIGN      4,K18
```

```
509             MSAVEVALUE  11+,P4,P1,K1,H
510             PRIORITY    MH9(P1,1)
511             QUEUE       35
512             SEIZE       35
513             DEPART      35
514             ADVANCE     MH9(P1,2),FN23
515             RELEASE     35
516             MARK        S
517             TRANSFER    ,CPU
          PNTR  MACRO       PNT18,36,10
518       PNT18 QUEUE       36
519             SEIZE       36
520             DEPART      36
521             TABULATE    2
522             ADVANCE     MH*2(P1,3),10
523             RELEASE     36
524             TERMINATE
        *
        *       NURSING UNIT - 8 EAST
        *
          TERM  MACRO       X19,FN21,FN20,K9,K19,MH9(P1,1),37,MH9(P1,2),FN23
525             GENERATE    X19,FN21,,,,,F
526             ASSIGN      1,FN20
527             ASSIGN      2,K9
528             ASSIGN      4,K19
529             MSAVEVALUE  11+,P4,P1,K1,H
530             PRIORITY    MH9(P1,1)
531             QUEUE       37
532             SEIZE       37
533             DEPART      37
534             ADVANCE     MH9(P1,2),FN23
535             RELEASE     37
536             MARK        S
537             TRANSFER    ,CPU
          PNTR  MACRO       PNT19,38,10
538       PNT19 QUEUE       38
```

```
539             SEIZE       33
540             DEPART      38
541             TABULATE    2
542             ADVANCE     MH*2(P1,3),10
543             RELEASE     38
544             TERMINATE
          *
          *       NURSING UNIT - 8 WEST
          *
           TERM  MACRO       X20,FN21,FN20,K9,K20,MH9(P1,1),39,MH9(P1,2),FN23
545             GENERATE    X20,FN21,,,,,F
546             ASSIGN      1,FN20
547             ASSIGN      2,K9
548             ASSIGN      4,K20
549             MSAVEVALUE  11+,P4,P1,K1,H
550             PRIORITY    MH9(P1,1)
551             QUEUE       39
552             SEIZE       39
553             DEPART      39
554             ADVANCE     MH9(P1,2),FN23
555             RELEASE     39
556             MARK        9
557             TRANSFER    ,CPU
           PNTR  MACRO       PNT20,40,10
558        PNT20 QUEUE       40
559             SEIZE       40
560             DEPART      40
561             TABULATE    2
562             ADVANCE     MH*2(P1,3),10
563             RELEASE     40
564             TERMINATE
          *
          *       NURSING UNIT - IMCU
          *
           TERM  MACRO       X21,FN21,FN20,K9,K21,MH9(P1,1),41,MH9(P1,2),FN23
565             GENERATE    X21,FN21,,,,,F
```

```
566                ASSIGN      1,FN20
567                ASSIGN      2,K9
568                ASSIGN      4,K21
569                MSAVEVALUE  11+,P4,P1,K1,H
570                PRIORITY    MH9(P1,1)
571                QUEUE       41
572                SEIZE       41
573                DEPART      41
574                ADVANCE     MH9(P1,2),FN23
575                RELEASE     41
576                MARK        9
577                TRANSFER    ,CPU
           PNTR    MACRO       PNT21,42,10
578        PNT21   QUEUE       42
579                SEIZE       42
580                DEPART      42
581                TABULATE    2
582                ADVANCE     MH*2(P1,3),10
583                RELEASE     42
584                TERMINATE
           *
           *       NURSING UNIT - ICU
           *
            TERM   MACRO       X22,FN21,FN20,K9,K22,MH9(P1,1),43,MH9(P1,2),FN23
585                GENERATE    X22,FN21,,,,,F
586                ASSIGN      1,FN20
587                ASSIGN      2,K9
588                ASSIGN      4,K22
589                MSAVEVALUE  11+,P4,P1,K1,H
590                PRIORITY    MH9(P1,1)
591                QUEUE       43
592                SEIZE       43
593                DEPART      43
594                ADVANCE     MH9(P1,2),FN23
595                RELEASE     43
596                MARK        9
```

```
597             TRANSFER    ,CPU
        PNTR    MACRO       PNT22,44,10
598     PNT22   QUEUE       44
599             SEIZE       44
600             DEPART      44
601             TABULATE    2
602             ADVANCE     MH*2(P1,3),10
603             RELEASE     44
604             TERMINATE
        *
        *       DIETARY
        *
        PNTR    MACRO       PNT23,46,10
605     PNT23   QUEUE       46
606             SEIZE       46
607             DEPART      46
608             TABULATE    2
609             ADVANCE     MH*2(P1,3),10
610             RELEASE     46
611             TERMINATE
        *
        *       PROCESSOR
        *
612     CPU     TABULATE    1           TABULATE CPU INTERARRIVAL TIME
613             SAVEVALUE   25,C1       SAVE THE TIME OF ARRIVAL
614             QUEUE       47          ENTER PROCESSOR QUEUE
615             SEIZE       47          SEIZE PROCESSOR
616             DEPART      47          LEAVE QUEUE
617             ADVANCE     4           PROCESS TRANSACTION
618             RELEASE     47        RELEASE FACILITY
619             TEST NE     P8,K1,CRT1  REQUESTS FOR DISPLAY GO TO 'CRT1'
620             TEST E      P8,K2,CNT2  IF P8 .NE. K2 GO TO 'CNT2'
621             SPLIT       1,CNT2      SEND A COPY TO 'CNT2'
622             TRANSFER    ,CRT1       TRANSFER TRANSACTION TO 'CRT1'
623     CNT2    ASSIGN      6,K0        ZERO P6
624             ASSIGN      8,K0        ZERO P8
```

```
625             SPLIT       MH*2(P1,4),DISTB,6     SEND COPIES TO 'DISTB'
626             ASSIGN      7,V4           ASSIGN P7=PRINTER NUMBER FOR VERIFICAT'N
627             TRANSFER    ,CONT          ROUTE ALL TRANSACTIONS TO 'CONT'
628     DISTB   ASSIGN      7,MH*2(P1,V1)  ASSIGN P7=DESTINATION CODE FROM MAT'X
629             TEST E      P7,K99,CONT IF P7 .NE. 99 GO TO 'CONT'
630             ASSIGN      7,V5           ASSIGN P7=PRINTER DESTINATION
631     CONT    TEST NE     P7,K2,PNT1
632             TEST NE     P7,K4,PNT2
633             TEST NE     P7,K6,PNT3
634             TEST NE     P7,K8,PNT4
635             TEST NE     P7,K10,PNT5
636             TEST NE     P7,K12,PNT6
637             TEST NE     P7,K14,PNT7
638             TEST NE     P7,K16,PNT8
639             TEST NE     P7,K18,PNT9
640             TEST NE     P7,K20,PNT10
641             TEST NE     P7,K22,PNT11
642             TEST NE     P7,K24,PNT12
643             TEST NE     P7,K26,PNT13
644             TEST NE     P7,K28,PNT14
645             TEST NE     P7,K30,PNT15
646             TEST NE     P7,K32,PNT16
647             TEST NE     P7,K34,PNT17
648             TEST NE     P7,K36,PNT18
649             TEST NE     P7,K38,PNT19
650             TEST NE     P7,K40,PNT20
651             TEST NE     P7,K42,PNT21
652             TEST NE     P7,K44,PNT22
653             TEST NE     P7,K46,PNT23
654             SAVEVALUE   *7+,K1
655             TERMINATE
656             GENERATE    18000
657             TERMINATE   1
                START       24
                REPORT
                EJECT
```

```
 BLO    TITLE       ,TOTAL BLOCK ENTRIES AND CURRENT XACT LOCATIONS
        SPACE       3
*       TOTAL DATA FILE READ/WRITE OPERATIONS
        SPACE       1
        TEXT        HOSPITAL BED MASTER FILE            #X50,2/XXXXX#
        TEXT        INPATIENT BILLING MASTER FILE       #X51,2/XXXXX#
        TEXT        OUTPATIENT BILLING MASTER FILE      #X52,2/XXXXX#
        TEXT        CHARGE DESCRIPTION MASTER FILE      #X53,2/XXXXX#
        TEXT        PRE-ADMISSION STATUS FILE           #X54,2/XXXXX#
        TEXT        INPATIENT BILLING NUMBER FILE       #X55,2/XXXXX#
        TEXT        HOSPITAL DEPARTMENT CHARGE FILE     #X56,2/XXXXX#
        EJECT
 FAC    TITLE       ,UTILIZATION OF EQUIPMENT (ODD NUMBERS = READERS AND E
EVEN NUMBERS = PRINTERS)    - CPU=F47
        EJECT
 QUE    TITLE       ,QUEUE FORMATION AT READERS (ODD #'S) AND PRINTERS (EV
VEN #'S)    - CPU=G47
        EJECT
 TAB    TITLE       1,DISTRIBUTION OF TRANSACTION INTERARRIVALS AT C.P.U.
        EJECT
 TAB    TITLE       2,DISTRIBUTION OF TRANSACTION RESPONSE TIMES
        EJECT
 MHSA   TITLE       1,ADMITTING OFFICE TRANSACTION SPECIFICATION MATRIX
        SPACE       2
 MHSA   TITLE       2,EMERGENCY ROOM TRANSACTION SPECIFICATION MATRIX
        SPACE       2
 MHSA   TITLE       3,LABORATORY TRANSACTION SPECIFICATION MATRIX
        SPACE       2
 MHSA   TITLE       4,CENTRAL SUPPLY TRANSACTION SPECIFICATION MATRIX
        EJECT
 MHSA   TITLE       5,PHARMACY TRANSACTION SPECIFICATION MATRIX
        SPACE       2
 MHSA   TITLE       6,RADIOLOGY TRANSACTION SPECIFICATION MATRIX
        SPACE       2
```

```
MHSA   TITLE      7,PHYSICAL THERAPY TRANSACTION SPECIFICATION MATRIX
       SPACE      2
MHSA   TITLE      8,SURGERY TRANSACTION SPECIFICATION MATRIX
       EJECT
MHSA   TITLE      9,NURSING TRANSACTION SPECIFICATION MATRIX
       SPACE      2
MHSA   TITLE      11,TRANSACTION VOLUMES BY ORIGIN(ROW) AND TYPE(COL)
       EJECT
MSAV   TITLE      10,MEAN INTERARRIVAL TIME MATRIX (8:00AM - 8:00PM)
       EJECT
       GRAPH      TF,1,,*
       ORIGIN     59,4
       X          ,2,2,0,1,31
       Y          0,10,55,1
75     STATEMENT  3,45,DISTRIBUTION OF CPU TRANSACTION INTERARRIVALS
75     STATEMENT  4,26,X AXIS = TIME(1/10 SECOND)
75     STATEMENT  5,31,Y AXIS = NUMBER OF TRANSACTIONS
       ENDGRAPH
       EJECT
       GRAPH      TF,2,,*
       ORIGIN     59,4
       X          ,2,2,20,1,31
       Y          0,2,50,1
75     STATEMENT  3,29,DISTRIBUTION OF RESPONSE TIME
75     STATEMENT  4,39,GRAPH EXCLUDES RESPONSES IN < 2 SECONDS
75     STATEMENT  5,26,X AXIS = TIME(1/10 SECOND)
75     STATEMENT  6,31,Y AXIS = NUMBER OF TRANSACTIONS
       ENDGRAPH
       END        RETURN CONTROL TO OPERATING SYSTEM
```

VITA

David Barclay Kennamer was born in Chattanooga, Tennessee, on January 7, 1949. He attended elementary schools in that city and graduated from the East Ridge High School in June 1967. The following September he entered the University of Tennessee at Knoxville and in December 1971 he received a Bachelor of Science Degree in Industrial Engineering. While an undergraduate, he was elected to the honorary societies: Tau Beta Pi, Alpha Pi Mu, and Phi Kappa Phi. In the winter of 1972, he accepted an assistantship at the University of Tennessee and began study toward a Master's degree. During November 1972, he was employed by the East Tennessee Baptist Hospital, Knoxville, Tennessee, as the Director of Industrial Engineering. He is an associate member of the American Institute of Industrial Engineers and a full member of the Hospital Management Systems Society. He was elected Vice President of the Tennessee HMSS Chapter in 1975.

He is married to the former Karen Jo Bales of Knoxville, Tennessee.