GPSS SIMULATION: A MANAGEMENT TOOL TO EVALUATE COMPUTER EQUIPMENT CONFIGURATIONS

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PREFACE

The use of simulation is increasing rapidly in all areas of business decision-making. With the availability of computers to aid in mathematical analysis, the application of statistics to help solve business problems is growing. At the same time, many general-purpose simulation languages are being developed to make statistics both more sophisticated and easier for the general manager to use and evaluate.

This report is designed to illustrate how simulation can be used in the area of computer equipment evaluation and planning. A specific example of the replacement of one type of printer hardware with a newer and faster type of hardware is simulated. The results are analyzed to determine where the bottlenecks are in the system and to indicate the effects of changing the equipment.

I would like to thank my major adviser, Dr. Donald R. Williams, for his guidance and assistance throughout this study. I also appreciate the advice and interest of the members of the Computing Procedures and Standards Division of the Central Computer Department of Continental Oil Company. I would also like to thank Mrs. Pat Wilkerson for her help in preparing the manuscript.

A special appreciation is given to the Central Computer Department of Continental Oil Company for allowing me to use their computer to prepare the programming model.

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INTRODUCTION

Background of Simulation

In the past twenty-five years, there has been increased interest in a management tool called system simulation. From a specialized start in the defense industry, it is now used to analyze problems from designing the economic system of the Nation to building a bridge over the River Nile.

The reason for such success is twofold. First of all, the use of the scientific method to evaluate problems is spreading to many areas where it was never used before. For example, in the area of business administration, mathematical and statistical courses are emphasized more every semester. In government and industry, econometric models are being developed to help predict future situations. The second reason for the growth of simulation is the advent of the computer as a business tool. The speed of designing and changing models allows a manager to look at more aspects of a problem than ever before.

System simulation has been defined as ". . . a technique that provides an effective means of testing, evaluating, and manipulating a proposed system without any direct action of the real system (7)." Another more descriptive definition is ". . . the technique of solving problems by following the changes over time of a dynamic model of a system (11)."

Both of these definitions have in common the basic idea of simulation. The system is represented by a model which has been designed to solve a certain problem dealing with that system. A simulation is an experiment which is conducted on that model. In many cases where it is impractical to conduct an experiment on the system itself, as in the case of a very large system, the simulation makes experimentation practical. Since experimentation is an essential part of science, simulation aids in the increased use of the scientific method.

What actually happens in a simulation is that all of the complex interdependencies and interactions of the model are characterized as formulas and are stored in the computer memory. The simulation begins at a specified starting state. Then the effects of events and the interaction formulae cause the system to move from one state to another through instants of time. The feature of time compression can cause years of history to evolve in a few minutes on a computer. In the study in this paper, an eight-hour work shift is simulated in a matter of seconds.

Historically, the modern use of simulation can be traced back to the work of von Neumann and Ulam in the late 1940's. These two men created the "Monte Carlo" mathematical technique of simulating a stochastic process with probability distributions to solve a nonprobabilistic problem. It was first used to solve some nuclear-shielding problems.

In the early 1950's, the use of the high-speed computer made it possible to experiment with mathematical models. The result was the development of game theory and the field of operations research.

Today the list of applications and the variations of those applications is too long to name.

There are two basic approaches to simulation: continuous system simulation and discrete system simulation. Each approach has special advantages for different problems.

Systems in which the changes are predominantly smooth are called continuous systems. A description of a continuous system is in the form of continuous differential equations showing how the system attributes change with time. There are usually only a few variables and the entities are considered as a group rather than individually. The planning horizon is for years in the future rather than for today. A common example is using continuous simulation as a design tool to solve a chemical processing problem.

Systems in which the changes are predominantly discontinuous are called discrete systems. A description of a discrete system is concerned with the events producing changes in the state of the system. There are usually a great many discrete entities and the planning horizon is more immediate. A discrete simulation is concerned with probability distributions, queue lengths, mean arrival times, and waiting times. The simulations are normally process-oriented and time-dependent. The problem in this paper, which is concerned with efficient machine configurations, is a common discrete simulation subject.

Why Simulate?

Many planning functions are hard to do because a decision has to be made without any direct experience.

For example, the study in this paper deals with replacing some present hardware equipment with some equipment which is new to the computer installation.

If the manager wants to find out the effect this new equipment will have, he could:

(1) call a friend who has one,

(2) try it out to see if it works,

(3) use traditional methods of analysis, or

(4) test it out in a system simulation.

In this case, the friend is usually Cities Service Oil Company and their advice is very helpful. But the system at Cities Service is not exactly like the Continental Oil system, and their research needs are seldom identical.

"Trying it out" is often too expensive if you have to buy the equipment first to see if you want to buy it later. This is especially true if the problem has a planning horizon of a number of years.

In the study presented in this paper, the traditional methods are highly effective and are probably the most economically feasible approach. However, in a larger problem, it is difficult to look at all of the possibilities with a traditional approach alone.

The fourth option is to simulate the problem first. Simulation makes it easy to try many different possibilities for comparison. The system changes can be tested without disrupting normal operations. The results of the simulation can be used to provide information which may supplement the traditional methods of analysis.

As the problems to be solved become more complex, the value of simulation increases. If a model is too complicated to solve with a dynamic programming model, or if the planning horizon is much too short or too long to include the variations in the system, a simulation is very valuable. If a decision involves spending several hundred thousand dollars, it will vitally affect the future operating costs and efficiencies of the company. In these cases, a systematic approach is needed to support and to improve the intuitive analysis.

A simulator is general in nature and can be used for many different types of applications. Many times one simulation model can be used to solve more than one problem by simply changing the "name" of the entities in the model. For example, the computer equipment analysis used in this paper in which computer print jobs are serviced by five printers is very similar to a supermarket checkout stand in which customers are served by five checkout counters. In both cases, the problem of interest may be the amount of time spent waiting for service. An example of the adaptability of a model is the familiar "management game" in which teams of players simulate the management of a government department, a company, or an entire city.

Of course, some models are very specific in nature. The most famous example is the simulation used in the National Space Program.

One of the greatest advantages of simulation is a by-product. The person doing the actual programming can be the person who really understands the problem instead of an intermediary. Many times the analyst gains new insight from structuring the problem and discovers interrelationships which were not previously known. Through the use of imagination, combined with new insight, more different ideas can be tested in a short period of time than would be feasible any other way.

What you don't get out of a simulation is one answer as in an optimization problem. The simulation answer is an estimate of a waiting time, for example, and is subject to statistical error. Any random variations should be considered when evaluating the results.

A great deal of effort is required to build a good model, even a simple one. If random number generation is used, sufficient retesting is needed to make sure the model really simulates the problem. In the model in this paper, several extra checks and queues were initially inserted to make sure the model was operating correctly. They were later removed to save process time.

Another problem can be the cost of simulation. To be practical, the decision problems must be of sufficient economic significance to justify the expense of the analysis. Computer simulation is often an expensive way to study a complex system.

The most elusive of the problems associated with simulation techniques is that of verification. If stochastic variables are introduced into the simulation, the variables used to measure system performance become random. The analysis must include a test for autocorrelation. Initial bias may be overcome by eliminating the initial section of the run.

The model is evaluated by its power to analyze the managerial problem being studied. Four possible ways to evaluate the model range from the specific to the very general as proposed by Myron Tribus (3).

First, make a detailed comparison between the computer output and the observations of the behavior of the system under study. For example, sit in the computer room and watch the printers.

Second, compare the outputs with statistics from other observations. For example, compare the simulation runs with the ASP accounting cards currently available.

Third, validate the subroutines individually by observation and satisfy the criterion that the system is logically correct. This approach is used on very large systems where detailed comparison is impossible.

Fourth, if the simulation represents the decision maker's view of reality and if he uses it as a tool to help him explore his understanding, the simulation may be "validated" for him.

Background of the Model

The model which is simulated in this paper is based on a real problem in the Central Computer Department of Continental Oil Company. The simulation is designed to help evaluate the effect of changing the configuration of some of the printer equipment in the computer room.

In order to understand the effects of changing the hardware, some software background is needed.

The print workload is processed by an IBM software system called "Asymmetric Multiprocessing System (ASP)." ASP is logically divided into a MAIN system which processes "batch" jobs, and a SUPPORT system which handles peripheral requirements for both the batch jobs from MAIN and tape input jobs.

The present printer hardware configuration on the ASP system is illustrated in Figure 1. There are five printers in the system, labeled P1PC through P5PC. They are referenced in preferential order (P1-P5) by the ASP system, and they are all located in Ponca City (PC).

The jobs which need to be printed by the ASP printers come from two sources.

The first source of jobs is normal batch output from the MAIN computer which is stored on disk. This type of job will hereafter be called "main jobs." They have a priority assignment from nine to fourteen and are selected to be printed on a first-in, first-out (FIFO) basis within priority. This is the same transaction selection scheme used by GPSS. A main job is added to the print queue when it finishes processing on MAIN. No printer is assigned for a main job. The main jobs will print on the first available printer in the system, with preference given to P1PC through P5PC, in that order.

The second source of jobs is output which is stored on magnetic tape. This type of job will hereafter be called "tape-to-print jobs." They have a priority assignment of fifteen only. Therefore, a tape-to-print job will have precedence over any main job output. The jobs are selected to be printed on a FIFO basis within priority fifteen. A tape-to-print job is added to the print queue when the SUPPORT operator types in a request. A printer is assigned in all cases. When the assigned printer is available, it will be seized.

Objectives of the Study

Two of the objectives which GPSS is designed to meet are: (1) to describe the current system, and (2) to explore a hypothetical system. The decision problem analyzed in this paper has both objectives in mind.

The first objective is to test the printer system as it is behaving originally. There is no concrete way to determine the amount of time the printers are really busy. A hardware monitor shows when the printers are in "READY" status, whether they are actively printing or not. The accounting cards which are punched for each print job contain only the number of lines printed, but do not indicate the amount of time required

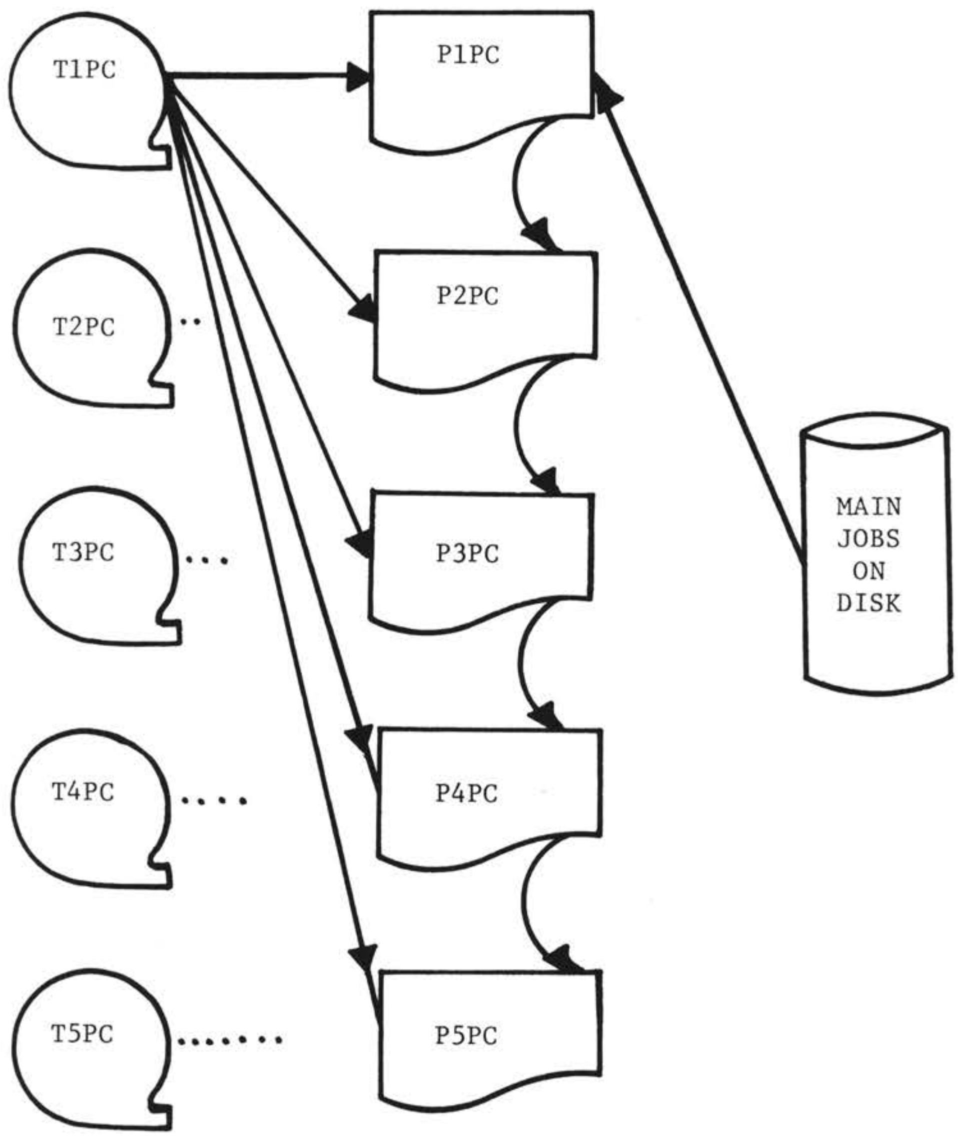


Figure 1. General Flowchart of the ASP Printer System

to print the lines. The GPSS simulation combines the information in the accounting cards with a queueing system to calculate an estimate of the time the jobs spend in the system.

The second objective is to see what would happen if the system is changed. The system could be changed in many ways. The work rules could be changed. The software could be redesigned. The layout of the current equipment could be rearranged.

The change which is simulated is to replace the current printers with a faster model of printer. The areas of interest are the resultant effect this change has on the utilization of the printers and on the speed at which the print jobs are processed.

The prime interest is in the total output of all five printers. The secondary interest is in the performance of each of the individual printers.

CHAPTER II

SURVEY OF LITERATURE

There is a great deal of activity in the area of statistical methodology today. Much of the concern is with simulation and the mathematical formulas used as its foundation.

One of the results of this activity has been the publication of a number of simulation languages. Some of the languages deal with discrete simulation and some deal with continuous simulation.

Ira M. Kay of Southern Simulation Service has compiled a list of thirty-five general purpose digital discrete simulation languages. (See Table I.) He excludes any special purpose and any digitial continuous languages. In general, there is no difference in the philosophy of how the languages work for modeling and simulation. They all have timing routines, and they all gather statistics. The reason there are so many languages is that simulation is still in the development stage. Some languages are written for specific computers. Some languages are developed for small refinements and pride of authorship.

All of the authors divided the discrete languages into three categories. Kay calls the three categories the GASP family, the GPSS family, and the SIMSCRIPT family.

The GASP family consists of subroutines of existing languages. Languages such as FORTRAN, ALGOL, COBOL, and PL/I are all general purpose

TABLE I

INVENTORY OF GENERAL PURPOSE DIGITAL DISCRETE SIMULATION LANGUAGES

GASP Family	GPSS Family	SIMSCRIPT Family
GASP	BOSS	CSL
HOCUS	EGPS	SEAL
PROSIM	FLOW SIMULATOR	SIMSCRIPT
SIMON	GESIM	SIMULA
SIMQUEUE	GPS	SOL
SPURT	GPS K	
UNS	GPSS	
	GPSS/ NORDEN	

Source: Kay, Ira M., "An Over-The-Shoulder Look at Discrete Simulation Languages," Procedures of the AFIPS 1972 Spring Joint Computer Conference (1972).

languages which can be used easily for simulation. The names listed in the GASP family are FORTRAN and ALGOL subroutines which perform timing, random number generating, and statistical functions. One of the advantages of writing simulation in languages like FORTRAN is that many programmers already know FORTRAN, thus eliminating the need to learn a new language. Also, most computer installations support FORTRAN and other general purpose languages. In the case of larger models and large amounts of data, FORTRAN programs may also run faster than a special language.

The SIMSCRIPT family consists of languages which have a syntax of their own and have a compiler. They require a knowledge of FORTRAN and assume some programming skill. Programs in this group are in readable prose form rather than in block diagrams and look a lot like FORTRAN. The most widely used of this family is the language, SIMSCRIPT. It was designed principally for simulating discrete systems and is event-oriented. The languages in the SIMSCRIPT family are more complex and more flexible than those in the GPSS family.

The GPSS family consists of block-oriented languages which use a logical block design for describing the model to be simulated. Each block in the model has a specific meaning. The most widely used language in this family is GPSS. GPSS was designed specifically for simulating discrete systems. It was written especially for users with little or no programming experience. A central part of any program which runs under GPSS is a queueing system which processes the transactions on a first-come, first-served basis within a priority class. A simulated clock time is used to control the length of the job and the time interval between each action in the system. Languages in the GPSS family are easier to use but are less flexible than those in the SIMSCRIPT family.

The three most common continuous system simulation languages are 1130/CSMP, 360/CSMP, and DYNAMO.

Using CSMP, a program is first designed as a block diagram and is then converted to a set of statements like GPSS. The statements include FORTRAN statements and functions, data statements, and control statements.

DYNAMO is a language used mainly for Industrial Dynamics problems. It is based on a mathematical model of a system consisting of first-order differential equations.

With the development of so many languages, a number of texts have been written for both the student and as a reference guide for the professional. One of these texts, A GPSS Primer, by Thomas J. Schriber, was very helpful in building the model for this paper.

With such an array to choose from, the problem becomes which language to use. In many cases, the answer is determined by two criteria. First, what language can the researcher program? Second, what language is available on the researcher's computer? There is probably no one person who thoroughly understands all of the languages and could thus provide an expert opinion. Besides, the ideal language would probably depend a lot on the specific problem to be solved.

The "state of the art" in simulation is still developing. As yet there are no underlying principles guiding the formulation of a simulation model. Each application is a "pioneer" to a large extent. The computer simulation languages come the closest to providing any general guidelines.

There is very little published about actual GPSS simulation applications. At a recent convention for computer users in Miami, a speech was given by a group from the University of Illinois. They were simulating a change in the priority scheduling algorithm in a HASP-OS environment.

The HASP software system is similar to the ASP system, and the basic problems are the same. The university group was concerned with how to select a benchmark, and how to validate the results. Their simulation was fairly complicated and was not yet complete.

Much of the published material deals with Queue Theory and is very mathematically oriented. A good source for technical publications is the periodical, Operations Research, published by the Operations Research Society of America.

Another periodical, Computing Reviews, has a section entitled "Simulation and Modeling" which lists the latest books and articles on simulation along with a synopsis of each publication.

CHAPTER III

THE RESEARCH METHOD

One of the most common and most useful applications of simulation is the area of equipment evaluation. A subset of this area is the analysis of the efficiency of computer hardware equipment. The IBM Corporation is currently spending a great deal of time and money developing methods of simulating different configurations to aid the manager interested in computer operations to determine what combination of equipment would be best in his particular shop.

The purpose of this research study is to use one of the current simulation packages to analyze the effects of changing hardware equipment.

The ASP system was selected for simulation because there is an abundance of accurate data available for defining the system. ASP accounting cards are punched for each job run under the ASP system which contain information about the characteristics of each job. Console listings are printed which contain the clock times for various stages of each job.

The printer area of the ASP system was selected for simulation because it is a good example of a waiting line model. Even though the model itself is very simple, it illustrates the queueing theory of the waiting lines well. The real value of the model is in its ability to explain GPSS simulation and to expand to more complicated decision models. For example, the model could be expanded to include all of the hardware in the computer shop. The logical side of the model could be expanded to simulate the software logic of the ASP system.

Design

The research model may best be described by isolating the elements of the system and describing the logical rules which govern the interaction of the elements. Also basic to a GPSS model is the queueing system which is used to control the flow of the transactions through the system.

There are four types of elements in the system model. (See Table II.)

The dynamic entities are the individual jobs which require print output. These print jobs are read from an input tape (JOBTA1) and become the transactions in the simulation. Each job which is stored on tape has five characteristics. The interarrival time (IA) of each job is the clock time at which it entered the system. The priority (PR) has a value from nine to fifteen, with fifteen indicating the highest priority. If the priority is fifteen, the job output is stored on tape. If the priority is less than fifteen, the job output is stored on disk from MAIN. The first parameter (P1) contains the number of lines which are to be printed for that job. The second parameter (P2) contains the number of minutes required to "set up" a printer before the job can be printed. This includes the time to mount tapes and/or special paper forms. In many cases, the set-up time will be zero because the job can use the paper which is already mounted or the job is read from the disk, which is always available. The third parameter (P3) is a special parameter used only by tape-to-print jobs. Tape-to-print jobs are directed to a

TABLE II

SYSTEM ELEMENTS OF THE GPSS MODEL

Type of Element	GPSS Name
Dynamic Entities	
a. Units of Traffic (Jobs)	JOBTA1
b. Characteristics of the Jobs	IA PR P1 P2 P3
Equipment Entities	
a. Printers	PRTP1 PRTP2 PRTP3 PRTP4 PRTP5
b. Storage	PRINT
c. Logic Switches	PR P3 GATE NU, PRTP1 GATE NU, PRTP2 GATE NU, PRTP3 GATE NU, PRTP4 GATE NU, PRTP5
Statistical Entities	
a. Queues	PRTQT REQP1 REQP2 REQP3 REQP4 REQP5
Operational Entities	
a. Printer Set-Up Time	V2
b. Print time	V1 V3

specific printer by the SUPPORT operator. The third parameter contains the assigned printer number (1-5).

The equipment entities are the elements of the system equipment which are used by the print jobs.

The system has five printers (PRTP1-PRTP5) which can process the print lines for the jobs. Each printer can service only one job at a time. Since there may be more than five jobs active in the system at a time, the printers represent a potential bottleneck. The five printers become the five "facilities" in the GPSS simulation.

If the five printers are considered as a group (PRINT), then the total printer utilization can be measured. The total group of printers can service from zero to five jobs at a time. Since there may be more than five jobs in the system at a time, the group of printers also represent a potential bottleneck in the system. The five printers taken as a group become the one "storage" in the GPSS simulation.

There are three types of logic switches in the system. The first logic switch tests the priority (PR) of each job. If the priority of the job is fifteen, the job will be processed by the tape-to-print section of the simulation. If the priority of the job is less than fifteen, the job will be processed by the main job section of the simulation. The second logic switch tests parameter three (P3) of the tape-to-print jobs only. Parameter three is used to queue the tape-to-print job to a specific printer until that printer is free. The third logic switch (GATE NU PRTPx) tests to see if a specific printer is free. If the job is a main job, the logic switch directs the job to the next available printer if the current printer is busy. The printers for main jobs are always tested in the order, P1PC to P5PC. If the job is a tape-to-print job, the logic switch directs the job to a queue to wait for a specific printer until it is free.

The statistical entities are used to gather information about the movement of the jobs through the system. A queue is a list of jobs which were delayed at a specific bottleneck in the simulation. The queue (PRTQT) is the bottleneck which results when jobs are waiting for print storage because all five printers are busy. The five other queues (REQP1 through REQP5) are bottlenecks which result when a tape-to-print job is waiting for a specific printer.

The operational entities are blocks which provide the logic of the system.

The three special operational entities in this simulation are VARIABLE blocks used to calculate the amount of time it takes a job to print. The first variable (V2) is the set-up time used to retain a job at a printer for the number of minutes specified in parameter three. Both main jobs and tape-to-print jobs may require set-up time to mount paper forms. Only tape-to-print jobs require set-up time to mount a tape. The second variable (V1) uses the number of lines entered for each job in parameter one to calculate the time required to actually print the job. If the active printer is a model 1403 (slower printer), the time is calculated at a rate of 700 lines entered in parameter one. If the active printer is a model 3211 (faster printer), the time is calculated at a rate of 1200 lines per minute.

All of the other operational entities are blocks which instruct the print jobs where to go and what to do next. They are best illustrated by the block diagram of the GPSS simulation in Appendix A. Each figure represents a specific GPSS block. The label of the block, if any, is found in parenthesis on the left side of the block. The command is placed inside the block, and the name of any referenced entity is placed to the right of the block. Each block is accompanied by an explanation of its meaning. The block diagram is a visual representation of the GPSS simulation itself and follows exactly the computer listing of the GPSS simulation in Appendix B.

The GPSS queueing system is defined by the input arrival process, the queue discipline, and the service mechanism.

Usually the pattern of arrivals into the system is given by the probability distribution of time between successive arrival events and the number of units which appear at these events. In this study, a magnetic tape is used to input print jobs into the system. The JOBTAPE instruction is used instead of the GENERATE instruction. Data for the JOBTAPE is gathered from actual information in the ASP system. The most significant field on the tape specifies an interval of time separating the entry of each print job from its predecessor. This time is in clock units (minutes) and becomes the interarrival time recorded when the print job enters the system. The frequency distribution of the interarrival times which result from the simulation run could be used to create a probability distribution and used in a GENERATE statement.

The queue discipline describes the order in which customers entering the system are eventually served. Some of the possible queue orders are first-in, first-out (as at a bank window), last-in, first-out (as in an elevator), and random order (as when a teacher calls on students). The queue discipline used in this model is FIFO within a priority system.

The service mechanism includes a description of the time required to complete a service. In this study, the service time is dependent upon which model of printer is chosen. The frequency distribution of the number of print lines which results from the simulation run could be used to create a probability distribution and used in an ADVANCE statement. The service mechanism also includes the number and configuration of servers. In this study, the printers are examples of servers in parallel, and the tape-to-print job requests are examples of assigned services.

A system is a series of events. One of the problems which a simulation has to solve is to decide which event will happen next. Therefore, the central task in the simulation program is the "scan," which examines all potential events.

All of the print jobs in this simulation are maintained in chains. There are four chains used, and a print job may be in any one of them at any given time. The four chains are:

(1) the "Current Events" chain,

(2) the "Storage Full" delay chain,

(3) the "Facility in Use" delay chain, and

(4) the "Future Events" chain. (See Figure 2.)

The Current Events chain is organized in descending order of priority and, within each priority class, in the sequence in which the jobs were entered into the system. Each job in the Current Events chain may be either in active (scan) status or in a delay status. If the job is in active status, the GPSS scan will continually try to move it into the next block. If the job has been blocked by one of the printers, the job is put in delay status and will be skipped over by the scan. Jobs

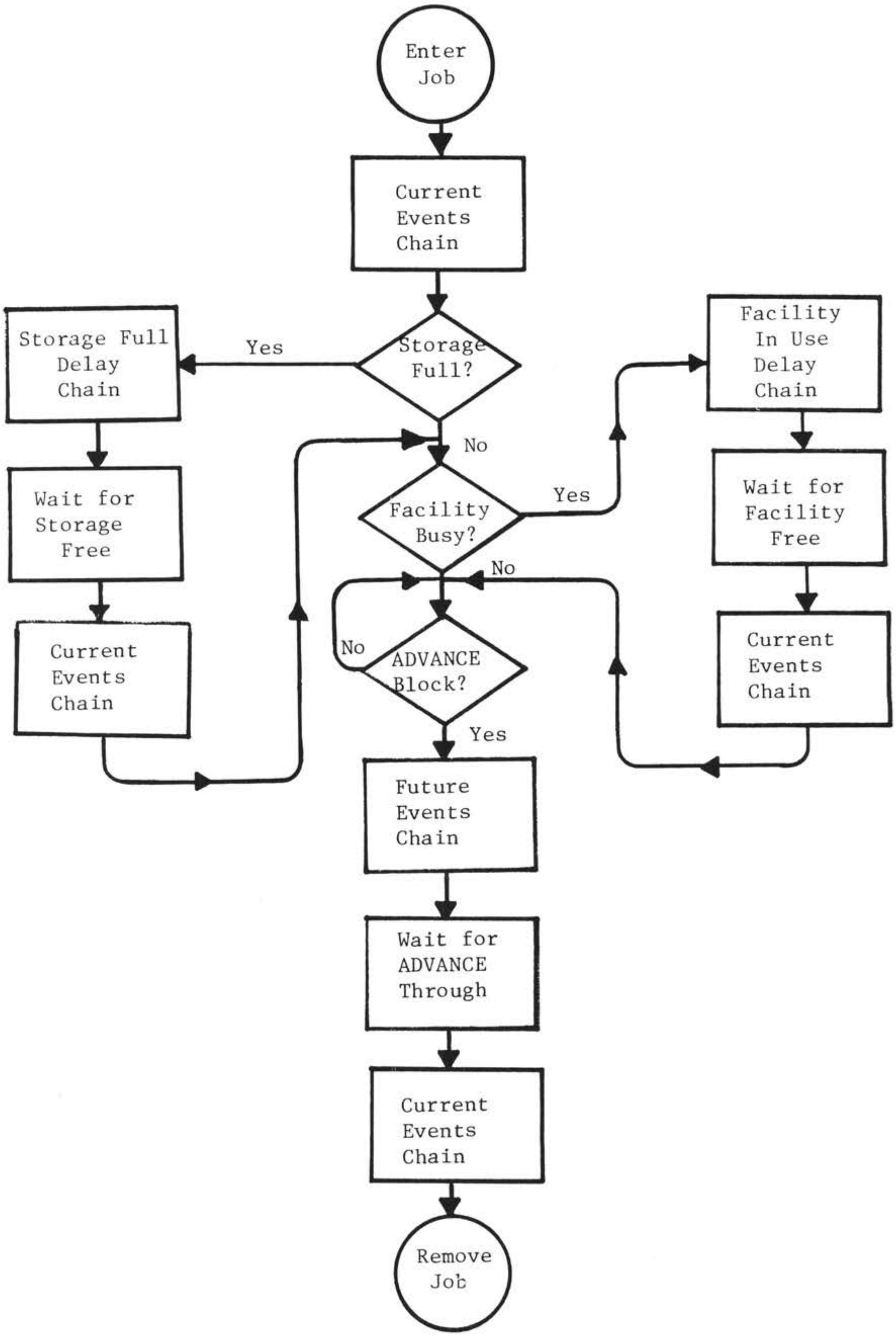


Figure 2. Queuing Chains Used by the GPSS Simulation

are added to the Current Events chain at BLOCK #1 in the GPSS block diagram (see Appendix A) and when they are released from the other three chains.

The two delay chains are "pushdown" lists of jobs that are waiting for a printer to become free. The Storage Full delay chain is a list of jobs which are waiting for any available printer. A job will be in this chain only when all five printers are busy. Jobs are added to the Storage Full delay chain when they are refused entry to BLOCK #3 in the GPSS block diagram. The Facility In Use delay chain is a list of jobs which are waiting for a particular printer. A job will be in this chain only if it is a tape-to-print job which is waiting for a printer which is busy. Jobs are added to the Facility In Use delay chain when they are refused entry to any of the five GATE BLOCKS with no specified transfer field in the tape-to-print section of the GPSS block diagram.

The Future Events chain is organized in ascending order by time. The job which has the smallest scheduled event time is the first in the chain. There are no distinctions made by priority. A job will be in this chain only if it is busy being "set up" or is busy printing. A job is added to the Future Events chain when it enters any of the ADVANCE BLOCKS in the GPSS block diagram.

The second step in the design of the research is to plan the experiment. The simulation is run six times. Each time the speed of one of the printers is increased from the previous run. In the first run, all of the printers are slower speed printers. In the sixth run, all of the printers are faster speed printers. The intermediate runs are a combination of the two speeds.

The two assumptions in the system design are:

(1) Print forms changes are allowed on all printers, and

(2) The speed of the model 1403 printers is not affected by the print chain that is mounted.

The four restrictions in the system design are:

(1) Only the five Ponca City (local) printers are included,

(2) The number of printers simulated is always five,

(3) All printing other than main jobs and tape-to-print jobs is ignored, and

(4) Only the first shift is simulated.

Any of these assumptions and restrictions may be relaxed in future runs in order to determine the effect they have on the system.

A comparison of the price of the two types of printers is shown in Table III. The model 1403 printers in the shop today are over six years old and the increase in long-term reliability gained from adding the new equipment would help balance the difference in price. A financial analysis is not included in this study, but the cost of the equipment would certainly be considered in a real situation.

A simulation is most meaningful to the person who designs it. The problem of convincing another analyst of its validity is major. A manager must become familiar with a tool in order for him to have confidence in it. Therefore, part of an effective simulation design is to integrate the operating personnel into the development of the model.

The final step in the design of a simulation system is to develop the computer program.

TABLE III

UNIT MONTHLY COST OF TWO MODELS OF PRINTERS

Model 1403, N1:	Printer (1100 LPM)	$ 743	
	UCS Adapter	---	
	1 Print Train	97	
	1 Control Unit	937	
	1100 LPM Adapter	---	
	1st UCS Adapter	---	
			$1,777.00
Model 3211	Printer (2000 LPM)	$1,428	
	1 Print Train	350	
	1 Printer Controller	630	
			$2,408.00

The GPSS simulation language was chosen for this project for several reasons. The first reason is a function of the GPSS system itself. GPSS is a computer language developed to ease the task of building a simulation model. It is easy for beginners to learn. The training for this model was entirely self-education from the IBM manuals and some GPSS texts. In order to become an expert in GPSS, it is probably essential to use some other source as well, but it is possible to learn the system on an elementary scale with no help at all.

The second reason that GPSS was chosen is that it is the only discrete simulation system supported on the computer which was available.

The last reason GPSS was chosen is to evaluate it in a practical sense. If it proves valuable, it may be used to solve some real problems in the future.

Data Base

The essential input data for this simulation is a group of print jobs which are representative of the workload on the ASP system. The ASP system operates six days a week, three shifts a day, with a slightly different type of workload on each shift. The three shifts are:

(1) Shift one - 8:00 A.M. to 4:00 P.M.

(2) Shift two - 4:00 P.M. to 12:00 Midnight

(3) Shift three - 12:00 Midnight to 8:00 A.M.

The workload on shift one is heavily oriented to processing main jobs and returning checkout runs to the users. The workload on shift two is more oriented toward running production systems. More tape-to-print jobs are done on shift two. Shift three is a light shift and has no specific workload.

Part of the design of the simulation was to build a JOBTAPE to create input transactions. Since there was real data available in the form of accounting cards and console listing which were kept for one month after they were generated, it was logical to build the JOBTAPE from actual history.

Two criteria were used to select the day which would provide the input data. First, the day should be one without any external complications. Special cases, such as one of the printers "breaking down" could be added to the simulation later, if desired. Second, the day should be one when a lot of work was processed. In this way, the greatest number of jobs would be waiting for service.

To find a day without external complications, two records in the Operations Division were examined. First, a record kept by the machine operators called the "Warm Start Log" was examined from the dates of October 5, 1973, through November 24, 1973. Several days were picked which had no software failures, known as "warm starts," including November 14. Next, a hardware log which is kept by the IBM Custom Engineers was examined to determine if there had been any hardware trouble on any of the chosen days. Again, November 14, as well as some other days, was error free.

The Operations Supervisor was used as a reference to determine what days met the criteria of a full workload. It was determined that Wednesday, November 14, was the tenth working day of the month, which is always one of the peak days. In fact, work had been left over on Thursday morning, which happens about once a month. It was verified that on that day all five printers were up and running, and SUPPORT operators were assigned on this basis: (1) Shift one, two operators, (2) Shift two, three operators, and (3) Shift three, one operator. The ASP accounting cards and all of the console listings were collected for that day and Wednesday, November 14, 1973, became the sample day.

Because the sample day was selected after it occurred, the SUPPORT operators were not aware that a study was being made and a psychological bias was avoided.

Two fields were added to the ASP accounting cards from information on the console listings. (See Table IV.)

Field one on the ASP accounting card is the clock time when the job is available for print processing. For main jobs, this time is when the job finishes processing on main. For tape-to-print jobs, the time is when the operators "calls" the job into the system. Field two of the ASP accounting card required quite a bit of research. The set-up time for a job which requires special forms includes the time to change the forms back again when the next job starts. It also includes end-of-reel recovery time for tape jobs. An estimate is also made of the time spent in an "INTERVENTION REQUIRED" status as indicated on the console messages, and one minute is added to every job requiring set-up because the operators continue to align forms after they have instructed the system that the forms are mounted. Two special jobs were added to represent two cases in which an operator ignored a mount forms message on P5PC and re-scheduled the job to another printer after waiting sixty-three and four minutes respectively. The two cards added use sixty-four and four minutes of set-up time, but print no lines.

Because of the time required to analyze these two fields, the simulation time horizon is restricted to first shift only. The other three fields are fully explained in Table IV.

TABLE IV

ASP ACCOUNTING CARD FORMAT

Field	Card Columns	Contents
1	1 - 6	Time of day that the print job became available for printing in hours, minutes, and seconds. This data was logged manually from the ASP consoles.
2	7 - 8	Number of minutes required to "set up" the printer with special paper forms. This data was logged manually from the ASP consoles.
3	37-40	The number of lines printed by this job (in 100's).
4	49-50	The priority of the print job. Tape-to-print jobs will be priority 15. Main jobs will be priority 9 - 14.
5	56-57	The printer number which was assigned for tape-to-print jobs.

A FORTRAN program was written to convert the ASP accounting cards to the standard GPSS tape format and to build the JOBTAPE for input to the GPSS simulation. The GPSS input tape format is illustrated in Table V.

Range of Alternatives

The problem which the simulation study is addressing is: "What would happen if the current slow speed printers were replaced with faster speed printers?"

To analyze this problem each simulation run has one more faster speed printer than the previous simulation. The six runs are illustrated in Figure 3. The number "1403" represents the current IBM 1403 printers, with a maximum rate of 1100 lines per minute and an effective rate of 700 lines per minute. The number "3211" represents the faster IBM 3211 printers, with a maximum rate of 2000 lines per minute and an effective rate of 1200 lines per minute.

Apparatus and Equipment

The analysis done in this study is a discrete system simulation of an equipment evaluation problem. A detailed summary of the model is found in the Design section of Chapter III. A GPSS block diagram and the computer listing of the model are found in Appendixes A and B, respectively.

The language used to develop this model is the IBM Program Product, General Purpose Simulation System/360/OS, 5734-XS1, Version 2, Modification Level 1.

The system which is simulated by the GPSS model is the printer SUPPORT section of the IBM Program Product, Asymmetrical Multiprocessing System (ASP), Version 2, Modification Level 5.

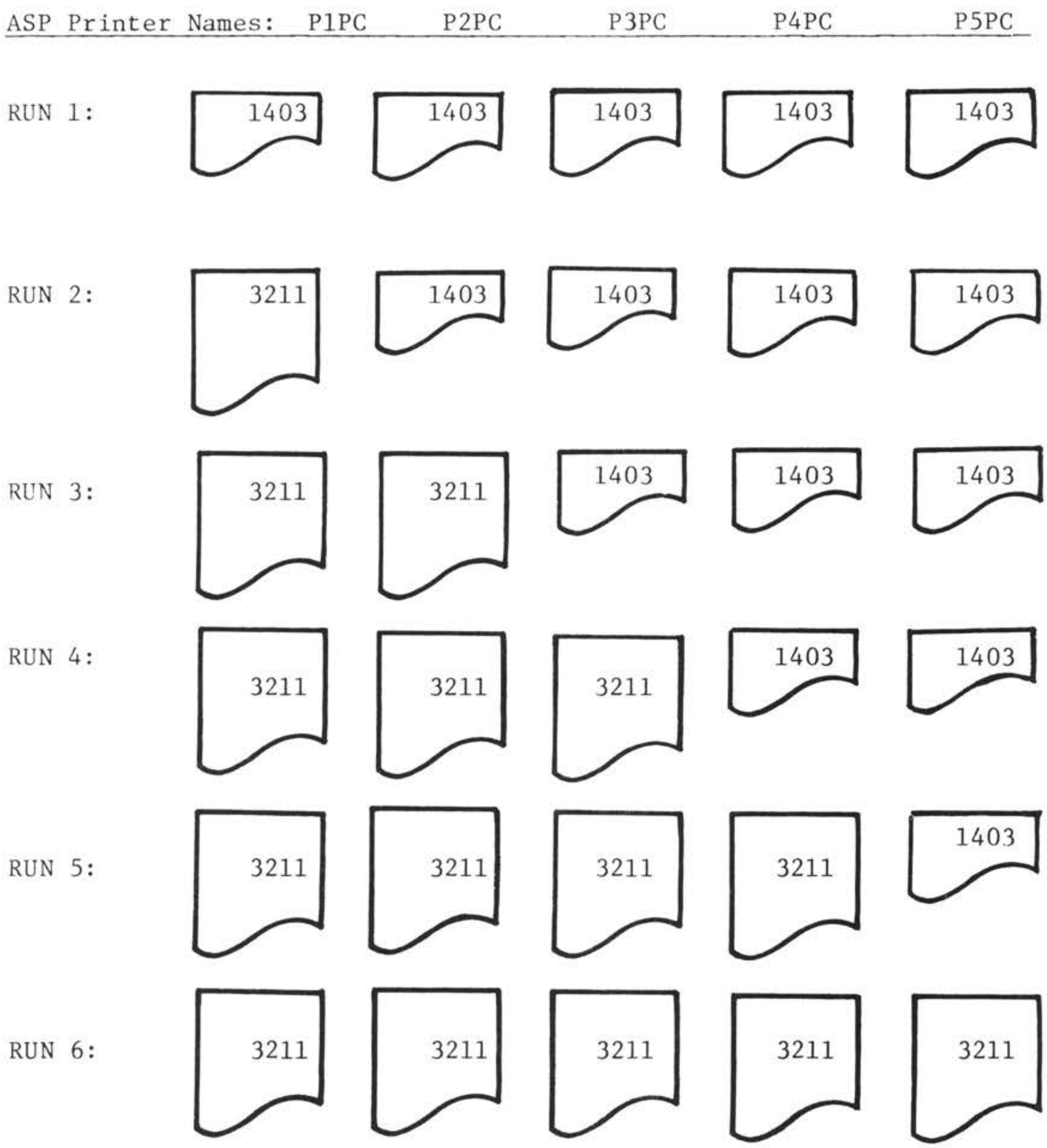
TABLE V

GPSS INPUT TAPE FORMAT

Field	Tape Positions	Contents
1	1 - 4	Interarrival time of a print job entering the system. (IA)
2	5 - 8	Unused.
3	9 - 10	Priority of the print job (9 - 15). (PR)
4	11	Always X'80'.
5	12	Always X'03' to indicate three input parameters.
6	13 - 16	Parameter one: Number of lines printed by this job. (P1)
7	17 - 20	Parameter two: Number of clock units (minutes) used to "set up" the printer with special paper forms. (P2)
8	21 - 24	Parameter three: The printer number which was assigned for tape-to-print jobs. (P3)

Each tape record is 128 characters in length, unblocked, as is required by GPSS standards. The final tape record has the words, "END OF JOB T" in positions 1 - 12.

A special FORTRAN program, BUILDJOB, is required to convert the ASP clock card data to GPSS tape input format.



Rules: 1. Replace a slow-speed printer (1403) with a high-speed printer (3211) each run.

2. Change one printer at a time.

Figure 3. Illustration of the Six Simulation Runs

The printers simulated are the IBM 1403, Model N1 printer and the IBM 3211 printer.

The model was programmed on an IBM System/370/155 in the Central Computer Department of Continental Oil Company.

CHAPTER IV

RESULTS OF RESEARCH

The results of a simulation are a symbolic representation of the system which is modeled. The output is not a precise analog of the actual system. Rather, the statistics in this simulation attempt to guide the manager to answer the question, "What if?" for six different printer configurations, holding all other factors constant.

The results of the six simulation runs give information in three areas. Each of the areas provide some insight into the system as it runs today and as it would run with faster printers.

The first area is an analysis of the job stream as it is read in from the input data tape, JOBTAPE. The job flow provides information about the current system which had never before been quantified. The five fields of the JOBTAPE are analyzed statistically, and frequency distributions are built which permit the system to be enlarged.

The second area is an analysis of the behavior of the printers taken as a group. Statistics are gathered on how the Storage, PRINT, is used in terms of time and activity. The queue, PRTQT, indicates how often and how long jobs have to wait for an available printer. The Storage area is concerned with how the system would work with new equipment.

The third area is an analysis of the behavior of each printer taken as a separate device. Statistics are gathered on how often each printer is busy and how long the jobs keep each printer active. The problem is waiting for a specific printer to become free for the tape-to-print jobs is also studied. The printer Facility area is also concerned with how the system would work with new equipment.

Analysis of the Job Stream

The job interarrival time is the first field in the JOBTAPE input tape format. (See Table V.) The IA specifies a time interval which elapses between each job as it enters the system.

The frequency distribution of the job interarrival times is shown in Table VI. To run the simulation with random number generation, the JOBTAPE statement could be replaced with a GENERATE statement containing a Function which uses the frequency distribution.

A histogram of the frequency distribution of the job interarrival times is shown in Figure 4. An examination shows that most of the jobs in the system arrive within one minute of the previous job. This time span reflects actual observation because the operator stacks several jobs in the card reader at one time, and the jobs are read into the system as fast as the card reader will read them. The next greatest frequencies are two through five minute intervals. These time intervals occur because the job input decks are allowed to accumulate on the job submittal table until there is another group of jobs. The larger interarrival times are indicative of a single large job which is read in by itself.

The job priority is the third field in the JOBTAPE input tape format. (See Table V.) The PR specifies the priority of the job as it enters the system. Jobs are serviced on a FIFO basis within their priority.

TABLE VI

FREQUENCY DISTRIBUTION OF JOB INTERARRIVAL TIMES FROM JOBTAPE

Upper Limit	Observed Frequency	Percent Of Total	Cumulative Percentage
0	67	25.00	25.0
1	98	36.56	61.5
2	41	15.29	76.8
3	20	7.46	84.3
4	19	7.08	91.4
5	9	3.35	94.7
6	3	1.11	95.8
7	2	.74	96.6
8	2	.74	97.3
9	4	1.49	98.8
10	2	.74	99.6
11	0	.00	99.6
12	1	.37	100.0

Remaining frequencies are all zero.

Entries in table = 268

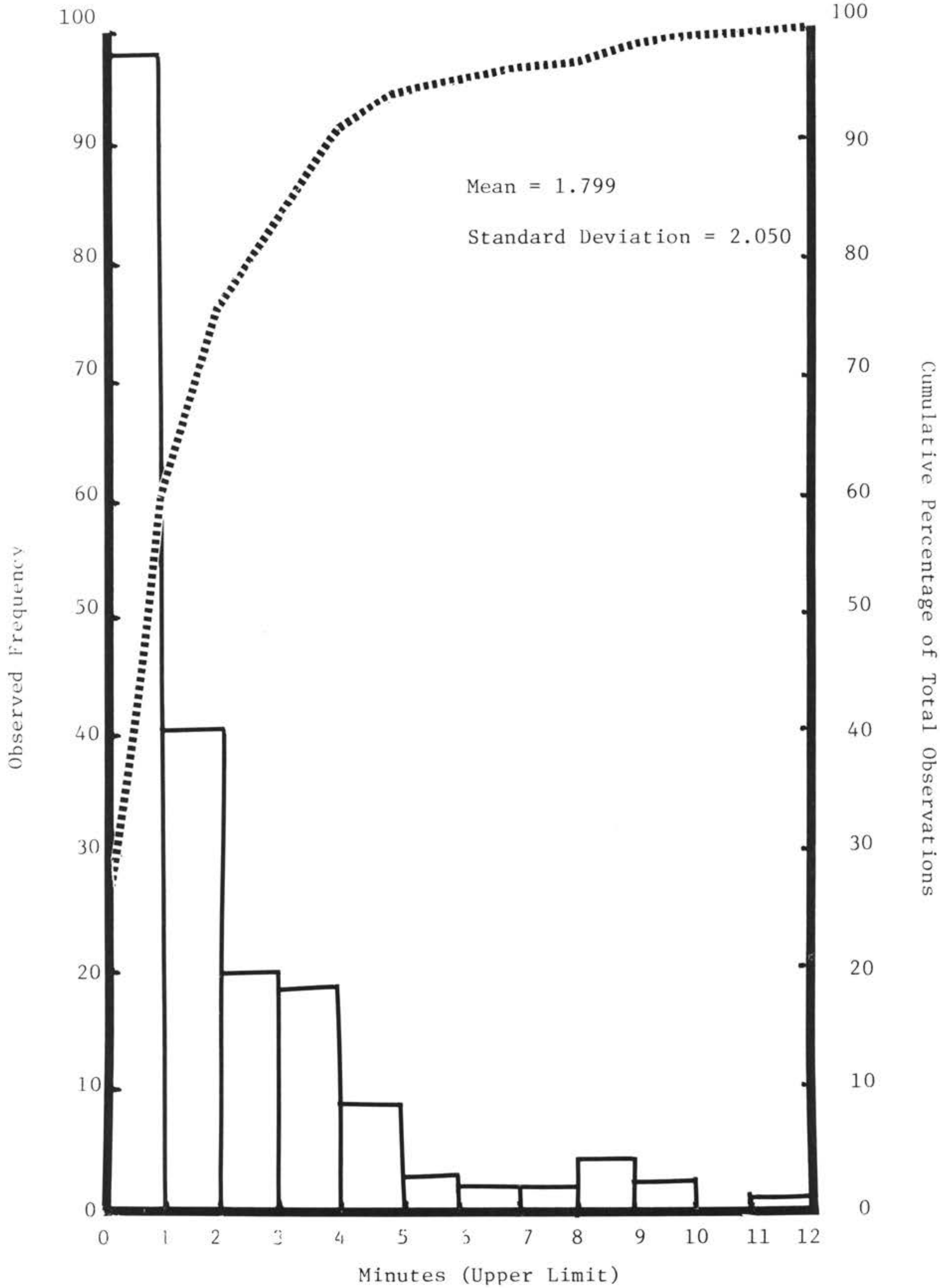


Figure 4. Histogram of the Frequency Distribution of Job Interarrival Times from JOBTAPE

The frequency distribution of the priorities is shown in Table VII. To run the simulation with random number generation, a PRIORITY block could be used containing a Function which uses the frequency distribution.

TABLE VII

FREQUENCY DISTRIBUTION OF JOB PRIORITIES FROM JOBTAPE

Priority	Observed Frequency	Percent Of Total	Cumulative Percentage
9	71	27.62	27.6
10	9	3.50	31.1
11	28	10.89	42.0
12	88	34.24	76.2
13	11	4.28	80.5
14	6	2.33	82.8
15	44	17.12	100.0

Remaining frequencies are all zero.

Entries in table = 257

A histogram of the frequency distribution of the job priorities is shown in Figure 5. An examination shows that the highest used priority is priority twelve and the second most used is priority nine. Priorities nine through fourteen are used for main jobs. Priority nine may be assigned without approval and is used for most checkout work. Each priority from nine to twelve must be signed by a supervisor, the higher the priority, the higher the supervisor. Priorities thirteen and fourteen are assigned by the MAIN operators. Priority

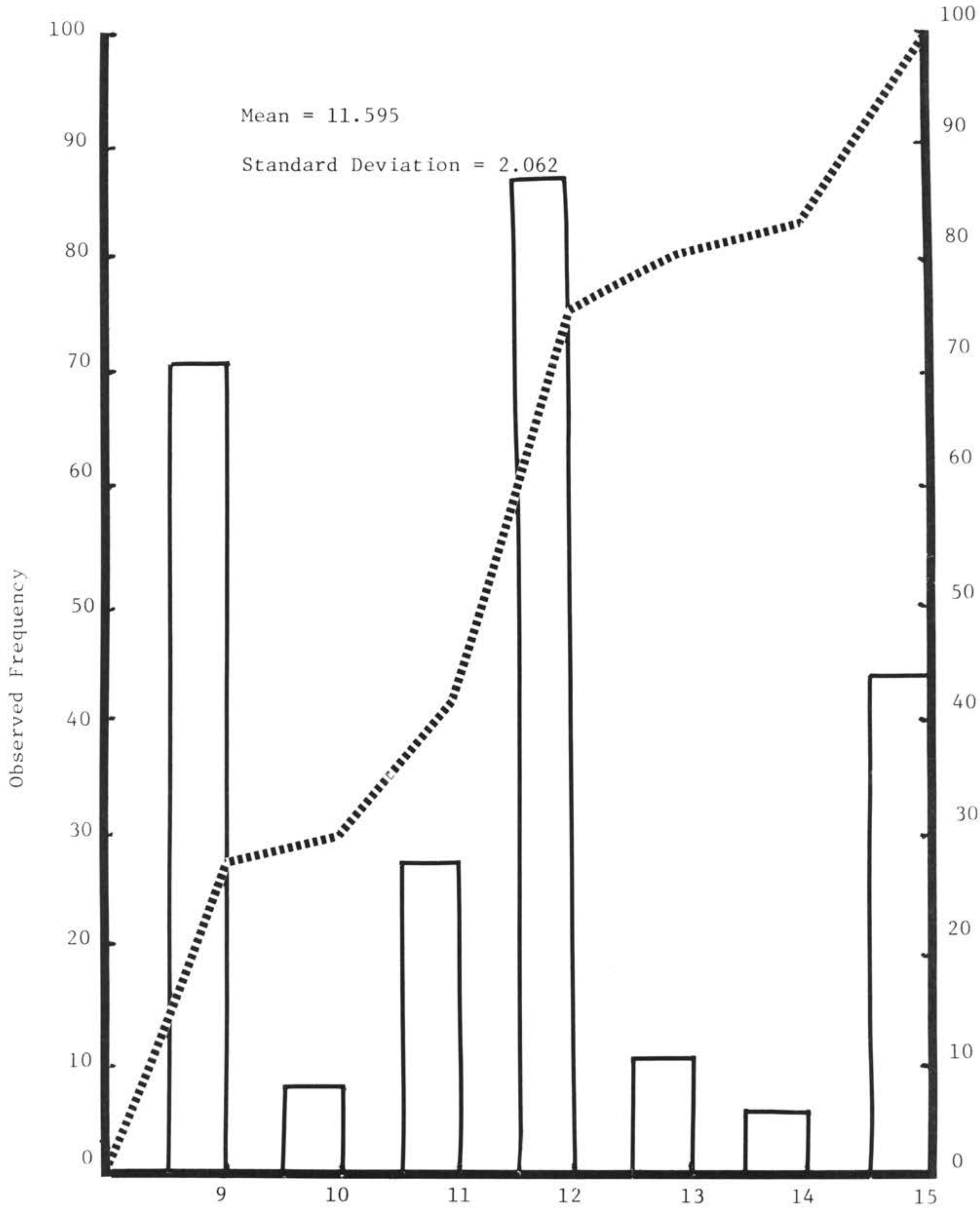


Figure 5. Histogram of the Frequency Distribution of Job Priorities from JOBTAPE

fifteen is reserved for tape-to-print jobs requested by the SUPPORT operators. During the first shift, the emphasis in on checkout work and a few production jobs on MAIN. On SUPPORT, the emphasis is on main job output with a secondary concern about tape-to-print work. This histogram would probably be quite different during a second shift analysis.

The number of lines printed is the first parameter field in the JOBTAPE tape format. (See Table V.) The number of lines is used to determine how long a print job is active at a printer.

The frequency distribution of the number of lines per job is shown in Table VIII. To run the simulation with random number generation, an ASSIGN block could be used for parameter one containing a Function which uses the frequency distribution.

A histogram of the frequency distribution of the number of lines is shown in Figure 6. An examination shows that most of the jobs print less than 1000 lines. Three overflow values with an average length of 147,000 lines each tend to inflate the mean value and the standard deviation. It would be better to use the distribution as a Function without the three overflow values and to enter the overflow values with a special switch in the program.

The number of minutes required to "set up" a printer is the second parameter field in the JOBTAPE tape format. (See Table V.) The number of set-up minutes is used to determine how long a print job waits for an operator to mount special paper and/or input tapes before the actual printing can begin.

TABLE VIII

FREQUENCY DISTRIBUTION OF THE
NUMBER OF LINES FROM JOBTAPE

Lines: Upper Limit	Observed Frequency	Percent Of Total	Cumulative Percentage	Cumulative Remainder
0	46	17.89	17.8	82.1
1000	96	37.35	55.2	44.7
2000	27	10.50	65.7	34.2
3000	13	5.05	70.8	29.1
4000	25	9.72	80.5	19.4
5000	12	4.66	85.2	14.7
6000	8	3.11	88.3	11.6
7000	5	1.94	90.2	9.7
8000	5	1.94	92.2	7.7
9000	2	.77	92.9	7.0
10000	3	1.16	94.1	5.8
11000	2	.77	94.9	5.0
12000	0	.00	94.9	5.0
16000	1	.38	95.3	4.6
20000	2	.77	96.4	3.5
24000	0	.00	97.2	2.7
28000	0	.00	97.6	2.3
32000	0	.00	97.6	2.3
36000	0	.00	98.0	1.9
40000	0	.00	98.0	1.9
44000	0	.00	98.0	1.9
48000	0	.00	98.0	1.9
52000	0	.00	98.8	1.1
56000	0	.00	98.8	1.1
60000	0	.00	98.8	1.1
Overflow	3	1.16	100.0	.0

Average value of overflow 147033.31

Entries in table = 257

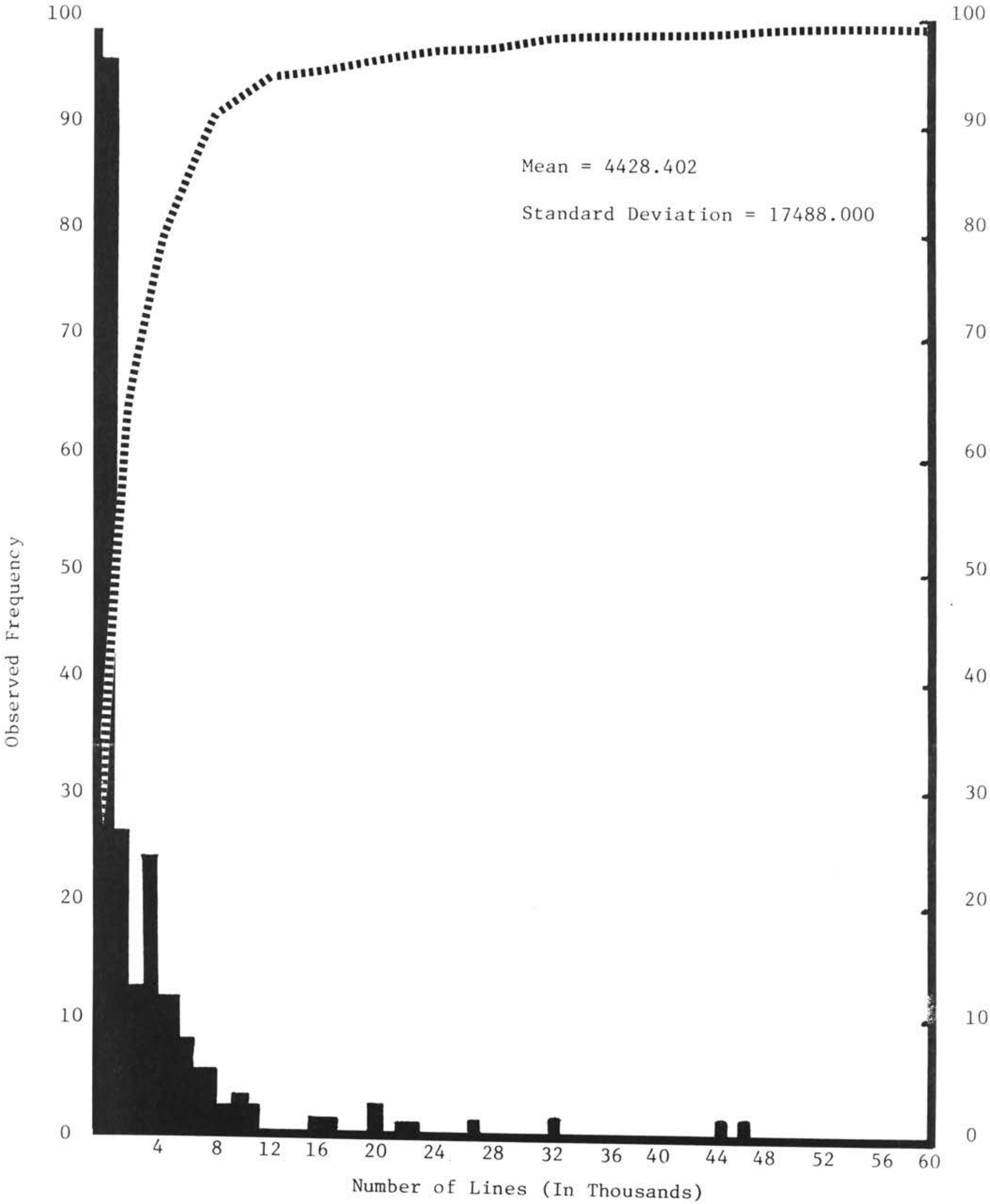


Figure 6. Histogram of the Frequency Distribution of Number of Lines from JOBTAPE

The frequency distribution of the number of set-up minutes is shown in Table IX. To run the simulation with random number generation, an ASSIGN block could be used for parameter two containing a Function which uses the frequency distribution.

TABLE IX

FREQUENCY DISTRIBUTION OF NUMBER OF SET-UP MINUTES FROM JOBTAPE

Minutes: Upper Limit	Observed Frequency	Percent Of Total	Cumulative Percentage
0	219	85.21	85.2
1	16	6.22	91.4
2	5	1.94	93.3
3	6	2.33	95.7
4	6	2.33	98.0
5	0	.00	98.0
6	3	1.16	99.2
7	0	.00	99.2
8	0	.00	99.2
9	0	.00	99.2
10	0	.00	99.2
11	0	.00	99.2
12	1	.38	99.6
Overflow	1	.38	100.0

Average value of overflow 63.00

Entries in table = 257

A histogram of the frequency distribution of the number of set-up minutes is shown in Figure 7. An examination shows that almost all of the jobs have no set-up time. Most of the thirty-eight jobs which do have set-up require less than six minutes. The overflow value of

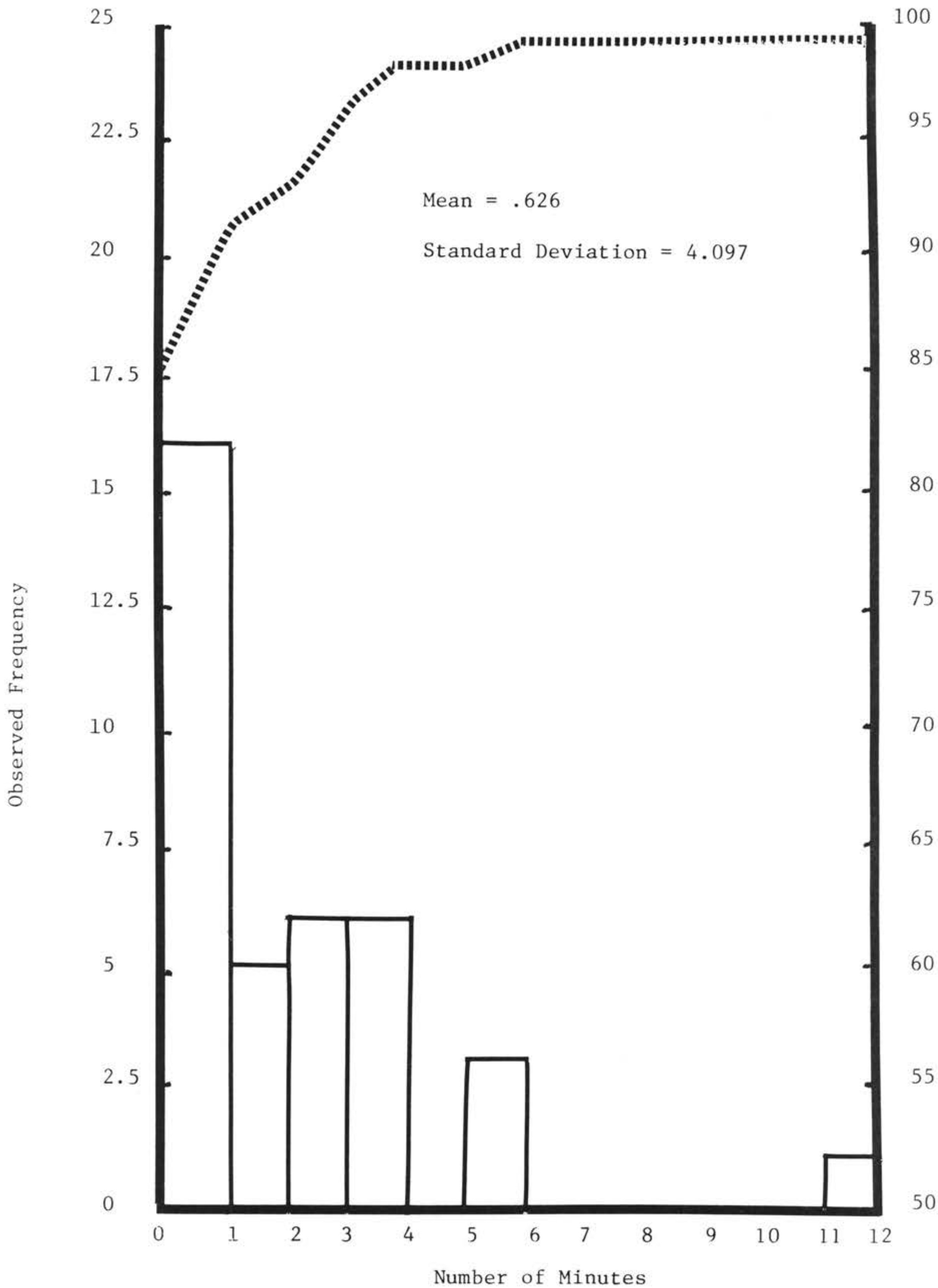


Figure 7. Histogram of the Frequency Distribution of Number of Set-Up Minutes from JOBTAPE

sixty-three minutes for a job which was never serviced on printer P5PC tends to inflate the mean value and the standard deviation. It would be better to use the distribution as a Function without the one overflow value and to enter the overflow value with a special switch in the program.

The printer which was assigned during the actual execution on the ASP system is the third parameter in the JOBTAPE tape format. (See Table V.) The printer assignment is needed only for the tape-to-print jobs to represent the assignment given by the SUPPORT operator when he requests a job.

The frequency distribution of the printer assignments is shown in Table X. To run the simulation with random number generation, an ASSIGN block could be used for parameter three containing a Function which uses the frequency distribution.

TABLE X

FREQUENCY DISTRIBUTION OF THE PRINTER ASSIGNMENTS FROM JOBTAPE

Printer Number	Observed Frequency	Percent Of Total	Cumulative Percentage
1	100	38.91	38.9
2	49	19.06	57.9
3	68	26.45	84.4
4	24	9.33	93.7
5	16	6.22	100.0

Remaining frequencies are all zero.

Entries in table = 257

A histogram of the frequency distribution of the printer assignments is shown in Figure 8. The distribution includes printer assignments for both main jobs and tape-to-print jobs so it could not be used to assign a printer in the simulation without some change. The same distribution is needed for priority fifteen jobs only in order to assign the printers. What the distribution does indicate is the number of jobs which are processed on each printer in the actual data. The actual data can be compared with the simulated data for Run 1 in Figure 20 and Table XIV. The most significant difference is that printer P3PC is as highly used in the simulated run. The other four printer assignments are comparable to the actual data.

Analysis of Print Storage

The evaluation of the Storage, PRINT, may be divided into three areas. The first area shows how the storage is used in terms of time. The second area shows how the storage is used in terms of activity. The third area shows how long jobs have to wait for a printer to become available.

Most of the averages in the simulations are based on the Cumulative Time Integral (C.T.I.). The cumulative time integral is the number of clock units an entity is occupied, weighted by the number of units of the entity which are used while there was no change in occupancy. The cumulative time integral is illustrated in Figure 9.

Table XI contains statistics on how busy the storage is over an eight-hour period. The average contents of storage refers to the average number of printers which are busy and is calculated from the formula:

$$\text{Average Contents} = \frac{\text{Cumulative Time Integral}}{\text{Eight hours}}$$

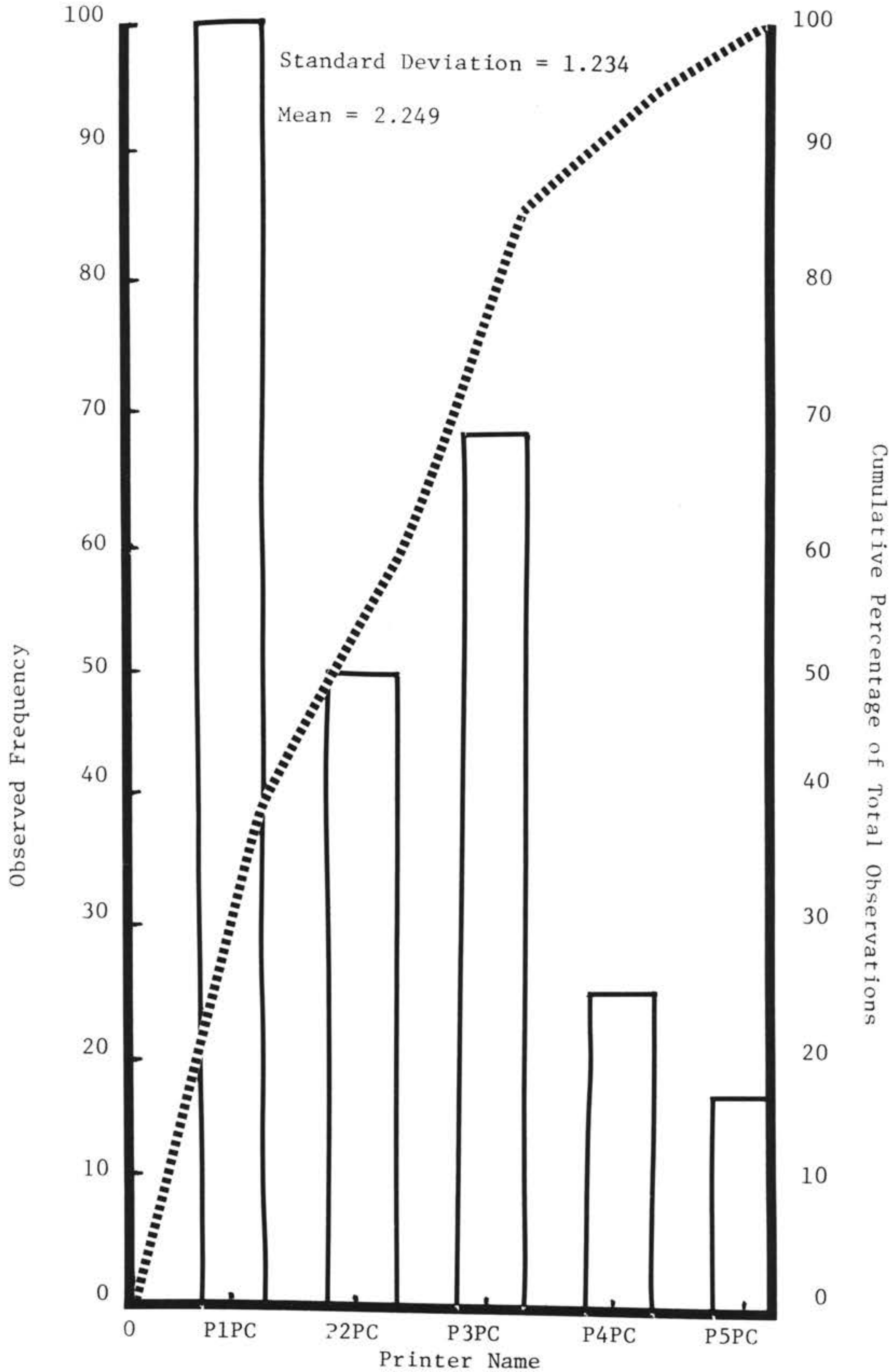


Figure 8. Histogram of the Frequency Distribution of Printer Assignments from JOBTAPE

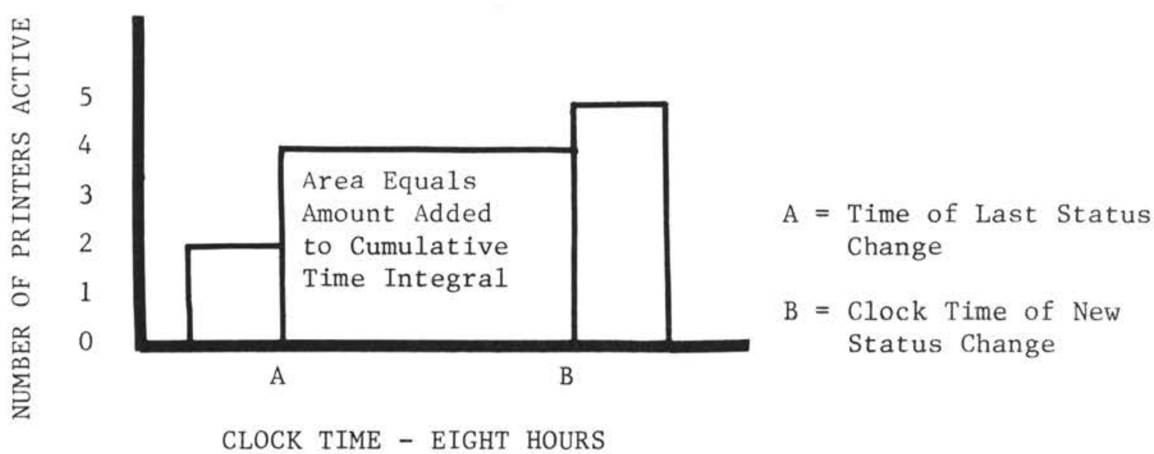


Figure 9. Illustration of the Cumulative Time Integral (C.T.I.)

The average contents of storage is illustrated in Figure 10. The most significant information in the table is that with the addition of one faster printer, less than four printers are busy. This might indicate that one of the slower printers should be eliminated.

TABLE XI

STATISTICAL PRINTOUT FOR STORAGE, PRINT

	Average Contents	Average Utilization	Average Time/Tran	Number Print Jobs	Maximum Contents
Run 1	4.250	.849	6.754	302	5
Run 2	3.783	.756	6.033	301	5
Run 3	3.514	.702	5.623	300	5
Run 4	3.243	.648	5.121	304	5
Run 5	2.935	.587	4.634	304	5
Run 6	2.797	.559	4.417	304	5

The average utilization of storage capacity is the average percent of the time that the storage was busy. This statistic is calculated by the formula:

$$\text{Average Utilization} = \frac{\text{Average Contents}}{\text{Eight hours}}$$

The average utilization of storage capacity is illustrated in Figure 11. The biggest drop in utilization comes with the addition of the first faster printer, resulting in a ten percent increase in free time. All of the other increases in free time are only about five percent each.

The average time each print job is active in storage is illustrated in Figure 12 and is calculated by the formula:

$$\text{Average Time Per Job} = \frac{\text{Cumulative Time Integral}}{\text{Number of Jobs}}$$

Each time a faster printer is added, the potential amount of time required to print a job is reduced. Again, the greatest gain is realized when the first printer is added.

The number of print jobs in Table XI includes all of the print jobs as they enter the system plus an extra count of one job every time a tape-to-print job cannot seize the printer which it requires and must wait in line again for print storage. Since the original system can process all of the jobs during the eight-hour shift, the addition of faster printers changes the number of jobs processed only slightly.

The maximum storage contents in Table XI indicates that at least at one time in the simulation, all five printers in print storage are active concurrently. Even in the sixth run, when the average utilization is only fifty-five percent, the jobs enter fast enough to keep all of the printers active at least part of the time.

The number of units of the printer storage which are used during the simulation are printed in Table XII. In this table, time is not considered. The table tells how many printers are being used, but it does not take into account how long the printers are busy. There is also no indication which printers are being used. For example, four printers in use could be any four printers in the system.

Figure 13 shows graphically the number of printers which are busy each time a new job seizes a printer. As the number of fast printers

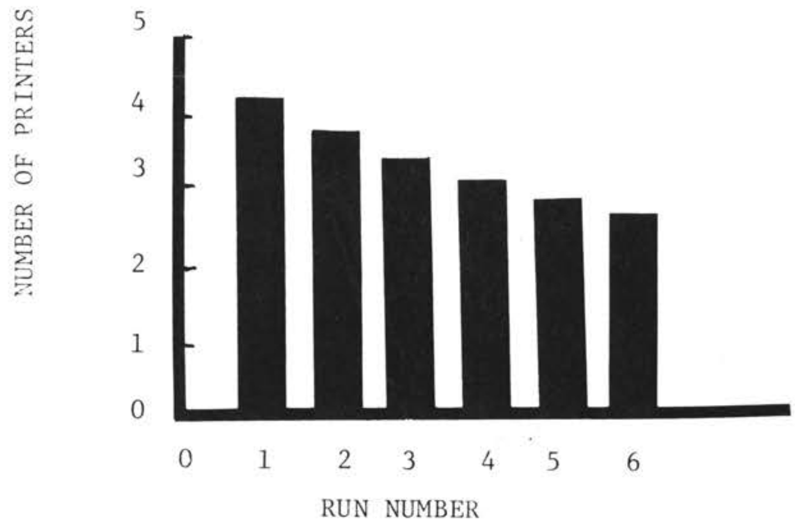


Figure 10. Average Contents of Storage, PRINT

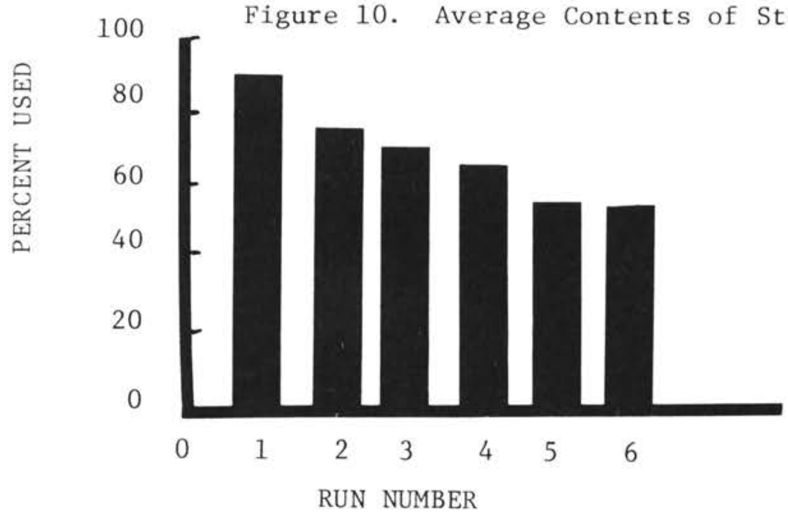


Figure 11. Average Utilization of Storage Capacity

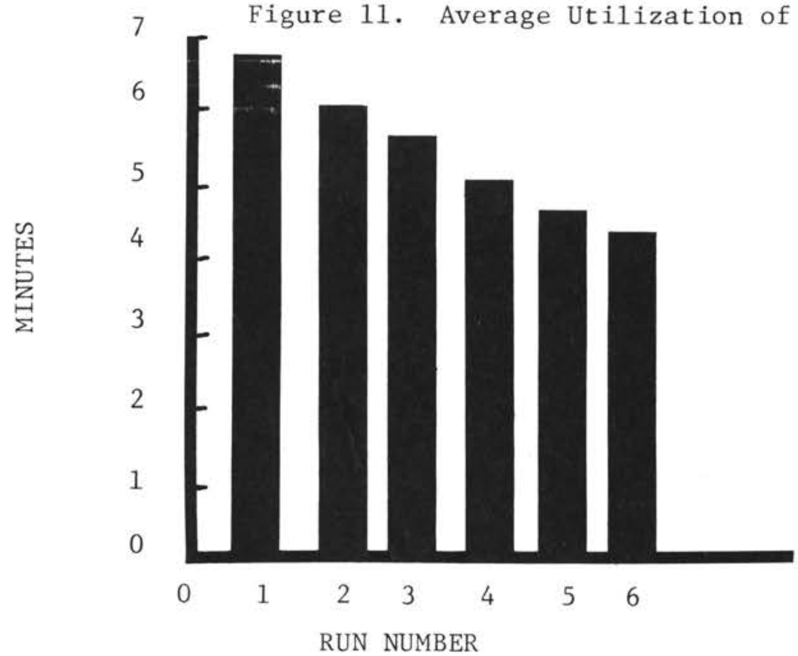


Figure 12. Average Time per Print Job in Storage

TABLE XII

FREQUENCY DISTRIBUTION OF NUMBER OF UNITS OF STORAGE USED

Number of Units Used	Observed Frequency					
	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
0	0	0	0	0	0	0
1	13	14	15	18	18	21
2	8	10	13	12	24	29
3	24	43	52	60	80	89
4	27	53	55	73	76	69
5	230	181	165	141	106	96
Mean Argument	4.500	4.252	4.139	4.009	3.750	3.625
Standard Deviation	1.042	1.109	1.152	1.164	1.183	1.214

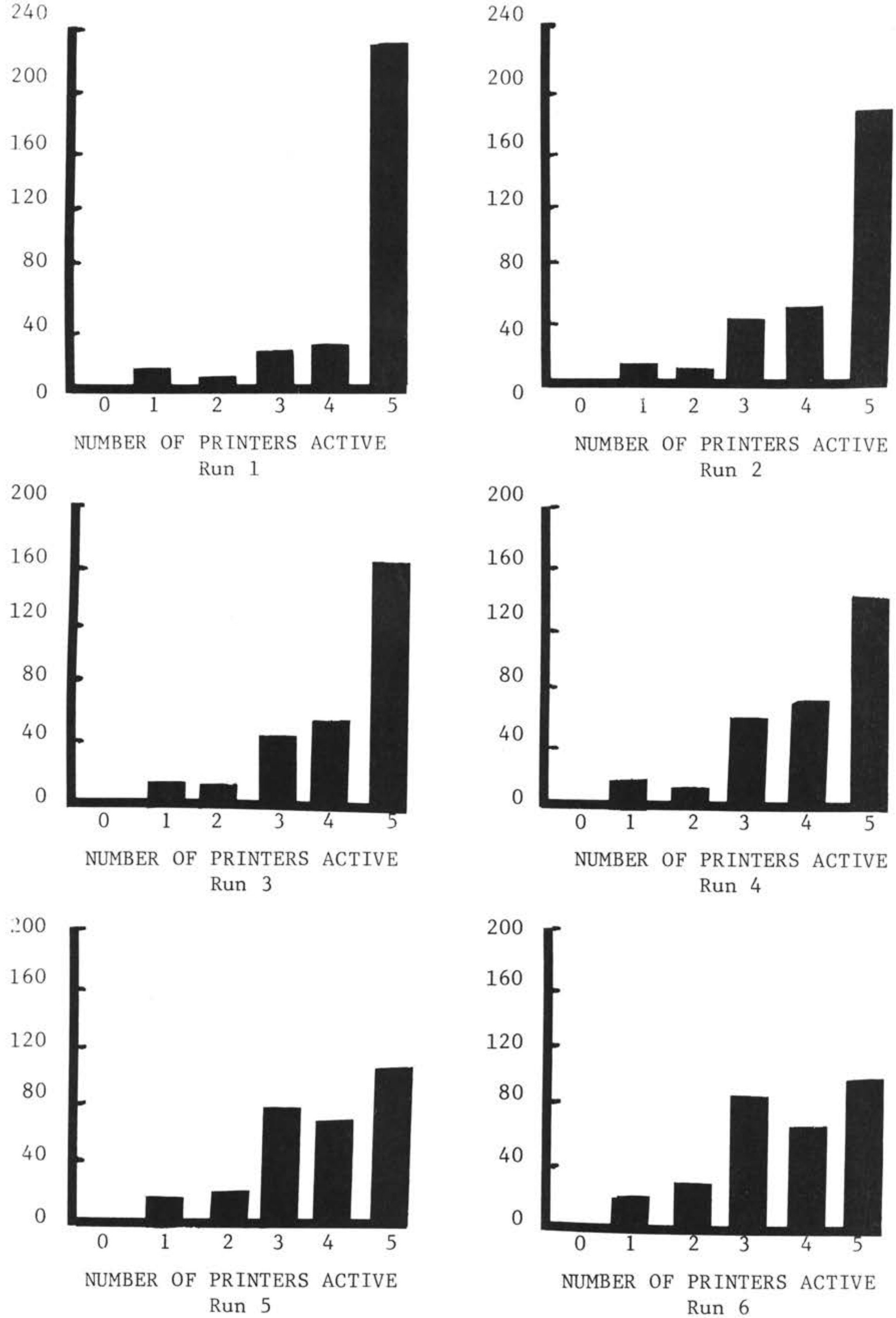


Figure 13. Histogram of the Current Contents of Print Storage Each Time a Job Seizes a Printer

increases, the times that all of the printers are busy decreases rapidly. The critical factor is the number of times five printers are busy because that is what causes the greatest amount of queueing. In Figure 13, the "five printers busy" is the area which is most affected, illustrating the benefit of adding faster printers.

The main value of the arguments is the arithmetic average of the number of printers active at one time. It is computed by the formula:

$$\text{Mean Value of Arguments} = \frac{\text{Sum of Table Arguments}}{\text{Number of Entries in the Table}}$$

The standard deviation of the table arguments is calculated from the following formula, yielding the square root of the variance:

$$\text{Table Standard Deviation} = \sqrt{\frac{D2 - (D1)^2/D3}{D3 - 1}}$$

where: D1 = Sum of the table arguments
D2 = Sum of the squared values of the table arguments
D3 = Number of entries in the table

When the printers are active at all, the mean value is the average number which are active. For example, in Run 1 of Table XII, when the printers are active, then on an average, four printers are always active, and five printers are active half of the time, resulting in a mean value of 4.500. The mean value is not to be confused with the average contents of storage which tells how many printers are active all of the time. The printers could run only one hour a day and the mean value could be 5.000 if, for that hour, all five printers were busy.

The queue entries in the GPSS simulation are provided to gather statistics on jobs which are delayed by the unavailability of a printer. Table XIII contains some of these statistics.

TABLE XIII

STATISTICAL PRINTOUT FOR QUEUE, PRTQT

	Maximum Contents	Average Contents	Percent Zeros	Average Time/Trans	Average* Time/Trans
Run 1	25	5.141	53.6	8.172	17.628
Run 2	11	1.279	68.4	2.039	6.463
Run 3	11	1.052	71.9	1.683	6.011
Run 4	6	.379	84.8	.598	3.956
Run 5	6	.147	89.8	.233	2.290
Run 6	6	.135	90.4	.213	2.241

*excluding zero entries

The maximum contents of the queue indicates the largest number of print jobs which are waiting for a printer at any one time. Figure 14 illustrates the maximum queue for the six simulation runs. There is a sharp drop in the queue contents when the first faster printer is added. Another smalled drop occurs when the third printer is added.

The average contents of the queue indicates how many jobs on the average are waiting for a printer at any one time. The average content is calculated by:

$$\text{Average Contents} = \frac{\text{Cumulative Time Integral of Queue}}{\text{Eight hours}}$$

The average contents of the queue is illustrated in Figure 15. Again, a sharp drop occurs when the first faster printer is added. A smaller drop occurs when the third printer is added.

The entry for percent of zero delay time indicates the percent of time that no job has to wait for a printer. The percent of zero delay jobs is illustrated in Figure 16. The addition of the first printer results in a fifteen percent increase of jobs which do not have to wait for a printer.

The average time each entry is in the queue, including zero entities, indicates how long the average job has to wait for a printer. The average time per entry is calculated by:

$$\text{Average Time Per Entry} = \frac{\text{Cumulative Time Integral of Queue}}{\text{Total Number of Entries}}$$

Figure 17 illustrates the average wait time per entry. There is a six-minute drop in average wait time when the first printer is added. The drop in wait time for Run 1 is approximately seventy-five percent. Again, an improvement is shown when the third printer is added.

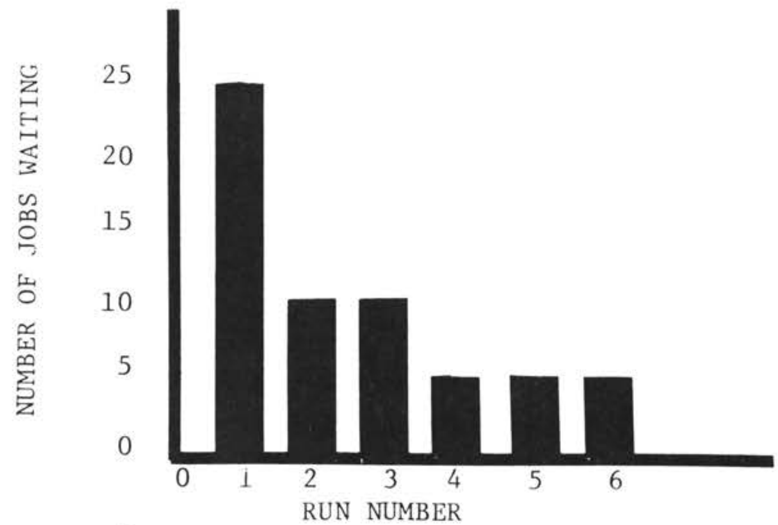


Figure 14. Maximum Contents of Queue, PRTQT

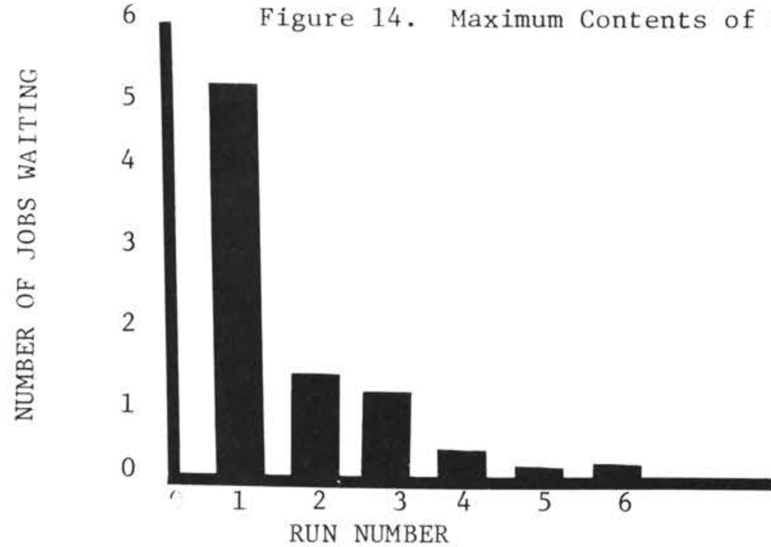


Figure 15. Average Contents of Queue, PRTQT

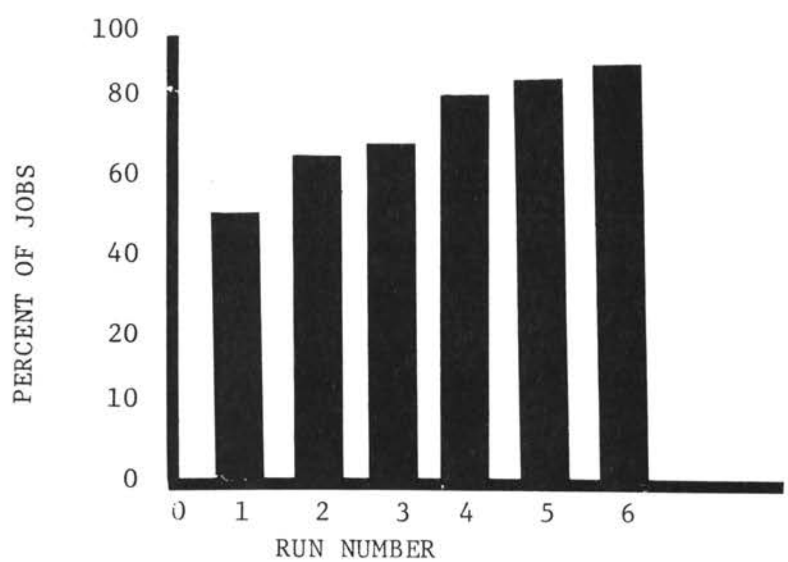


Figure 16. Percent of Jobs with Zero Wait Time

The average delay time for each entry which has to wait for a printer is calculated by:

$$\text{Average Time Per Delayed Entry} = \frac{\text{Cumulative Time Integral of Queue}}{\text{Number of Nonzero Entries}}$$

The average wait time for nonzero entries is shown in Figure 18. Even though the drop in wait time is about eleven minutes, the drop is not as significant as in Figure 17 because the zero jobs are missing. The drop in wait time in Run 1 of Figure 18 is approximately sixty-one percent. Figure 18 shows a true picture of the wait times if all of the printers are busy and the operator has a "hot job" he wishes to print.

Analysis of Printer Facilities

Each of the five printers which share the storage, PRINT, handle a share of the workload. The GPSS simulation also generate statistics for the printers, PRTP1 through PRTP5, in terms of time used, activity, and wait times in a queue.

Table XIV shows the average utilization of the five printers during the simulation run. The utilization, or average percent of the time each printer is busy, is also shown in Figure 19. The characteristics of the workload on each printer begin to show when the faster printers are added. In each case, when the specific printer is changed to a faster speed, the average utilization for that printer decreases. For example, PRTP5 is not affected by the different simulation runs until run number six, when it is changed to a 3211. Printer PRTP4 exhibits the same reaction. Printers PRTP2 and PRTP3 are benefited even when PRTP1 is changed as is evidenced by the decreased in their utilization in Run 2.

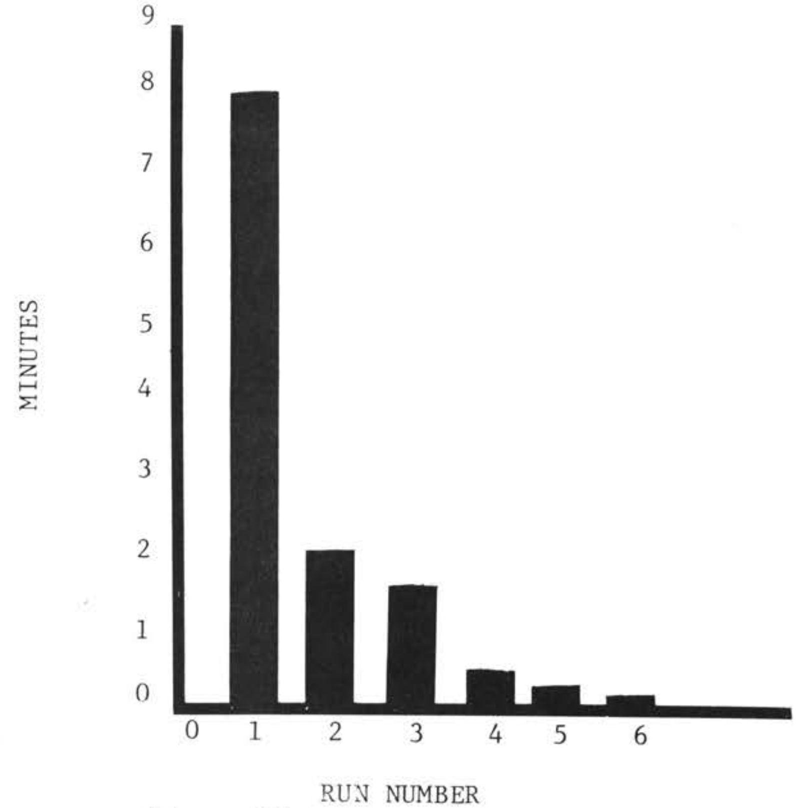


Figure 17. Average Time Print Jobs Wait in Queue, PRTQT

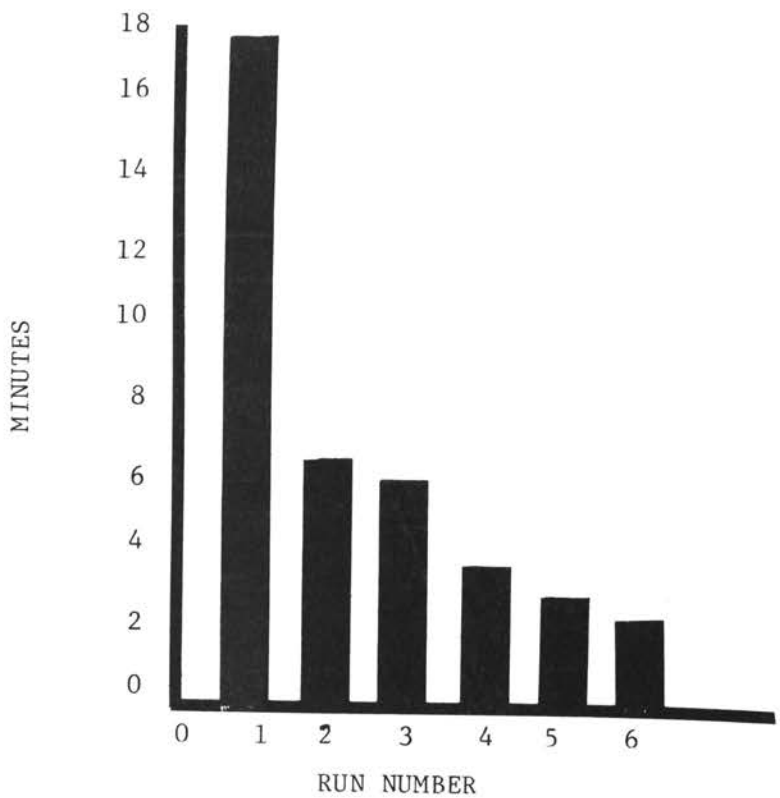


Figure 18. Average Time Print Jobs Wait in Queue, PRTQT, Excluding Jobs with Zero Wait Time

Part of the reason PRTP4 and PRTP5 are not affected too much is that many long tape-to-print jobs are sent to those two printers. The utilization is most affected for printers which process short jobs with no forms change. PRTP3 has the most usage in Run 1, but it is replaced by PRTP5 in the other runs.

TABLE XIV

AVERAGE UTILIZATION OF THE FIVE PRINTERS

Printer	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
PRTP1	.802	.637	.602	.512	.512	.512
PRTP2	.795	.645	.439	.439	.410	.410
PRTP3	.929	.820	.808	.614	.614	.614
PRTP4	.824	.783	.768	.762	.502	.502
PRTP5	.897	.895	.895	.895	.895	.758

Table XV and Figure 20 illustrate the number of print jobs which are run on each printer. PRTP1 is definitely the favorite printer. The reason for this is that the main jobs always attempt to print on PRTP1 first. The main jobs are normally short jobs with no set-up time. Each time a printer is changed for a faster speed, the number of jobs assigned to it is increased from the previous run.

Comparing the statistics for PRTP5 in Figure 19 and Figure 20, it is evident that in order for the utilization to be so high, the low number of jobs which print on PRTP5 must be very long. This theory is

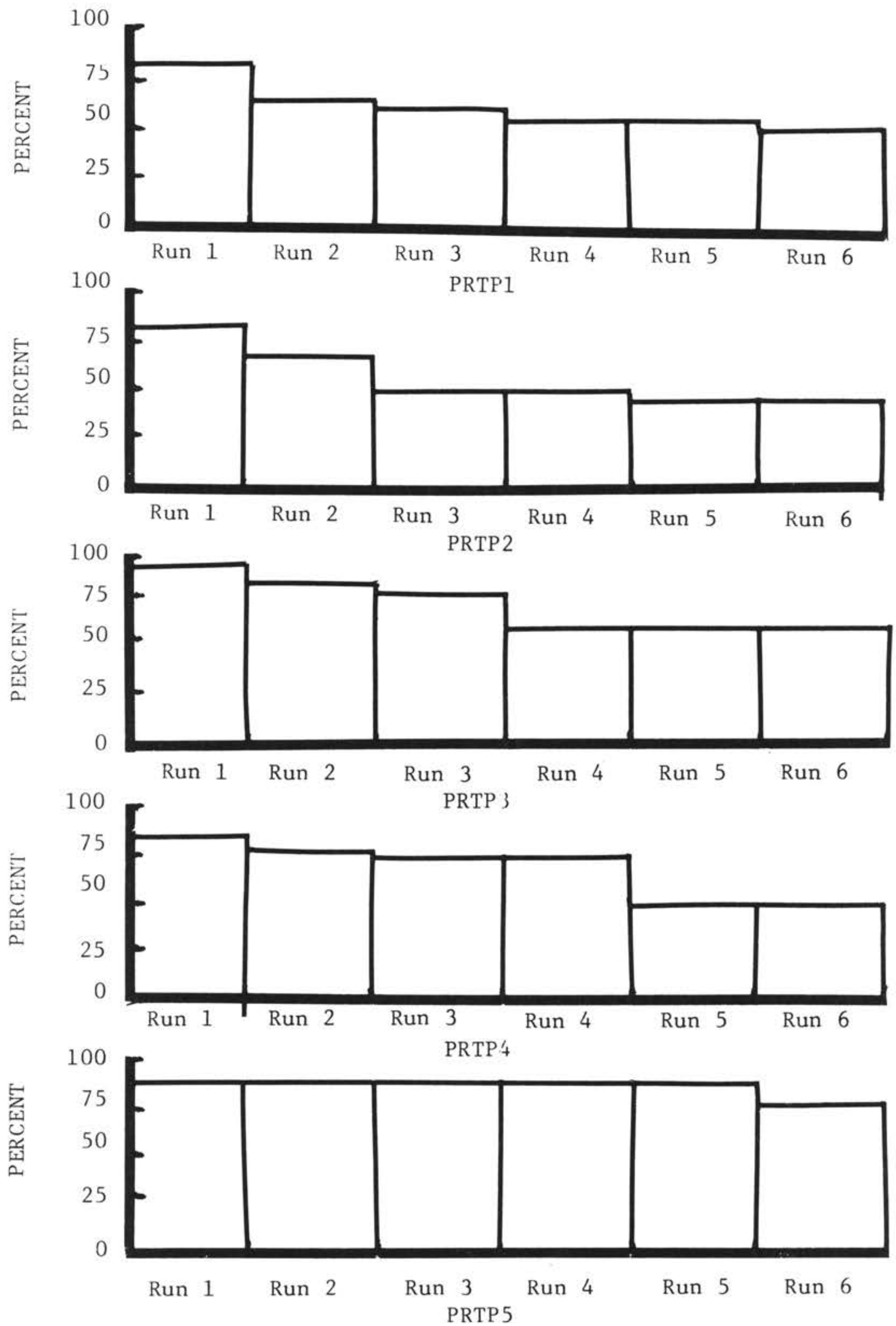


Figure 19. Average Utilization of the Five Printers

TABLE XV

NUMBER OF JOBS PRINTED ON EACH PRINTER

Printer	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
PRTP1	132	148	143	124	122	121
PRTP2	52	56	70	69	66	66
PRTP3	48	33	27	52	52	52
PRTP4	21	17	16	16	21	19
PRTP5	9	8	6	6	6	11

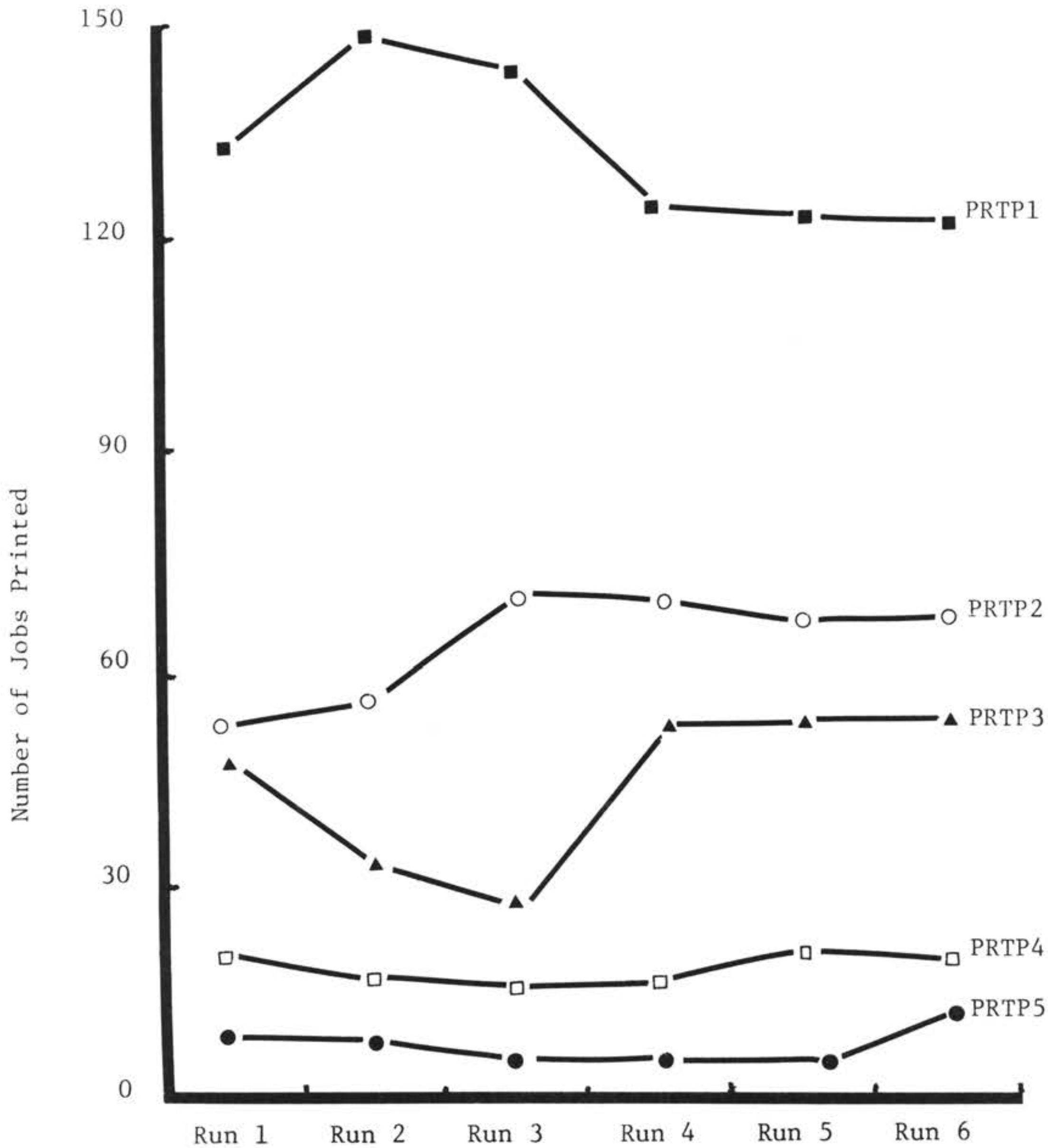


Figure 20. Number of Jobs Printed on Each Printer

validated in Table XVI and Figure 21 which show the length of the jobs which process on each printer. PRTP5 has the long tape-to-print jobs and PRTP1 has the short main jobs. The other three printers have a combination of each type of job.

TABLE XVI

AVERAGE TIME PER PRINT JOB ON EACH PRINTER

Printer	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
PRTP1	2.916	2.067	2.020	2.056	2.016	2.033
PRTP2	7.346	5.535	3.014	3.057	2.984	2.984
PRTP3	9.291	11.939	14.370	5.673	5.673	5.673
PRTP4	18.857	22.117	23.062	22.875	11.476	12.684
PRTP5	47.888	53.750	71.666	71.666	71.666	33.090

There are five special queues for the five printers which are used to calculate the time a tape-to-print job has to wait for a specified printer if the one which is needed is busy.

Table XVII and Figure 22 show the maximum number of jobs which wait for each printer at any one time. No jobs ever wait for printer PRTP4, and only one job waited for printer PRTP1 during the entire simulation. The printer which was most active was printer PRTP3 (Queue REQP3). This is natural because PRTP3 is physically located in the center of the printers. Main jobs try to seize printers from one end of the chain and

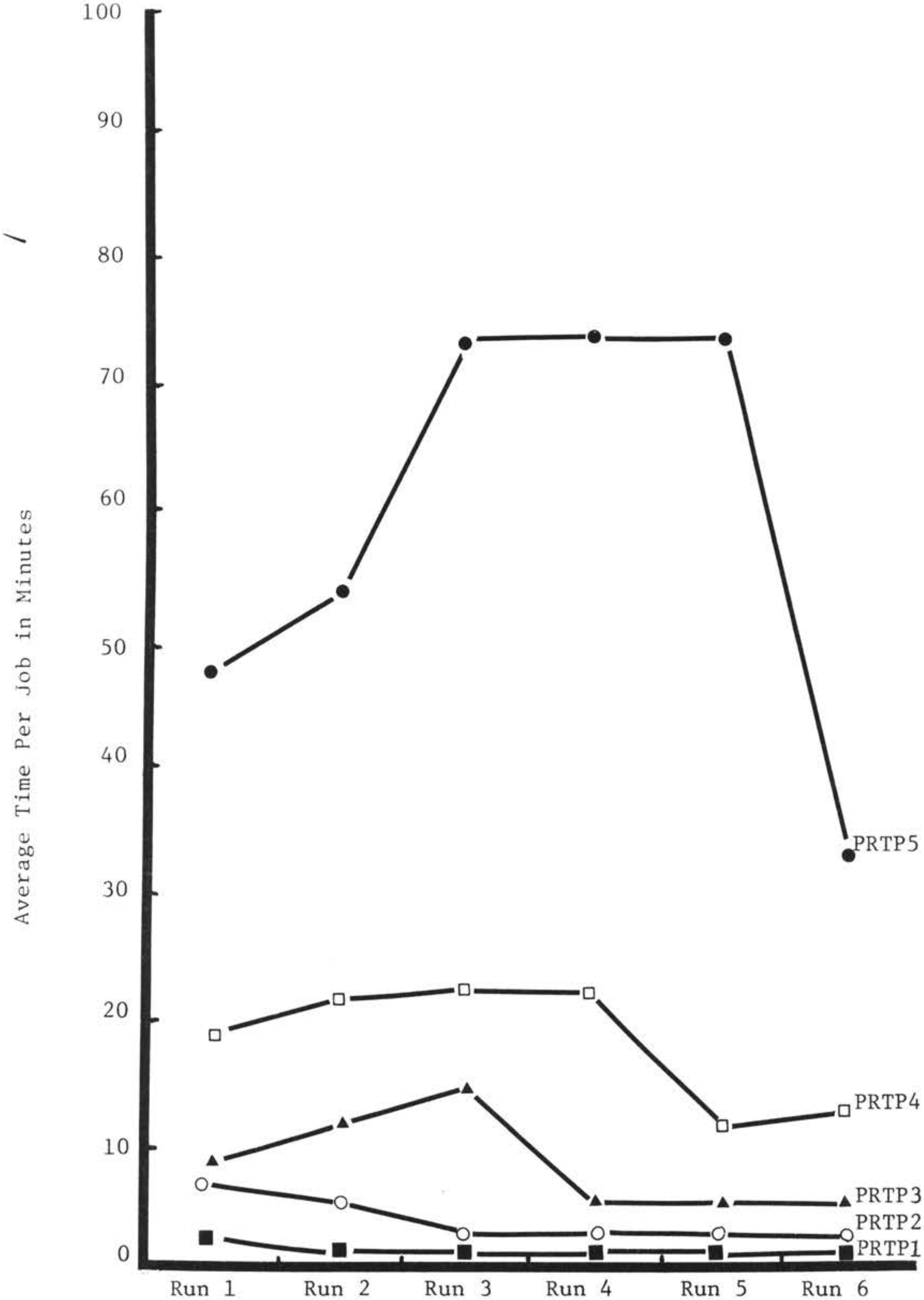


Figure 21. Average Time Per Print Job on Each Printer

TABLE XVII

MAXIMUM CONTENTS OF QUEUES, REQP1-REQP5

Queue	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
REQP1	1	0	0	0	0	0
REQP2	2	2	2	2	2	2
REQP3	6	6	6	6	6	6
REQP5	2	2	2	2	2	1

the tape-to-print jobs are assigned starting with PRTP5. PRTP3 then gets "double duty" and has the most intervention required.

Table XVIII and Figure 23 show the total number of jobs which have waited for each printer throughout the run. Again, PRTP3 has the greatest number of waiting times. PRTP4 is always free when it is selected, so there are queue times for it. Perhaps PRTP4 is seldom used for tape-to-print work.

TABLE XVIII

NUMBER OF JOBS QUEUED IN QUEUES, REQP1-REQP5

Queue	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
REQP1	1	0	0	0	0	0
REQP2	7	8	7	7	7	7
REQP3	25	24	24	23	23	23
REQP5	7	7	7	7	7	5

Table XIX and Figure 24 show the average time jobs wait in the queues for a specific tape-to-print printer. PRTP3 and PRTP5 have the greatest amount of wait time. Both printers are highly affected when they are changed to the faster speed. (See Run 4 for PRTP3 and Run 6 for PRTP5).

TABLE XIX

AVERAGE TIME PRINT JOBS WAIT IN QUEUES, REQP1-REQP5

	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6
REQP1	.000	.000	.000	.000	.000	.000
REQP2	10.285	9.750	6.714	6.714	6.857	6.857
REQP3	49.719	51.541	51.541	26.260	26.347	26.347
REQP5	36.142	36.142	36.428	36.428	36.428	12.799

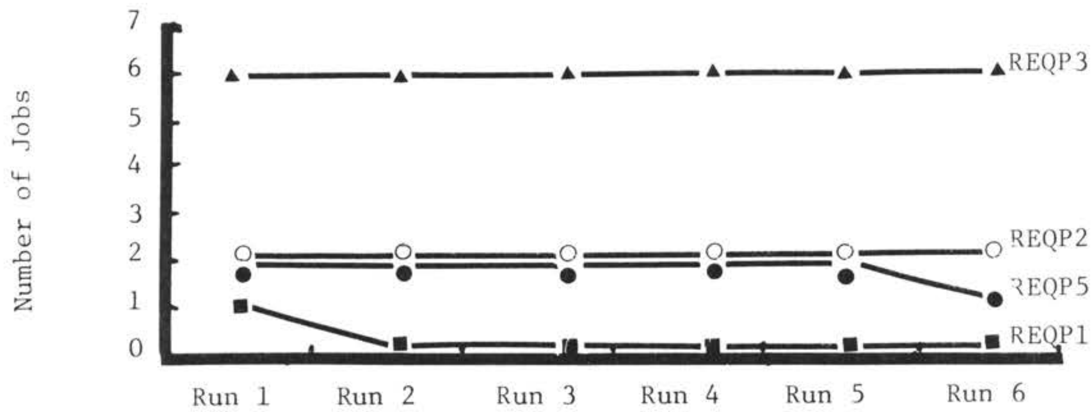


Figure 22. Maximum Contents of Queues, REQP1-REQP5

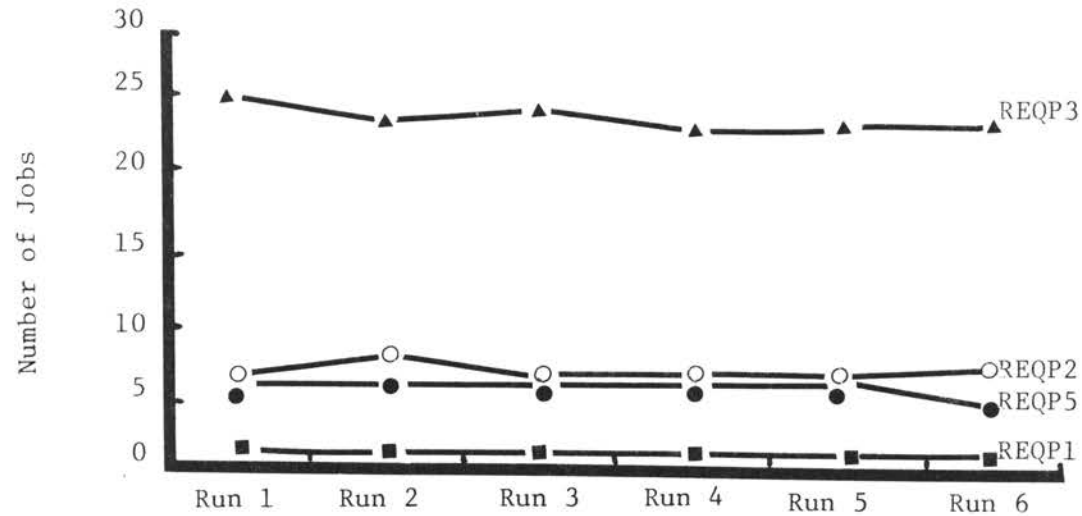


Figure 23. Number of Jobs Queued in Queues, REQP1-REQP5

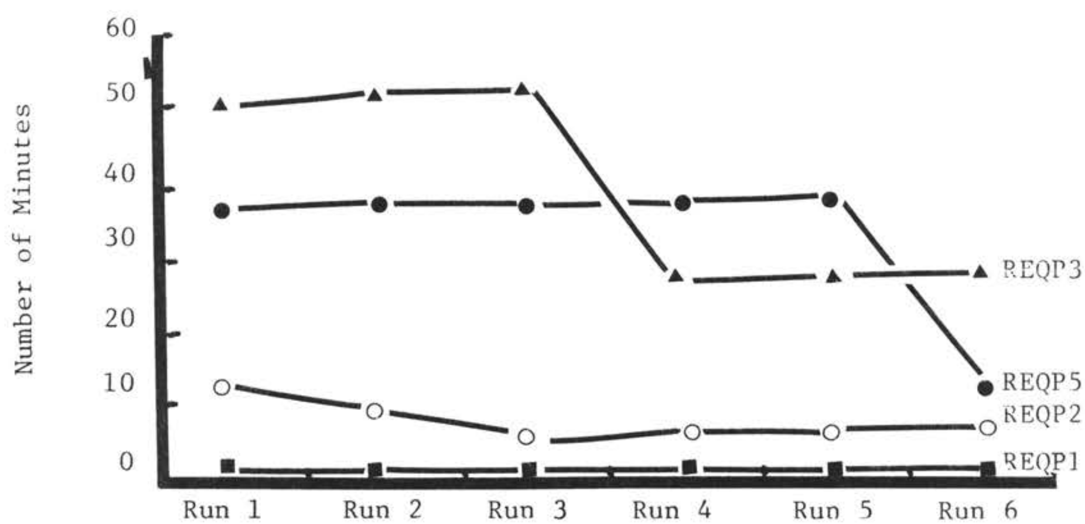


Figure 24. Average Time Print Jobs Wait in Queues, REQP1-REQP5

All of the statistics seem to reinforce two ideas. First, the two printers which are most affected by a change in print speed are PRTP1 and PRTP3. The change exhibited by PRTP1 may be because it is the first printer changed, or it may be because of the workload. Second, the workload seems to be dependent upon the physical location of the printers and on the search scheme for main jobs, starting at PRTP1.

Another experimental order of changing the print speeds should be considered as a result of analyzing the first group of simulations.

If only one printer is to be changed, which printer should it be? Before the simulations were run, the logical choice would have been printer P1PC because it is the first printer in the series to be assigned by main service jobs. The simulations indicate that the greatest number of jobs print on printer P1PC which seems to reinforce that choice. (See Figure 20.) P1PC is also the printer which is located physically the furthest away from the operator. It processes many short main jobs which did not require many paper changes.

However, Figure 21 indicates that printer P5PC processes the longest print jobs. Printer P5PC is also located the closest to the SUPPORT operator and requires the largest number of paper changes. P5PC processes many long tape-to-print jobs and very few main service jobs. The simulation order should be tested where P5PC is the first printer altered.

Finally, Figures 22 through 25 show that printer P3PC has the most wait time for service. P3PC is physically located in the center of the printers and is semi-close to the SUPPORT operator. The work load on P3PC is a combination of long tape-to-print jobs and short main jobs. The simulation order should be tested where P3PC is the first printer altered.

CHAPTER V

SUMMARY AND CONCLUSIONS

The purpose of this study is to analyze the use of simulation as a business tool for evaluating computer hardware equipment. The GPSS simulation language is used and an actual problem is simulated.

The problem is that two speeds of printer hardware are available to process the print workload in the Central Computer Department of Continental Oil Company. GPSS simulation is used to manipulate, test, and evaluate changing the printers to new equipment without affecting the present day environment.

The two objectives of the study are to describe the current system and to explore the hypothetical system. Both objectives are met by analyzing the statistical output of the simulation run. The first objective is met by obtaining frequency distributions of many of the variables in the current system. These distributions may then be used to build future simulations. The second objective is met by comparing the results of six simulation runs in which the hardware is changed in an orderly fashion.

The first step is to develop a model which includes all of the important variables which uses the GPSS timing and queueing methods. The elements of the model include five printers and a storage which controls all five printers at once. The experiment is designed to change one of the printers at a time to a newer model of printer with a faster speed. A specific day is selected to be simulated and, five variables of the system are gathered to generate an input tape.

The result of the simulation is a representation of the system as it would be if the hardware is changed. In each case, the first printer to be changed produces the greatest benefits. Future changes are also beneficial to a lesser degree. Several different managers with different goals could use this simulation, picking the parts which deal with their problem.

One of the best results of a simulation is the insight gained into the current system. Several operational problems were discovered when the input tape data was gathered. Most of the problems dealt with the areas of paper forms mounting and assigning printers for tape-to-print jobs.

The greatest limitation of the study was the generation of input data. A great deal of effort is required to pick a representative day. A special program is required to convert the input data into a GPSS input tape. If more runs are needed for the same day of input, GPSS is easy to change to try new things. If a new day or a longer time period is needed, data is very difficult to collect. The solution to this problem is to take the frequency distributions which are obtained from the input data and to convert them to probability distributions for use in random number generation. In order to cover the GPSS program to random variables, the JOBTAPE should be replaced with these four blocks:

```
GENERATE - Interarrival times
ADVANCE  - Print duration
PRIORITY - Job priorities
ASSIGN   - Number of lines per job
ASSIGN   - Number of set-up minute per job
ASSIGN   - Specific printers for tape-to-print jobs
```

The next step should be to consult with management, obtain their help in formulating new modifications to the model, and build the model for future projects. Future runs would be very helpful in the areas of workload, work rules, configuration changes, and software changes. Each area could be analyzed and problems worked into the GPSS model.

An example of a workload change would be to incorporate an increased print load resulting from a recent consolidation of another department with Central Computer. The time span might be increased to shift 2, shift 3, or even a month or a year in length.

The operational problems mentioned above in the tape and paper form areas might be evaluated. For example, tape-to-print jobs might not be assigned to a printer. Form change might be restricted on specific printers.

The restriction of five printers might be relaxed and more or fewer printers simulated. The order of change of the printers might be altered. The print speeds on the two models of printers might be changed to include a range of times.

The software can also be tested with this model. The priority scheme could be eliminated or altered to test improved efficiency. Core storage queues could be added to insure that enough core was available to service the printers.

In conclusion, it has been shown that GPSS simulation is an effective tool for evaluating equipment configurations. Simulation is very probably the tool of the future for the illumination and solution of many business problems.

A SELECTED BIBLIOGRAPHY

(1) Ackoff, Russell L. A Concept of Corporate Planning. New York: John Wiley and Sons, 1970.

(2) Gordon, Geoffrey. System Simulation. New Jersey: Prentice-Hall, 1969.

(3) Greenberg, Stanley. GPSS Primer. New York: John Wiley and Sons, 1972.

(4) IBM Corporation, Technical Publications Department. An Introduction to Discrete System Simulation: A Management Tool in Decision Making, GE20-0272-1. 2nd ed. New York: IBM, 1972.

(5) IBM Corporation, Technical Publications Department. Continuous System Simulation for the Management Scientist, GE20-0349-0. 1st ed. New York: IBM, 1971.

(6) IBM Corporation, Technical Publications Department. General Purpose Simulation System/360, Application Description, H20-0186-2. 3rd ed. New York: IBM, 1967.

(7) IBM Corporation, Technical Publications Department. General Purpose Simulation System/360, Introductory User's Manual, GH20-0304-4. 5th ed. New York: IBM, 1969.

(8) IBM Corporation, Technical Publications Department. General Purpose Simulation System/360 OS, Operator's Manual, GH20-0311-3. 4th ed. New York: IBM, 1969.

(9) IBM Corporation, Technical Publications Department. General Purpose Simulation System/360, User's Manual, GH20-0326-4. 5th ed. New York: IBM, 1970.

(10) Kay, Ira M. "An Over-The-Shoulder Look at Discrete Simulation Languages." Procedures of the AFIPS 1972 Spring Joint Computer Conference, Volume 40 (1972), pp. 791-798.

(11) Naylor, Balintfy, Burdick, and Chu. Computer Simulation Techniques. New York: John Wiley and Sons, 1966.

(12) Schriber, Thomas J. Preliminary Printing of a GPSS Primer. Michigan: The University of Michigan, 1972.

(13) Tribus, Myron. "Management's Risk Reducer." Business Automation, April (1971), pp. 18-21.

(14) ------. "The Software of Change." Vital Speeches, October 15 (1969), pp. 14-17.

(15) Wagner, Harvey M. Principles of Operations Research, With Applications to Managerial Decisions. New Jersey: Prentice-Hall, 1969.

GLOSSARY

ASP. An IBM software package used by Continental Oil Company to control the flow of jobs through the computer system.

FACILITY. A piece of equipment which can handle only one transaction at a time. In the case of Continental Oil, a printer which can handle only one print job at a time.

LOGIC SWITCH. A two-state indicator which can be set on by one print job and which will modify the flow of the other print jobs through the system.

QUEUE. A statistical entity which maintains a list of transactions which are delayed at a point in the system. For Continental Oil, the number of print jobs delayed and the length of the delay are recorded by the queue.

STORAGE. A piece of equipment which can handle several transactions at a time. In the case of Continental Oil, the printer control unit can drive five printers and thus handle five print jobs at once.

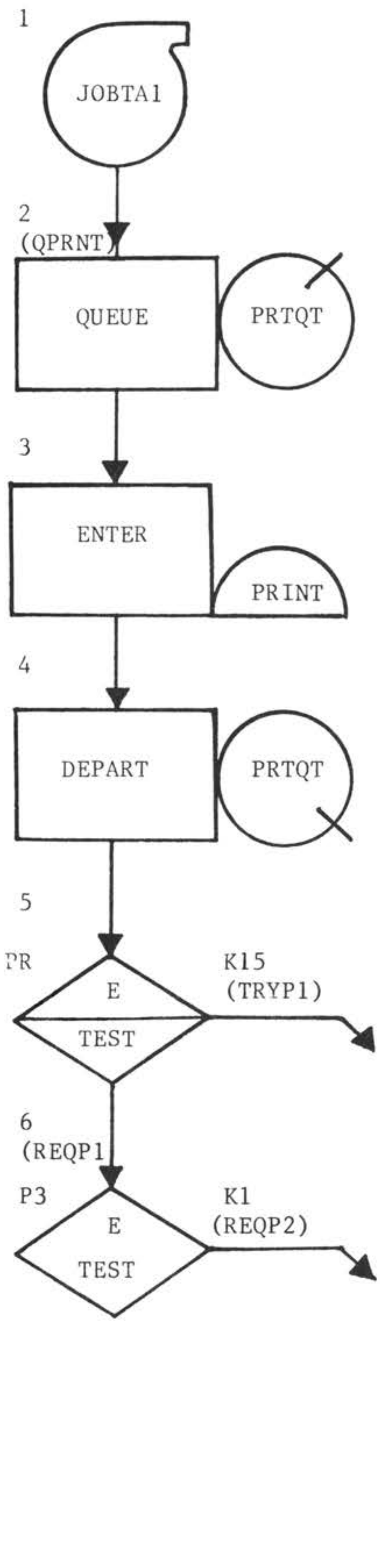
TABLE. A statistical entity which collect frequency distributions.

TRANSACTION. A "unit of traffic" in a GPSS simulation. In the case of Continental Oil, a print job.

APPENDIXES

APPENDIX A

BLOCK DIAGRAM OF THE GPSS MODEL



READ PRINT JOBS AT AN INTERARRIVAL RATE IN MINUTES DETERMINED BY THE JOBTAPE FORMAT, FIELD 1.

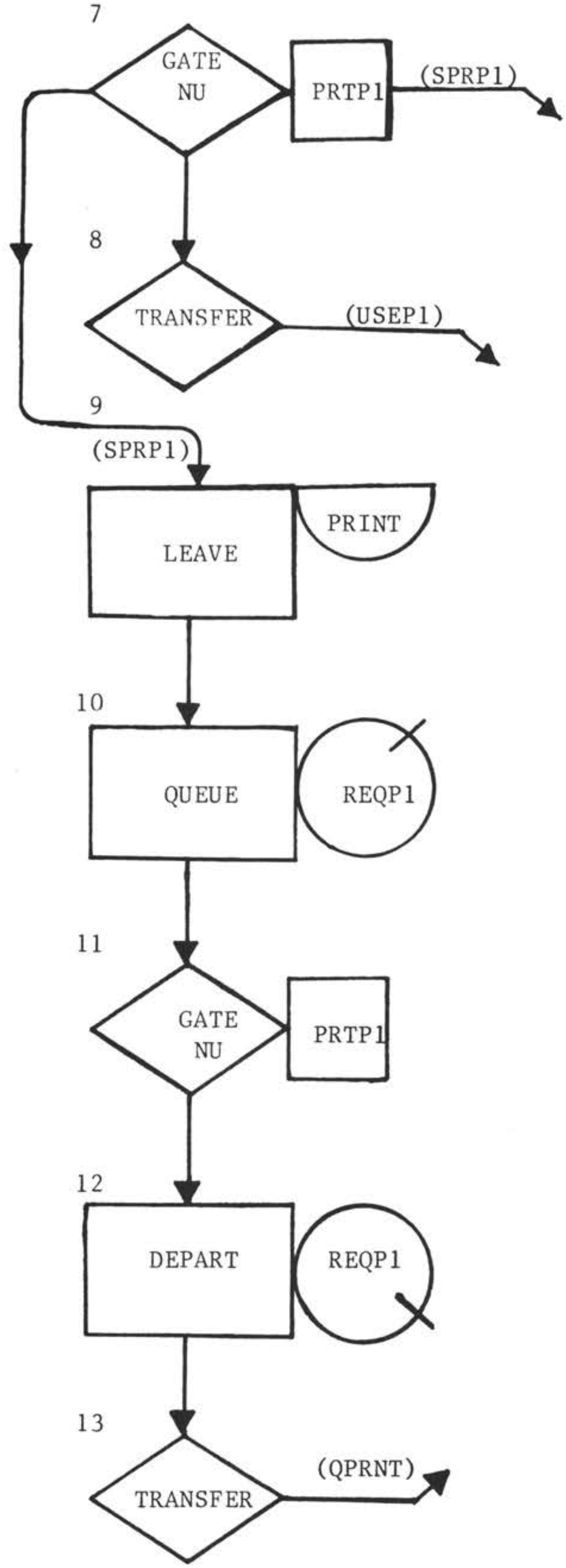
QUEUE UP PRINT JOBS IF THE STORAGE, PRINT, IS BUSY.

ENTER THE STORAGE, PRINT, WHEN IT HAS AVAILABLE SPACE, AND OCCUPY ONE PRINTER.

DEPART FROM THE QUEUE WHEN THE STORAGE, PRINT, IS ENTERED.

TEST FOR A PRIORITY OF 15 FOR THE JOB. IF PRIORITY = 15, THE JOB IS A TAPE-TO-PRINT. OTHERWISE, THE JOB IS A MAIN JOB. GO TO TRYP1.

TAPE-TO-PRINT: TEST TO SEE IF P1PC WAS ASSIGNED. IF NOT, GO TO REQP2.



IF FACILITY PRTP1 IS NOT IN USE, GO TO NEXT BLOCK.
IF FACILITY IS BUSY, GO TO SPRP1.

GO TO USEP1 TO SEIZE THE PRINTER.

FREE ONE PRINTER IN THE STORAGE WHILE THE TAPE-TO-PRINT JOB WAITS FOR A SPECIAL PRINTER.

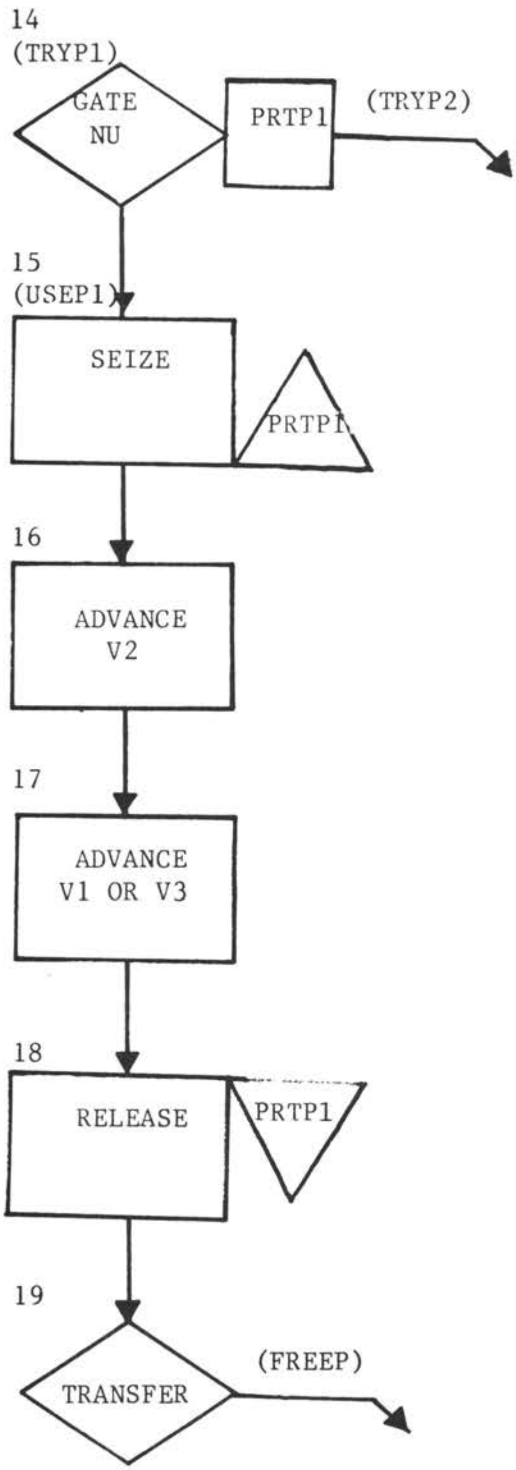
QUEUE UP PRINT JOBS IF THE FACILITY, PRTP1 IS BUSY.

WAIT IN THIS BLOCK UNTIL PRTP1 IS FREE.

DEPART FROM THE QUEUE WHEN THE FACILITY, PRTP1 IS FREE.

GO TO QPRNT TO ENTER THE STORAGE, PRINT.

[BLOCKS 6 - 13 ARE REPEATED FOR PRINTERS PRTP2 THROUGH PRTP5.]



IF FACILITY PRTP1 IS NOT IN USE, GO TO NEXT BLOCK.
IF FACILITY IS BUSY, TRY NEXT FACILITY.

SEIZE THE FACILITY, PRTP1.

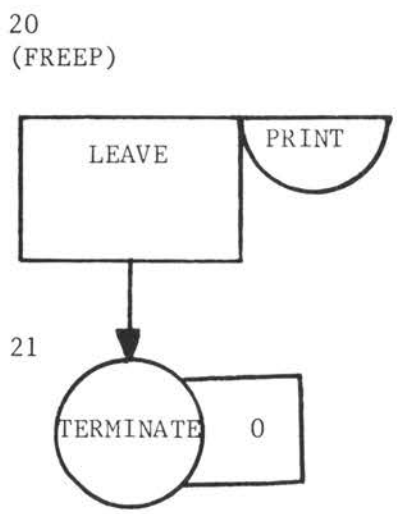
PRINT JOB IS BEING SET UP. NUMBER OF MINUTES IS IN PARAMETER 2 of JOBTAPE.

JOB IS PRINTING.
IF A 1403 IS USED, TIME IS PARAMETER 1/700.
IF A 3211 IS USED, TIME IS PARAMETER 1/1200.

RELEASE THE FACILITY, PRTP1.

GO TO FREEP TO FREE ONE PRINTER IN THE STORAGE.

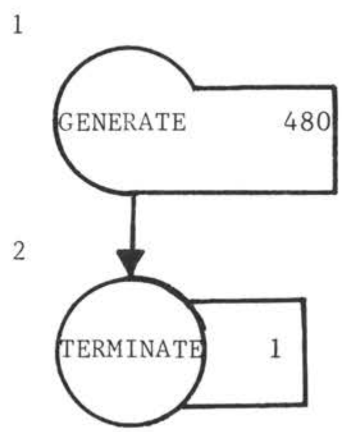
[BLOCKS 14 - 19 ARE REPEATED FOR PRINTERS PRTP2 THROUGH PRTP5.]



FREE ONE PRINTER IN THE STORAGE.

REMOVE ONE PRINT FROM THE SYSTEM. THE RUN TERMINATION COUNT IS NOT AFFECTED.

END OF MODEL SEGMENT 1.



RUN EACH SIMULATION FOR 480 MINUTES. ONE EIGHT-HOUR SHIFT.

SATISFY THE TERMINATION COUNT.

END OF MODEL SEGMENT 2

(TIMER SEGMENT)

START 1

SET THE TERMINATION COUNT TO END WHEN THE TIMER SEGMENT REACHES 480 MINUTES.

APPENDIX B

COMPUTER LISTING OF THE GPSS MODEL

```
********************************************************************************
*
*                          GPSS SIMULATION OF
*                       PRINTER EQUIPMENT STUDY
********************************************************************************
*       SIMULATE
********************************************************************************
*  PRINTER USAGE PROBLEM
*  USING FIVE PRINTERS
*          1. P1PC - 1403
*          2. P2PC - 1403
*          3. P3PC - 1403
*          4. P4PC - 1403
*          5. P5PC - 1403
*  USING TWO TYPES OF JOBS
*          1. MAIN JOBS SEIZE P1PC-P5PC IN THAT ORDER
*          2. TAPE-TO-PRINT JOBS ARE ASSIGNED TO SPECIFIC PRINTERS
*  THIS MODEL MAINTAINS WAITING LINE STATISTICS
*  ONE CLOCK UNIT  =  1  MINUTE
********************************************************************************
*
********************************************************************************
*  READ ONE 8-HOUR SHIFT OF ACCOUNTING CARDS
********************************************************************************
*
        JOBTAPE     JOBTA1,START
*
********************************************************************************
*  KEEP STATISTICS ON THE PRINT STORAGE
********************************************************************************
*
QPRNT   QUEUE       PRTQT        WAIT IN QUEUE IF PRINTER IS BUSY
        ENTER       PRINT        ENGAGE THE AVAILABLE PRINTER
        DEPART      PRTQT        JOB LEAVES THE QUEUE
*
********************************************************************************
*  TEST FOR MAIN OR TAPE-TO-PRINT JOBS
********************************************************************************
*
        TEST E      PR,K15,TRYP1
*
********************************************************************************
*  ALL TAPE-TO-PRINT GO TO ASSIGNED PRINTERS (PARAMETER 3)
********************************************************************************
*
**********
*  P1PC  - ASSIGNED BY TAPE-TO-PRINT
**********
*
REQP1   TEST E      P3,K1,REQP2       IS P1PC REQUESTED?
GATE1   GATE NU     PRTP1,SPRP1       YES, IS P1PC AVAILABLE?
        TRANSFER    ,USEP1            YES, GO USE P1PC
*
SPRP1   LEAVE       PRINT  RELEASE PRINTER FOR ANOTHER JOB (NOT P1PC)
        QUEUE       REQP1       CALCULATE WAIT TIME FOR JOBS WHICH
*                                   ARE ASSIGNED ONLY TO P1PC
        GATE NU     PRTP1  REMOVE JOB FROM CE QUEUE UNTIL P1PC IS FREE
        DEPART      REQP1       P1PC IS FREE AGAIN
        TRANSFER    ,QPRNT
*
********************************************************************************
```

```
********************************************************************************
*  P2PC  - ASSIGNED BY TAPE-TO-PRINT
**********
*
REQP2   TEST E      P3,K2,REQP3       IS P2PC REQUESTED?
GATE2   GATE NU     PRTP2,SPRP2       YES, IS P2PC AVAILABLE?
        TRANSFER    ,USEP2            YES, GO USE P2PC
*
SPRP2   LEAVE       PRINT  RELEASE PRINTER FOR ANOTHER JOB (NOT P2PC)
        QUEUE       REQP2       CALCULATE WAIT TIME FOR JOBS WHICH
*                                   ARE ASSIGNED ONLY TO P2PC
        GATE NU     PRTP2  REMOVE JOB FROM CE QUEUE UNTIL P2PC IS FREE
        DEPART      REQP2       P2PC IS FREE AGAIN
        TRANSFER    ,QPRNT
*
**********
*  P3PC  - ASSIGNED BY TAPE-TO-PRINT
**********
*
REQP3   TEST E      P3,K3,REQP4       IS P3PC REQUESTED?
GATE3   GATE NU     PRTP3,SPRP3       YES, IS P3PC AVAILABLE?
        TRANSFER    ,USEP3            YES, GO USE P3PC
*
SPRP3   LEAVE       PRINT  RELEASE PRINTER FOR ANOTHER JOB (NOT P3PC)
        QUEUE       REQP3       CALCULATE WAIT TIME FOR JOBS WHICH
*                                   ARE ASSIGNED ONLY TO P3PC
        GATE NU     PRTP3  REMOVE JOB FROM CE QUEUE UNTIL P3PC IS FREE
        DEPART      REQP3       P3PC IS FREE AGAIN
        TRANSFER    ,QPRNT
*
**********
*  P4PC  - ASSIGNED BY TAPE-TO-PRINT
**********
*
REQP4   TEST E      P3,K4,REQP5       IS P4PC REQUESTED?
GATE4   GATE NU     PRTP4,SPRP4       YES, IS P4PC AVAILABLE?
        TRANSFER    ,USEP4            YES, GO USE P4PC
*
SPRP4   LEAVE       PRINT  RELEASE PRINTER FOR ANOTHER JOB (NOT P4PC)
        QUEUE       REQP4       CALCULATE WAIT TIME FOR JOBS WHICH
*                                   ARE ASSIGNED ONLY TO P4PC
        GATE NU     PRTP4  REMOVE JOB FROM CE QUEUE UNTIL P4PC IS FREE
        DEPART      REQP4       P4PC IS FREE AGAIN
        TRANSFER    ,QPRNT
*
**********
*  P5PC  - ASSIGNED BY TAPE-TO-PRINT
**********
*
REQP5   TEST E      P3,K5,ERR2        IS P5PC REQUESTED?
GATE5   GATE NU     PRTP5,SPRP5       YES, IS P5PC AVAILABLE?
        TRANSFER    ,USEP5            YES, GO USE P5PC
*
SPRP5   LEAVE       PRINT  RELEASE PRINTER FOR ANOTHER JOB (NOT P5PC)
        QUEUE       REQP5       CALCULATE WAIT TIME FOR JOBS WHICH
*                                   ARE ASSIGNED ONLY TO P5PC
        GATE NU     PRTP5  REMOVE JOB FROM CE QUEUE UNTIL P5PC IS FREE
        DEPART      REQP5       P5PC IS FREE AGAIN
        TRANSFER    ,QPRNT
*
********************************************************************************
```

```
**************************************************************************
*                                                                        *
*  TAPE TO PRINT JOB DID NOT ASSIGN A PRINTER                            *
ERR2    TABULATE    NOREQ                                                *
        TRANSFER    ,FREEP                                               *
*                                                                        *
*                                                                        *
**************************************************************************
*  ALL MAIN JOBS TRY TO SEIZE P1PC-P5PC IN THAT ORDER                    *
**************************************************************************
*                                                                        *
*                                                                        *
**********                                                               *
*  P1PC                                                                  *
**********                                                               *
*                                                                        *
TRYP1   GATE NU     PRTP1,TRYP2       IS P1PC AVAILABLE?                 *
USEP1   SEIZE       PRTP1             P1PC IS FREE - USE IT              *
        ADVANCE     V2          ADVANCE SETUP TIME FOR TAPES AND PAPER   *
LPMP1   ADVANCE     V1          ADVANCE PRINT LINES / 700 LPM (1403)     *
        RELEASE     PRTP1                                                *
        TRANSFER    ,FREEP                                               *
*                                                                        *
*                                                                        *
**********                                                               *
*  P2PC                                                                  *
**********                                                               *
*                                                                        *
TRYP2   GATE NU     PRTP2,TRYP3       IS P2PC AVAILABLE?                 *
USEP2   SEIZE       PRTP2             P2PC IS FREE - USE IT              *
        ADVANCE     V2          ADVANCE SETUP TIME FOR TAPES AND PAPER   *
LPMP2   ADVANCE     V1          ADVANCE PRINT LINES / 700 LPM (1403)     *
        RELEASE     PRTP2                                                *
        TRANSFER    ,FREEP                                               *
*                                                                        *
*                                                                        *
**********                                                               *
*  P3PC                                                                  *
**********                                                               *
*                                                                        *
TRYP3   GATE NU     PRTP3,TRYP4       IS P3PC AVAILABLE?                 *
USEP3   SEIZE       PRTP3             P3PC IS FREE - USE IT              *
        ADVANCE     V2          ADVANCE SETUP TIME FOR TAPES AND PAPER   *
LPMP3   ADVANCE     V1          ADVANCE PRINT LINES / 700 LPM (1403)     *
        RELEASE     PRTP3                                                *
        TRANSFER    ,FREEP                                               *
*                                                                        *
*                                                                        *
**********                                                               *
*  P4PC                                                                  *
**********                                                               *
*                                                                        *
TRYP4   GATE NU     PRTP4,TRYP5       IS P4PC AVAILABLE?                 *
USEP4   SEIZE       PRTP4             P4PC IS FREE - USE IT              *
        ADVANCE     V2          ADVANCE SETUP TIME FOR TAPES AND PAPER   *
LPMP4   ADVANCE     V1          ADVANCE PRINT LINES / 700 LPM (1403)     *
        RELEASE     PRTP4                                                *
        TRANSFER    ,FREEP                                               *
*                                                                        *
*                                                                        *
**************************************************************************
```

```
**************************************************************************
*  P5PC                                                                  *
**********                                                               *
*                                                                        *
TRYP5   GATE NU     PRTP5,ERR1        IS P5PC AVAILABLE?                 *
USEP5   SEIZE       PRTP5             P5PC IS FREE - USE IT              *
        ADVANCE     V2          ADVANCE SETUP TIME FOR TAPES AND PAPER   *
LPMP5   ADVANCE     V1          ADVANCE PRINT LINES / 700 LPM (1403)     *
        RELEASE     PRTP5                                                *
        TRANSFER    ,FREEP                                               *
*                                                                        *
*  ALL PRINTERS BUSY, THE STORAGE SHOULD HAVE REFUSED ENTRY              *
ERR1    TABULATE    NOPRT                                                *
*                                                                        *
**************************************************************************
*  END OF PRINT JOB - GET NEXT JOB                                       *
**************************************************************************
*                                                                        *
FREEP   LEAVE       PRINT       RELEASE THE PRINTER                      *
        TERMINATE   0           REMOVE THE JOB FROM THE SYSTEM           *
*                                                                        *
**************************************************************************
*  SEPARATE TIME JOB FLOW                                                *
**************************************************************************
*                                                                        *
KTIME   GENERATE    480         GENERATE TIME FOR 8 HOUR OF SIMULATED TIME *
        TERMINATE   1           STOP THE SIMULATION                      *
*                                                                        *
**************************************************************************
*  TABLE DEFINITION CARDS                                                *
**************************************************************************
*                                                                        *
PRINT   STORAGE     5           FIVE PRINTER IN THE SYSTEM               *
*                                                                        *
QTABT   QTABLE      PRTQT,0,1,37   REAL TIME EACH JOB WAS WAITING FOR    *
*                                  ALL PRINTERS (INCLUDING ZERO TIME)    *
NOPRT   TABLE       C1,0,60,8                                            *
NOREQ   TABLE       C1,0,60,8                                            *
*                                                                        *
1       VARIABLE    P1/700      # OF LINES / PRINT SPEED       (1403)    *
2       VARIABLE    P2          NUMBER OF MINUTES FOR SETUP TIME         *
3       VARIABLE    P1/1200     # OF LINES / PRINT SPEED       (3211)    *
*                                                                        *
**************************************************************************
*  INPUT TAPE FORMAT                                                     *
**************************************************************************
*                                                                        *
*       WORD 1 - INTERTRANSACTION TIME                                   *
*       WORD 2 -   UNUSED                                                *
*       WORD 3 -   PRIORITY                                              *
*       PARAMETER 1 -    NUMBER OF LINES PRINTED                         *
*       PARAMETER 2 -    MINUTES WAITED FOR INTERVENTION REQUIRED        *
*       PARAMETER 3 -    PRINTER USED IN ASP CLOCK CARD                  *
*                                                                        *
**************************************************************************
*  CONTROL CARD                                                          *
**************************************************************************
*                                                                        *
        START       1           START THE SIMULATION                     *
*                                                                        *
**************************************************************************
```

VITA

Marylynn Overman Luther

Candidate for the Degree of

Master of Business Administration

Thesis: GPSS SIMULATION: A MANAGEMENT TOOL TO EVALUATE COMPUTER EQUIPMENT CONFIGURATIONS

Major Field: Business Administration

Biographical:

Personal Data: Born in Tulsa, Oklahoma, August 3, 1941, the daughter of Mr. and Mrs. Forrest R. Overman.

Education: Graduated from Ponca City Senior High School, Ponca City, Oklahoma, in May, 1959; received Bachelor of Science degree from the University of Oklahoma in 1962, with a major in Mathematics; completed requirements for the Master of Business Administration degree in May, 1974.

Professional Experience: Systems Analyst in the Central Computer Department, Continental Oil Company, Ponca City, Oklahoma.

Name: Marylynn O. Luther   Date of Degree: May 11, 1974

Institution: Oklahoma State University

Location: Stillwater, Oklahoma

Title of Study: GPSS SIMULATION: A MANAGEMENT TOOL TO EVALUATE COMPUTER EQUIPMENT CONFIGURATIONS

Pages in Study: 86   Candidate for Degree of Master of Business Administration

Major Field: Business Administration

Purpose of Study: The purpose of this study is to analyze simulation as a business tool. The particular application of simulation is in the area of equipment evaluation for computer hardware. Using General Purpose System Simulation language, a model is built to represent the printer hardware and workload in the Central Computer Department of Continental Oil Company in Ponca City. The experimental design is to replace five printers with five newer model printers in an orderly fashion and to compare the results of each change. Data is obtained from actual accounting records and console listings produced in the printer shop. Each print job enters the system and competes for the availability of one of the five printers. GPSS provides statistical information on printer usage and on queue times resulting from jobs waiting on a printer.

Findings and Conclusions: The two objectives of the study are to describe the current system and to explore the hypothetical situation of changing the printer hardware. Both objectives are met by analyzing the statistical output of the simulation runs. One of the best results is an insight into the present system which is gained by developing the model and gathering the data. The current system is described by frequency distributions for five characteristics of the print jobs. An initial simulation run indicates the locations and lengths of the queues which are present in the unmodified system. The hypothetical situation is described by five experimental runs which show the locations and lengths of the queues after the equipment is changed. The simulation results can answer questions in many areas of operational problems, including workload scheduling, operational work rules, and software evaluation, as well as in hardware planning. GPSS simulation is an effective tool to test and evaluate changing hardware equipment without affecting the current environment.

ADVISER'S APPROVAL Donald R. Williams