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This is to certify that the thesis prepared by *Prentice Frazier* entitled *Utilization of Printer Resources within a Computer Graphics Department: A Print Queue Analysis* has been approved by his committee as satisfactory completion of the thesis requirement for the degree of Master of Science in Mathematics (Operations Research).




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VIRGINIA COMMONWEALTH UNIVERSITY

**UTILIZATION OF PRINTER RESOURCES WITHIN A COMPUTER
GRAPHICS DEPARTMENT:
A PRINT QUEUE ANALYSIS**

**A THESIS SUBMITTED TO
THE FACULTY OF THE DIVISION OF MATHEMATICAL SCIENCES
IN CANDIDACY FOR THE DEGREE OF
MASTERS OF SCIENCE**

DEPARTMENT OF MATHEMATICAL SCIENCE/OPERATIONS RESEARCH

BY

PRENTICE FRAZIER

RICHMOND, VIRGINIA

May 1999

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Introduction

Most individuals have had the unpleasant experience of waiting in line. Whether it is the line at the local grocery store, fast food restaurant, or the infamous Department of Motor Vehicles, no one enjoys having to spend idle time waiting to be served. During this idle time you may often reflect on why the wait is necessary. Waiting lines will occur

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ABSTRACT

This paper examines print queue management for the graphics department of a financial services company. The current network configuration has proven to be sub-optimal. The IT department is currently undergoing testing of possible alternative network configurations. The objective is to improve performance by leveraging existing resources with new technology. In this paper, the effect of consolidating the queue into one primary queue manager is analyzed, along with prioritizing print jobs, and forecasting future printer needs. Analysis was performed using queuing theory concepts along with an analysis of both steady state and transient behavior using simulation modeling.

whenever the current demand for a service exceeds the current capacity to provide that service. Capital One currently has this problem in its graphics artist department, where the customers are the artists and the servers are their quality graphics printers .

As a customer or individual waiting to be served, it seems that you only need to add more servers to eliminate this “waiting line” problem. As a service manager, it may not be beneficial to have more than enough servers because you have to be concerned about controlling cost and having idle employees does not help the bottom line. Therefore, the goal is to achieve an economic balance between the cost of service and the cost associated with waiting for that service. This is extremely difficult to do in real world situations because you cannot accurately predict arrival times of customers and the amount of each server time.

Queuing Theory offers us the ability to analyze these behaviors. In general, Queuing Theory is the mathematical study of queues, or waiting lines. It provides various mathematical models that can be used to represent different “waiting line” scenarios. A queue or waiting line is categorized by the maximum amount of customers that it can contain. They are defined as either infinite or finite depending upon the maximum capacity. An infinite queue has no capacity limit and is the assumed category for most queueing models. This is the standard approach because dealing with queues with large finite upper bounds is often complex. Infinite queues are the focus of this paper and we shall begin with a statement of the problem. As shown in this thesis, sometimes solutions to queuing problems are not possible. The application of computer simulation allows solutions to these more difficult (and more realistic) problems.

Statement of Problem

A group of graphical artists currently have a computer network configuration that does not provide adequate performance for its networked printers. The utilization of printers is inconsistent across the board and there is no load balancing in place. Speed of the printers are not of much concern. One tends to sacrifice speed for quality with high-end graphic printers. Print jobs are graphically intense and consequently large in nature.

Several attempts have been made to analyze the problem of print queue management, and the IT department is currently undergoing testing of a possible alternative to the network configuration. This alternative may improve network performance greatly by leveraging existing resources with new technology.

The proposed alternative will not however address the issue of printer utilization directly. Although there is a lot of confidence in how beneficial this new configuration will be, it will actually shed light on an underlying problem. Even if the network configuration is optimized, the printers will still only print out a certain amount of jobs on average. This brings up the question of whether or not additional printers are needed.

- Are there enough printers currently to meet the goals?
- How will upgrading network hardware and software impact the management of print jobs?
- Will new printers have to be purchased?
- If so, how many?
- How should the print queue be managed?

Currently the graphics group consists of 8 graphic artists, 7 freelance artists, and 6 designers. These artists are responsible for printing proofs used in the company's solicitation letters. When a print job is sent to the printer it will take 3 minutes on average to process the job. With only 8 graphic printers, artists find themselves having to wait until a printer is no longer busy in order to send a print job. There currently is no automated method of managing a print queue. Printers are allocated according to line of business. The lines of business are:

- Secured Card and Inserts,
- High Response,
- Students/Affinities and Installment Loans,
- HELOC and Apollo/Special Projects,

- Cell Phones
- Designers,
- Account Management/ Broadscale and X-Sells.

The technical support staff for the company has agreed to automate the print queue management for the group. Traditionally, this automated print queue manager has a “first come first serve” (FCFS) queue discipline. This automation will go a long way in improving productivity. Joy Black, the manager of the graphics group, would like to know

- The average number of jobs in the queue at any given time,
- The average wait (including service)
- If additional printers are needed to handle the volume of print jobs?
- If so, how many would she need for now?
- How many would she need a year from now?

They are expected to double their staff in one year. Also, the new automated system will be implemented within the next year.

Existing System

The existing network configuration consists of 8 Xante Accelawriter 8200 printers. These printers are high-end color graphic printers with the capability to print 8 ½ x 11 as well as 11 x 17 sheets. The printers and computers communicate over 10 base T Ethernet (standard network media). Print distribution is allocated according to the different lines of businesses. The assignments are shown in table 1.

Table 1. Printer assignments for the graphic artist group.

<u>Printer Name</u>	<u># People to print</u>	<u>Line of Business</u>
A	2	Secured Card & Inserts
B	1	High Response
C	1	Students/Affinities & Installment Loans
D	1	Special Projects
E	1	Cell Phones
F	1	Cell Phones
G	6	Designers
H	2	Acct. Mgmt./Broadcast & X Sells

Artists are assigned to a particular line of business, which in turn gives them permission to print to certain printers. This approach yields 8 individual print queues. Each queue is assumed to have the characteristics of a M/M/1 queue (Gross and Harris). The artists only print to their assigned printers regardless of how busy the printer. This simple configuration is shown in figure 1.

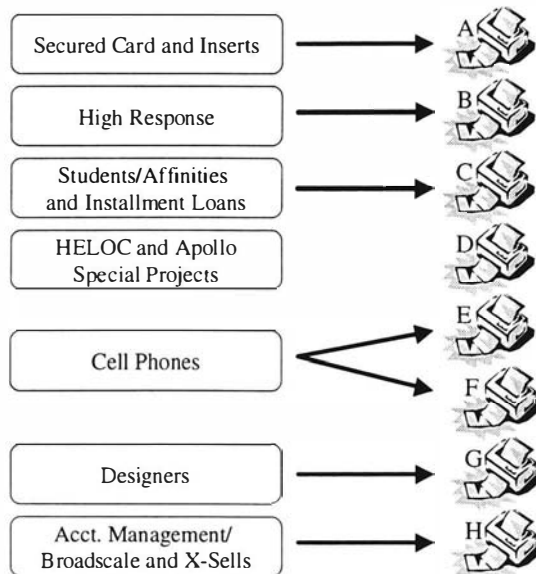


Figure 1. Current printer utilization by business function.

Proposed System

The proposed system will differ in the management of the print queues. A network print queue will be defined and used by all graphic artists. The result will be one automated print queue that allocates the next print job to the next available printer as opposed to a dedicated printer. Each of the 8 printers will be a server available to all customers. We will also consider prioritization of print jobs due to the fact everyone will be using one queue and first come, first serve (FCFS) may not yield the best results.

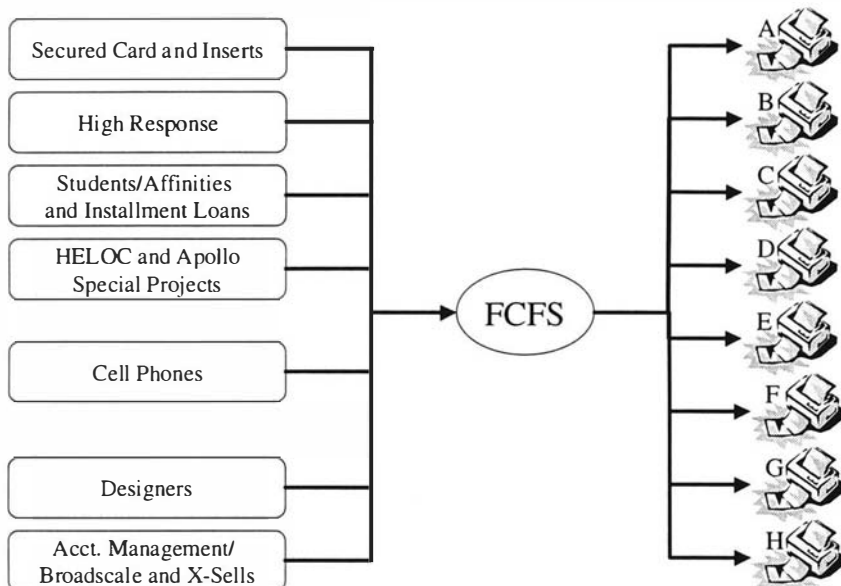


Figure 2. The proposed printer configuration.

Birth and Death Process

Most queuing models assume that inputs and outputs occur according to the birth and death process (Gross and Harris). The term “birth” refers to the arrival of a customer and “death” refers to the departure of a served customer. The “state” of the system at time t ($t \geq 0$), $N(t)$, is the number of customers in the queuing system at time t . The birth and death process describes probabilistically how $N(t)$ changes as t increases. Individual

births and death occur randomly, where the mean occurrence rates depend only upon the current state of the system. The assumptions to the birth-death process are:

- **Assumption 1** - Given $N(t) = n$, the current probability distribution of the remaining time until the next birth (arrival) is exponential with parameter, λ_n ($n=0,1,2,\dots$).
- **Assumption 2** - Given $N(t)=n$, the current probability distribution of the remaining time until the next death (service completion) is exponential with parameter μ_n ($n=1,2,\dots$).
- **Assumption 3** - Only one birth or death can occur at any given time.

Assumptions 1 and 2 yield a birth and death process that is a continuous time Markov chain. Queueing models that can be represented by a continuous time Markov chain are a lot easier to deal with analytically. With the addition of assumption 3, the analysis becomes even easier.

The relationship between the Poisson distribution and the exponential distribution implies that the λ_n and μ_n are mean rates, we can summarize these assumptions by the rate diagram shown in Figure 3. The arrows in this diagram show the only possible transitions in the state of the system (as specified by Assumption 3), and the entry for each arrow gives the mean transition rate (as specified by Assumptions 1 and 2) when the system is in the state at the base of the arrow.

Except for a few special cases, analysis of the birth-and-death process is very difficult when the system is in a transient condition. Some results about the probability distribution of $N(t)$ have been obtained, but they are too complicated to be of much practical use. On the other hand, it is a relatively straightforward to derive this distribution after the system has reached a steady-state condition (assuming that this condition can be reached). This derivation can be done directly from the rate diagram.

Consider any particular state of the system n ($n = 0, 1, 2, \dots$). Starting at time 0, suppose that a count is made of the number of times that the process enters this state and the number of times it leaves this state, as denoted below:

$E_n(t)$ = number of times that the process enters state n by time t .

$L_n(t)$ = number of times that the process leaves state n by time t .

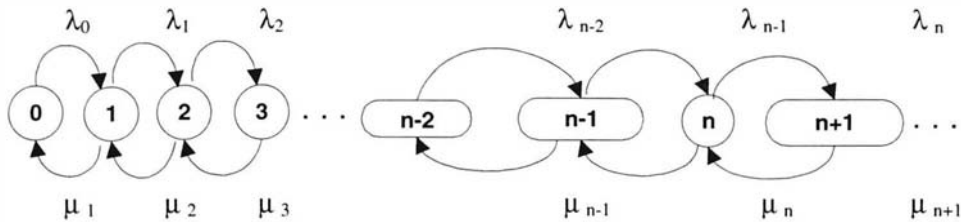


Figure 3. Rate diagram for the birth-and-death process

Exponential Distribution

The most common queueing models assume that inter-arrival times and service times follow the exponential distribution. The exponential distribution possesses the Markovian property, which is sometimes called the memorylessness property (Gross and Harris). In this case the property states that if service times are exponentially distributed, then the probability that a customer currently in service is completed at some future time t is independent of how long he has already been in service. One may ask why this assumption is important. In an effort to define a useful queueing model, the model should be realistic so that it can provide reasonable. Assumption of the exponential distribution gives you the flexibility.

Basically, the exponential distribution allows us to model a queueing system as a continuous time Markov chain. Phase type distributions, such as the Erlang distribution where the total time is broken down into individual phases having an exponential distribution are very useful because they are traceable for analysis.

Data

In order to gauge the performance of the current setup, it was decided to record metrics associated with the 8 printers that are in place. The metrics captured the amount of print jobs processed in a week; broken down by day. The network support analyst for the marketing group recorded the data from the printer's "performance configuration" page. The configuration page has information on the total number of jobs printed. The total time was an 8-hour day. As the actual inter-arrival times were not available, the arrival process was assumed to be a homogenous Poisson process and thus the inter-arrival times are exponential. The exponential distribution is parameterized by the average arrival rate, which can be found from the total number of arrivals over a given time period.

The service time distribution was determined by the average time taken to print a job and was also modeled using the exponential distribution. The network support analyst took samples to determine the average. There was some variance in the amount of time it would take to service a print job, but the average time was pretty consistent with the typical print jobs. There were instances of large print jobs being serviced as well as smaller print jobs. Confirmation of the average service time was given by both the graphic artist and the network support analyst (Keith Covington). The data used to estimate the arrival rates is shown in table 2.

Table 2. A summary of printer data.

Printer	# of Print Jobs in a Week							TOTAL
	1/27/97	1/28/97	1/29/97	1/30/97	1/31/97	2/1/97	2/2/97	
A	78	107	239	319	49	46	0	838
B	83	137	20	81	105	147	0	573
C	47	67	117	128	118	33	0	510
D	7	68	5	1	1	1	0	83
E	217	346	83	233	100	438	0	1417
F	127	34	68	20	26	3	0	278
G	124	194	79	131	92	92	0	712
H	201	314	195	283	229	160	0	1382
Total	884	1267	806	1196	720	920	0	5793

The exponential distribution has been assumed for the arrival and service times. This was due to a lack of data on the actual inter-arrival times. Thus the usual process of choosing

a “best-fit” distribution was not possible. The question remains if this was the correct distribution to model the arrival and service processes. This question will be explored through sensitivity analysis.

Simulation

At times it is not possible to find closed form solutions to model of queuing systems. This can be attributed to the characteristics of the input and/or service mechanisms, the complexity of the system design, the nature of the queue discipline or combinations of the above. For these types of problems it may be best to analyze the system through simulation. Because simulation is similar to analysis by experimentation, the usual problems associated with running experiments must be addresses in order to make inferences concerning the real world therefore, you must be concerned with run length, number of replications, and statistical significance.

The performance of the real system is imitated by using probability distributions to randomly generate the various events that occur in the system. Therefore, a simulation model synthesizes the system by building it up component by component and event by event. It then runs the simulated system to obtain statistical observations of the performance of the system that results from the various randomly generated events. Because the simulation runs typically require generating and processing a vast amount of data, these simulated statistical experiments normally are performed on a computer.

Simulation is a controlled statistical sampling technique for estimating the performance of complex stochastic systems when analytical models do not suffice. Rather than describing the overall behavior of the system directly, the simulation model describes the operation of the system in terms of individual events of the individual components of the system. In particular, the system is divided into elements whose behavior can be predicted, at least in terms of probability distributions for each of the various possible states of the system and its inputs. The interrelationships among the elements also are built into the model.

After constructing the model, we can use random numbers to generate simulated events over time according to the appropriate probability distributions. The result is a simulation of the actual operation of the system over time, and we can record its aggregate behavior.

In this paper we deal strictly with discrete event simulations (Gross and Harris). In these simulations, changes in the state of the system occur at random points in time as a result of the occurrence of discrete events. The basic building blocks of a model for a discrete event simulation are the possible states and events, a simulation clock for recording the passage of simulated time, a mechanism for randomly generating the different kinds of events, and a mechanism for then generating state transitions. These typical simulation studies focus on systems that operate continually in a steady-state condition. How do you obtain data that represents the steady state behavior or real world systems? Running a simulation model for a significant period of time until the system is believed to be in steady state condition is one method. However, it is a time consuming and expensive method in most cases.

Formulating and Implementing a Simulation Model

A. Constructing the Model

The first step in simulation is to develop the model representing the system. This requires the analyst to be very familiar with the system and the objectives of the study. The typical approach is to reduce the real system to a logical flow diagram where the components can be broken down into sub-components. The simulation model needs to be a realistic representation of the real system. If the behavior of an element is not deterministic, given the state of the system, it is better to take random observations from the probability distribution involved than to use averages to simulate the performance of this element.

B. Generating Random Numbers

Implementing a simulation model requires random numbers to obtain random observations from probability distributions. A random number generator is an algorithm

that produces sequences of numbers that follow a specified probability distribution and possess the appearance of randomness. The reference to “sequence of numbers” means that the algorithm produces many random numbers in a serial manner. Although an individual user may need only relatively few of the numbers, it is generally required that the algorithm be capable of producing many numbers. The probability distribution is usually taken to be the uniform distribution between 0 and 1, in which case the numbers generated by the algorithm may be called uniform random numbers or simply random numbers.

For this thesis problem, we will use the random number to generate random variates from the exponential distribution using the inverse transform method. This method is used to generate a sequence of random observations from a given probability distribution whether discrete or continuous (Ross, 1990). Let X be the random variable involved. Denote the cumulative distribution function by

$$F(x) = P\{X \leq x\}$$

Generating each observation then requires the following two steps.

- Generate a uniform random number r between 0 and 1
- Set $F(x) = r$ and solve for x , which then is the desired random observation from the probability distribution.

For this particular problem the simulation model was programmed using GPSS/H software (Banks, Carson) which is a C based simulation language, which handles generation of random -variates from many well-known probability distributions.

Measures of Effectiveness

Within a queueing system there are certain performance measures of effectiveness that tend to describe the effectiveness or efficiency of a system. They are:

- The waiting time that a customer must incur
- An indication of how customers may accumulate, and
- A server’s idle time

We will focus on:

- Expected waiting time (\bar{W}_q)
- Average number of jobs in the system (L)
- Total time spent in the system including service (W)
- Percentage of time when a server is idle ($P_r\{\text{any server idle}\}$)

Formulas used for calculating measures of effectiveness are all derived from Little's formula ($L=\lambda W$) (Hillier, 1990). For a simple queue with exponential arrival and service times and a single server, also known as an M/M/1 queue:

$$L = \lambda / \mu - \lambda$$

$$W = 1 / \mu - \lambda$$

$$W_q = \lambda / (\mu - \lambda)$$

$$P_r\{\text{any printer idle}\} = 1 - \lambda / c\mu$$

The proposed printer configuration is more complex as there are 8 servers utilized on a first come first served basis. As the service and arrival times are still assumed to be exponentially distributed this queue is called an M/M/8 queue. Measures of effectiveness for this model are derived by utilizing the steady-state probabilities given by the following equations

$$p_n = \frac{\lambda^n}{n! \mu^n} (p_0) \quad (1 \leq n \leq c)$$

$$p_n = \frac{\lambda^n}{c^{n-c} c! \mu^n} (p_0) \quad (n \geq c)$$

$$p_0 = \left[\sum_{n=0}^{c-1} \frac{r^n}{n!} + \frac{cr^c}{c!(c-r)} \right]$$

$$p_0 = \left[\sum_{n=0}^{c-1} \frac{1}{n!} (\lambda/\mu)^n + \frac{1}{c!} (\lambda/\mu)^c (c\mu / c\mu - \lambda) \right]^{-1}$$

*All values for “L” should be rounded to the nearest whole number

Results for the Existing System

Table 3 shows the steady state results of the analytical model for the existing system, while the results from the simulation model are shown in table 4 for comparison.

Table 3. Queuing model steady state results for the existing system.

	Lambda(/h)	Mu (/hr)	L (# jobs)	W (min)	Wq(min)	Pr {idle}
PRINTER A	18	20	9	30	27	10%
PRINTER B	12	20	1.5	7.5	4.5	40%
PRINTER C	11	20	1.2	6.6	3.6	45%
PRINTER D	2	20	0.1	3.3	.3	90%
PRINTER E	19	20	19	60	57	5%
PRINTER F	6	20	0.4	4.4	1.3	70%
PRINTER G	15	20	3	12	9	25%
PRINTER H	19	20	19	60	57	5%

In this configuration, the results show that only Printer D and F are not sufficiently utilized (above 50%). There is also great variance in waiting times for service. While some users have less than 3 minutes to wait for a print job, others are waiting as much as an hour.

Table 4. Simulation model steady state results for the existing system

	LAMBDA	MU	L	W	Wq	Pr{idle}
PRINTER A	18	20	7.8	25.9	22.8	6.8%
PRINTER B	12	20	1.7	8.5	5.2	34.5%
PRINTER C	11	20	1.4	4.4	7.8	41.9%
PRINTER D	2	20	0.1	0.1	3.5	88.4%
PRINTER E	19	20	41.3	47.4	46.3	0.3%
PRINTER F	6	20	0.4	3.5	0.4	66.7%
PRINTER G	15	20	2.5	10.3	7.1	23.8%
PRINTER H	19	20	41.3	47.4	46.3	0.3%

The simulation program results are good estimates of steady state results. An additional advantage of simulation is the ability to examine more than the average results. The

variability in each of these measures is also of interest. Figures 4 through 11 show the distribution of the waiting times in each of the queues under the existing system.

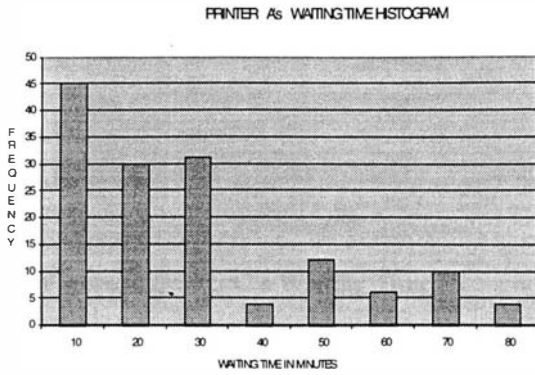


Figure 4. Printer A's Waiting Time Histogram

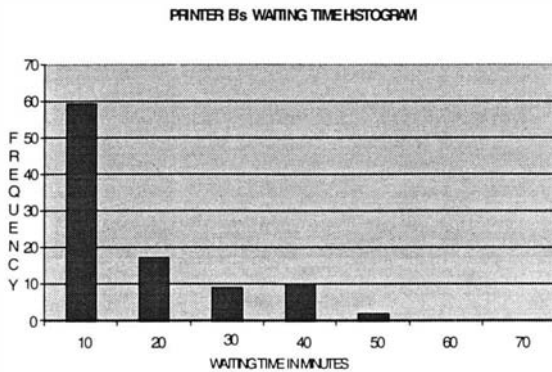


Figure 5. Printer B's Waiting Time Histogram

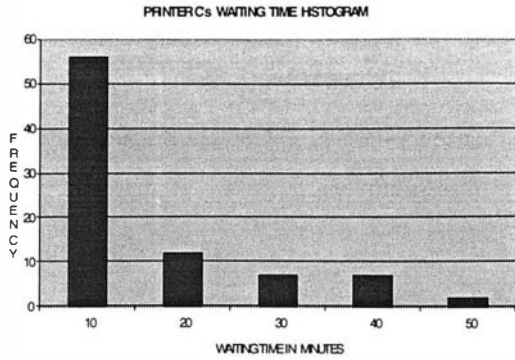


Figure 6. Printer C's Waiting Time Histogram.

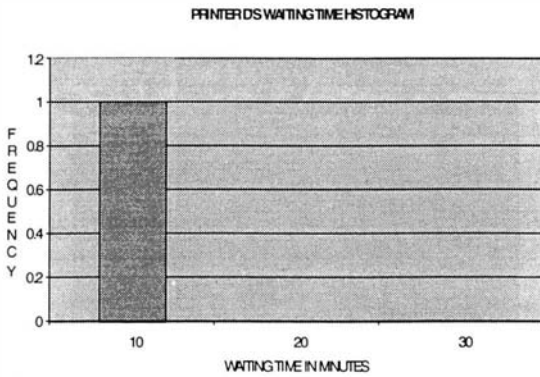


Figure 7. Printer D's Waiting Time Histogram.

Printer E's M/M/1 Queue Waiting Time

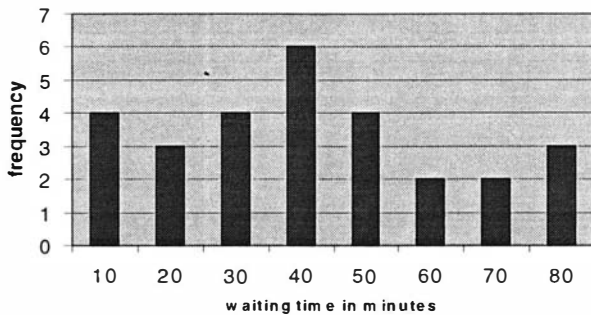


Figure 8. Printer E's Waiting Time Histogram.

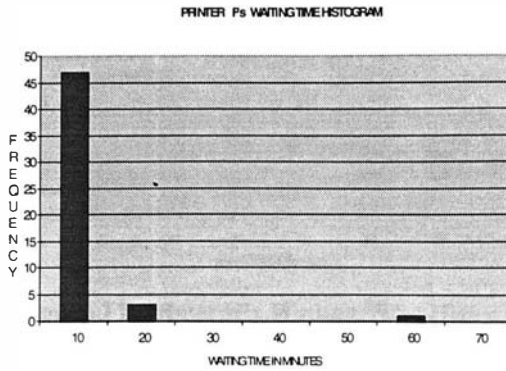


Figure 9. Printer F's Waiting Time Histogram.

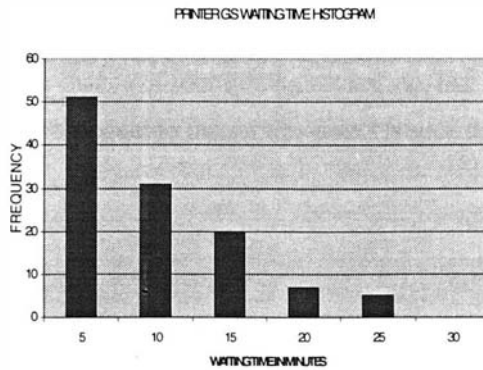


Figure 10. Printer G's Waiting Time Histogram.

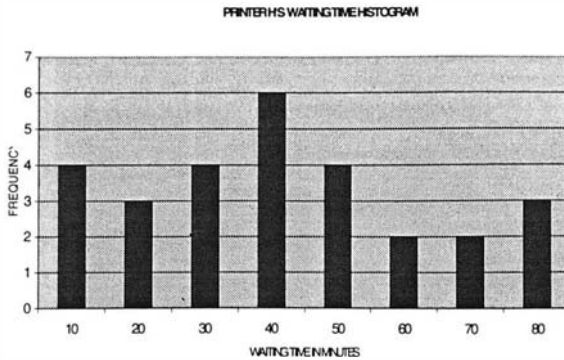


Figure 11. Printer H's Waiting Time Histogram.

Notice that in Figures 7 and 9 there are not a lot of print jobs with significant wait times. This can be attributed to both Printers D and F having only one user whom is in fact not heavy users. Figures 4, 5, 6, and 10 show that the majority of the print jobs are processed in 3 minutes or less. In this case service time is relatively faster than arrival time so there is less of a chance of jobs getting backed up. For Figures 8 and 11 we have arrival rates that are almost equal to the service time. Notice the greater variance in wait times.

Results for the Proposed Queue

The proposed system allows for improved service time because jobs are routed to the next available printer, which decreases overall average wait time. This results in the average number of jobs in queue decreasing as well. For the proposed system, the average wait time before service is 6.06 minutes. Figure 12 shows the distribution of the waiting times observed in the simulation run.

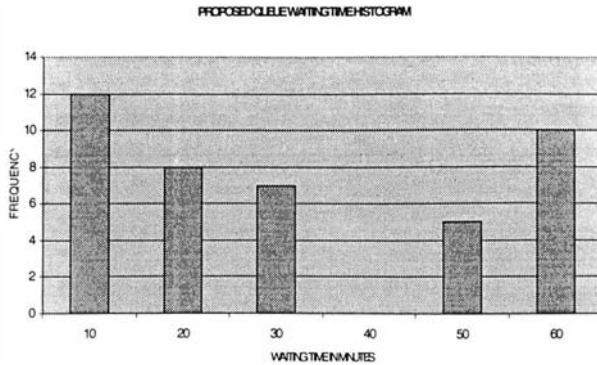


Figure 12. Proposed Queue Waiting Time Histogram

All business functions are given equal priority in the queue and therefore we have a total increased average waiting time in comparison to some of the individual M/M/1 queues. Thus a prioritized queue was proposed allowing higher priority to the more critical business functions. This queue gave priority to those lines of businesses, which were deemed critical due to the volume of output they generated. Those businesses that did not generate a high volume of output were given top priority. This was done in an effort to process all print jobs with the thought that the power users would have less impact on the queue if they allow other users to print first. The order of print priority was defined as:

- 1 HELOC and Apollo
- 2 Cell Phones II
- 3 Designers
- 4 High Response
- 5 Students, Affinities and Installment Loans
- 6 Secured Card and Inserts
- 7 Cell Phones I
- 8 Acct. Management, Broadscale and X-Sells

The average wait time under the priority queue is 3.1 minutes, which is an improvement on the proposed queue.

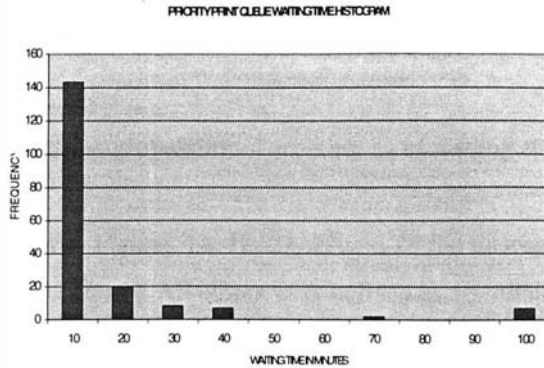


Figure 13. Proposed Priority Queue Waiting Time Histogram

Table 5 shows the steady state results for the proposed queue and the priority queue. The priority queue is superior in each measure of effectiveness, except the length of the queue. Luckily, the artists are not as interested in the length of the queue as this is not visible to them.

Table 5. Propose Queue and Proposed Priority Queue Results

	ρ_0	# servers	LAMBDA	MU	L	W	Wq	Pr(idle)
Queuing Model Steady State Results/Proposed System	0.007	8	102	20	6	3.2	0.2	36.3%
Simulation Model Results/Proposed System	0.007	8	102	20	5.1	3.1	0.1	36.2%
Simulation Model Results/Proposed System w/Priority	0.007	8	102	20	7.9	3.1	0.1	0.8%

Service Quality

As a customer, one of the things you are constantly concern about is the quality of service you receive from a service provider. In the given scenario, a graphic artist will primarily be concerned about the average time needed to print a job. The graphic artists have defined what we called an “unacceptable wait time” for each of the different queues (Table 6). For the majority of these print queues the frequency of times that someone has to wait an unacceptable amount of time is low. However, Printer E and H are both

consistently over 30 minutes in waiting time. This is due to the high frequency of arrivals to the system.

These waiting times and the probability of meeting or exceeding the unreasonable limit are captured in f

Figures 14 through 23. For Figures 14, 18, 21, 22, and 23 the unacceptable waiting times have been defined as 30 minutes. All others were defined as 15 minutes. The probabilities of exceeding the unacceptable waiting times are captured in the table 6.

Table 6. Probability of Reaching Unacceptable Waiting Times

Printer Queue	Unacceptable Waiting Time	Probability of Exceeding
Printer A	30 minutes	25%
Printer B	15 minutes	11%
Printer C	15 minutes	11%
Printer D	15 minutes	0%
Printer E	30 minutes	60%
Printer F	15 minutes	0%
Printer G	15 minutes	7.20%
Printer H	30 minutes	60%
Proposed Queue	30 minutes	33%
Priority Queue	30 minutes	28%

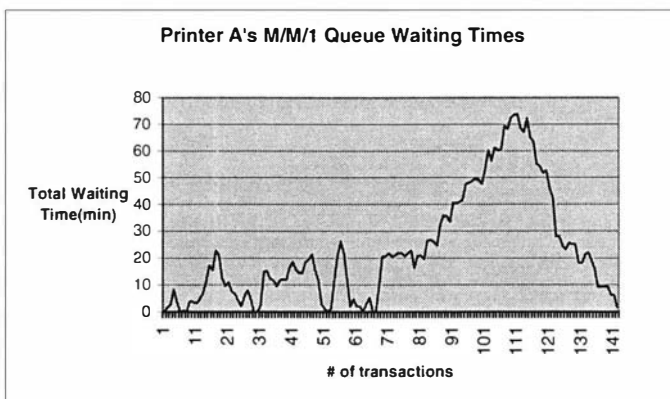
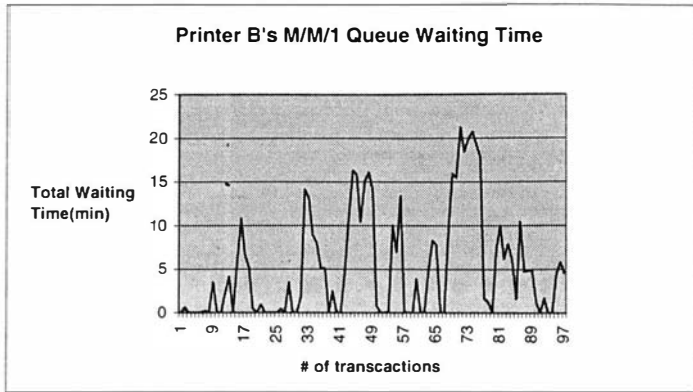


Figure 14. Simulation Results for Printer A.**Figure 15.** Simulation Results for Printer B

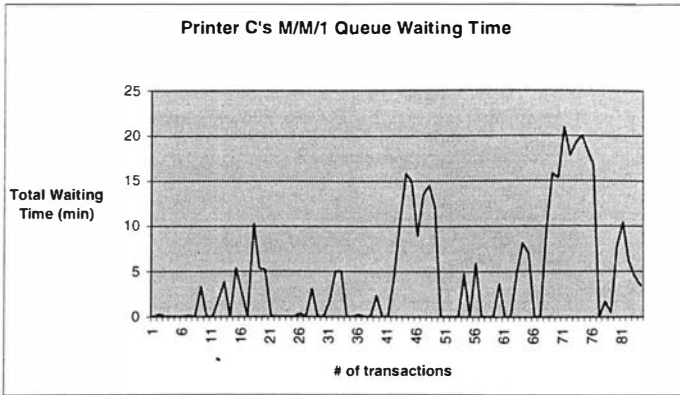


Figure 16. Simulation Results for Printer C

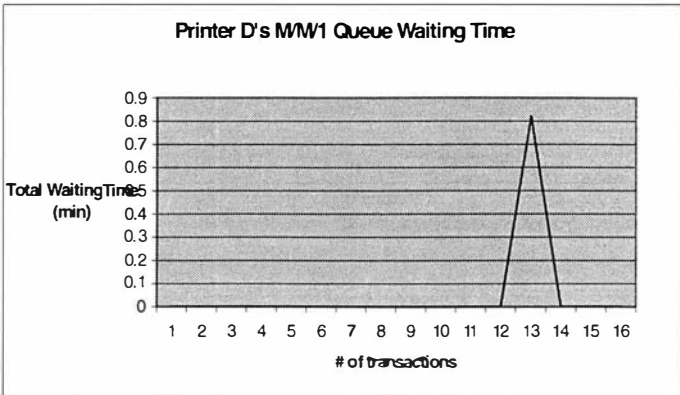


Figure 17. Simulation Results for Printer D

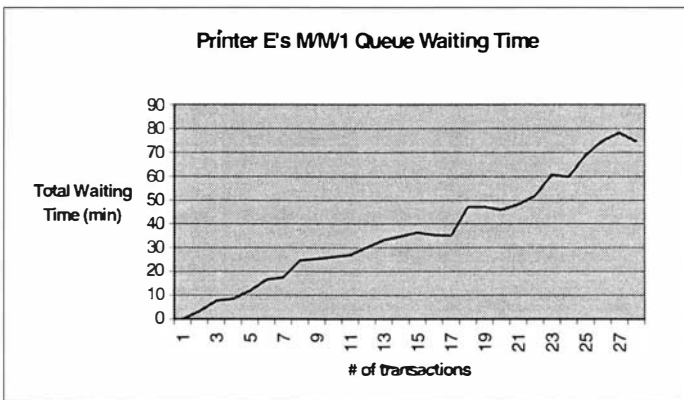


Figure 18. Simulation Results for Printer E

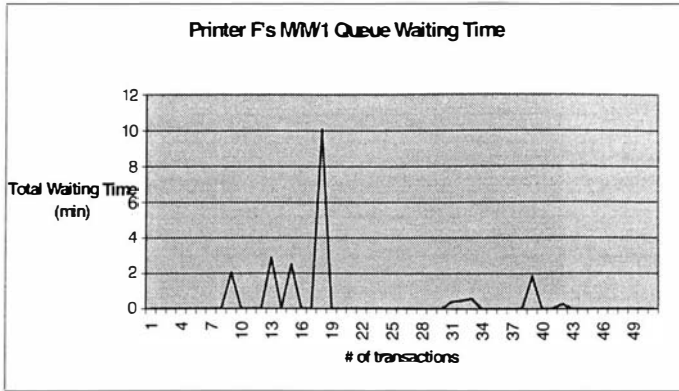


Figure 19. Simulation Results for Printer F

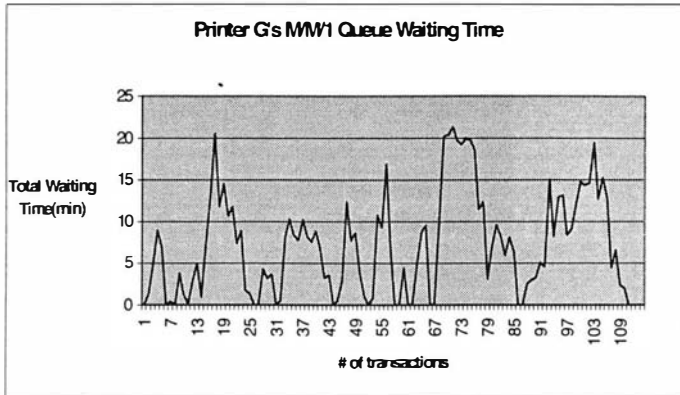


Figure 20. Simulation Results for Printer G

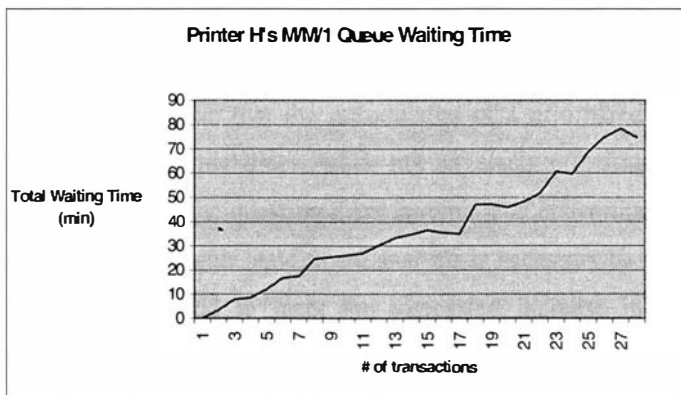


Figure 21. Simulation Results for Printer H

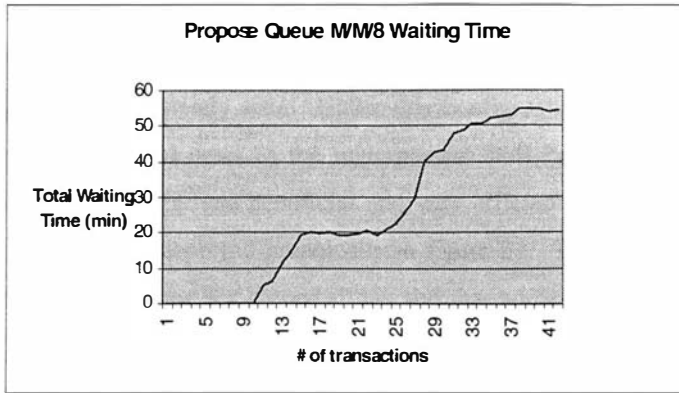


Figure 22. Simulation Results for Proposed Queue

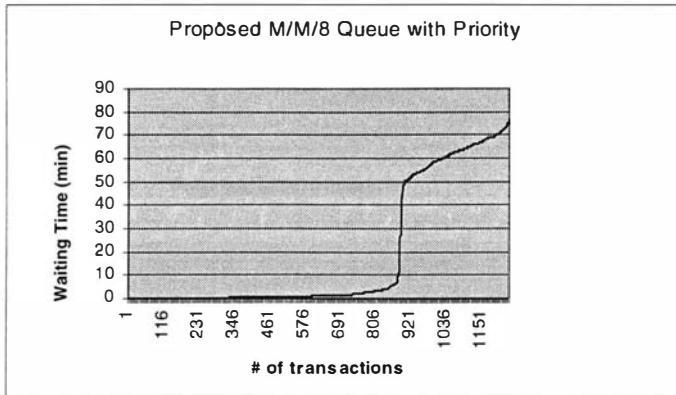


Figure 23. Simulation Results for Proposed Queue with Priority

Future Needs Forecasting

The analysis thus far has shown that the introduction of a prioritized queuing network will improve the average waiting times, while not adversely effecting the high priority business functions. However, the question there is remaining concern about the ability of the system to meet future demands. Additional analysis is necessary to determine whether additional printers are required to meet the forecasted increase in staff. The rapid expansion of Capital One means that a doubling in graphic artists is expected in the year.

By doubling the arrival rates in the simulation model, it was found that this increase in staff would cause an “explosive queue”. This is interpreted as a queue that cannot

terminate transactions faster than they can arrive. Eventually, the number of pending print jobs grows out of control. However, by increasing the number of printers by two, the queue was able to reach a steady state. Under this configuration the printers would be 91% utilized. This is good news to the management staff because the additions and enhancements to the setup proved beneficial and very efficient. The simulation results for the M/M/10 queue is displayed graphically in figure 24. The cyclical nature of the graph depicts the waiting time for a normal day and that some print jobs are done after hours which is represented by the decrease in waiting time followed by a steep increase. The print jobs left for after hours processing are normally completed within the first hour. This was evident by running the extended simulation program for 60 additional minutes while not creating any new transactions. The result was a flushing out of the queue within that 60 minute time frame.

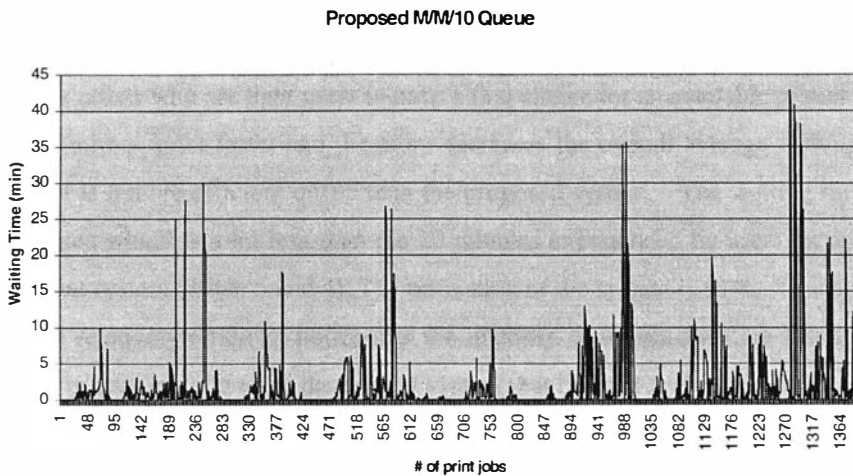


Figure 24. Simulation results for the forecasted system with two additional printer.

Conclusion

The current system is not efficient. Having dedicated printers assigned to users does not offer optimal use of every printer. Most printers were efficiently utilized, that is $Pr\{idle\}$

is less than 50% (Table 3 and 4). This means that of the time printers were available artists were using them over 55% of the time. Although the printers were utilized for the most part, the average waiting time was approximately 20 minutes; this is a considerable amount of time to wait for a print job. It appears that more printers are needed for the heavier users.

The proposed system is a lot more efficient. The average total waiting time is reduced to 3 minutes. The $Pr\{idle\}$ is 37% (Table 5). This indicates an increase in utilization for the printers. A great improvement in efficiency, considering the average waiting time has decreased by 17 minutes as well. This FCFS queue discipline works well in general but there are some users who get increasing waiting time because it is now all one queue. Users of all printers except E and H will experience an increase in waiting time but the benefit will be a better managed and efficient print queue overall.

In our priority queue power users are assigned low priority for print jobs. This should allow artists who are light users to have a first choice for an available printer. This allows their jobs to print faster and therefore decreases the overall average waiting times. The affect is a more efficient queue than the proposed system. The waiting time was also 3 minutes which is a lot less than the 20 minutes experienced by users on average for the current system (Table 5 and 4). The utilization of the system is 91%. This system appears to be relatively efficient, notice that the majority of transactions are less than a minute. This is a sharp contrast to the current system that boasted an unacceptable wait time and two underutilized printers.

The decision was made to go with the priority print queue configuration. Although the priority queue requires additional maintenance, the increase in productivity for the power users will more than offset the cost associated with additional maintenance. The improvement in efficiency is also a great justification for going with the priority queue. The performance of the queue is the same as the proposed system but having “intelligence” built into the queue management process pays great dividends.

The prioritized system will allow a minimal investment to meet the forecasted departmental growth. The purchase of a single printer will give a performance better than the current system, despite the forecasted doubling in arrival rates.

APPENDIX:

Basic GPSS/H Simulation Program

GPSS/H Simulation Program

```
1      SIMULATE
2
3      GPSS/H BLOCK SECTION
4
5  1  GENERATE RVEXPO(1,5)
6  2  ADVANCE
7  3  SEIZE  PRINTER
8  4  ADVANCE RVEXPO(1,3)
9  5  RELEASE PRINTER

10 6  TERMINATE 1
11
12  GPSS/H CONTROL STATEMENTS
13
14  START 480 - TERMINATE SIMULATION
      AFTER 480 min(8 hrs)
15  END
```

Sunday, October 11, 1998

6:34 PM

GPSS/H SIMULATION PROGRAM

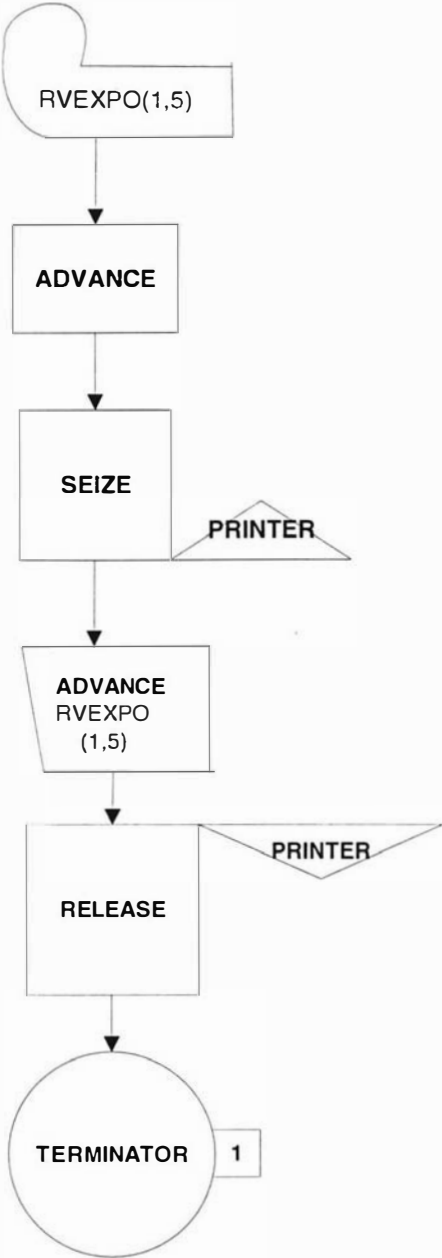


Figure 25 GPSS/H Simulation Program Flow Diagram

Accel-a-writers

A
B
C
D
E
F
G
H

Tektronics Color Printer
CP

LaserMaster
LM

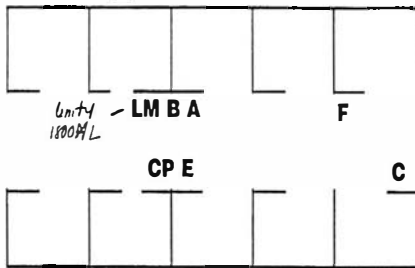
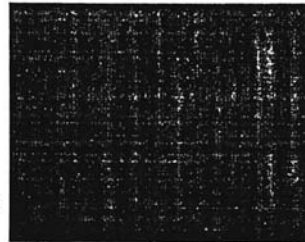
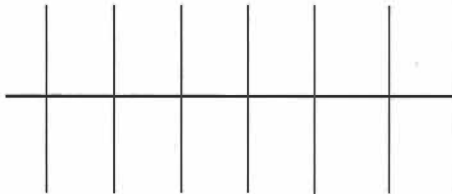
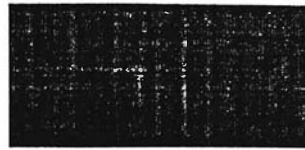
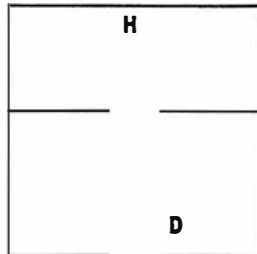


FIGURE 26 LOCATION LAYOUT FOR PRINTERS (SERVERS)

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