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The Determination of the Operating Characteristics of a Newspaper Camera Department by Using Queueing Analysis

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THE DETERMINATION OF THE OPERATING CHARACTERISTICS OF A NEWSPAPER CAMERA DEPARTMENT BY USING QUEUEING ANALYSIS

by

Owen Smith

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in the School of Printing in the College of Graphic Arts and Photography of the Rochester Institute of Technology

May, 1978

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MASTER'S THESIS

This is to certify that the Master's Thesis of

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THE DETERMINATION OF THE OPERATING CHARACTERISTICS OF A NEWSPAPER CAMERA DEPARTMENT BY USING QUEUEING ANALYSIS

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An Abstract

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ABSTRACT

The methods of operation of many newspaper camera departments have been established over a long period by many different supervisors and department heads. The system may have been good once but went bad because the nature of the department's operations changed without corresponding changes in the system.

The production manager must be able to detect when a system needs modifying. Presently, there are few tools available to the manager for evaluating the effectiveness of the department.

The goal of this study was to demonstrate how a very simple analytical technique could be applied to a camera department's operations and, thereby, determine the department's operating characteristics. This analytical technique is called queueing analysis.

The particular camera department studied contained two independent systems. One camera serviced pasted-up pages while the other serviced halftones and artwork. Each of these systems or channels was studied separately.

However, before the systems could be studied, several assumptions of the queueing model had to be satisfied. These assumptions were:

(1) copy arrivals must be Poisson distributed,

(2) copy service time must be exponentially distributed,

(3) copy can not leave the waiting line after having entered,

(4) the service discipline must be first-in-first-out,

(5) and the arrival pattern must be random.

The only raw data required by the analysis were the copy arrival time and the service time of each piece of copy. The data were compiled to form empirical distributions which were compared to theoretical distributions to determine the feasibility of the assumptions.

The average arrival rate and service rate were also determined from this compiled data. These two averages were substituted into formulas developed by theorists to determine the operating characteristics or measures of effectiveness for the camera department.

The analysis was carried out over a two week period and considered each system on a weekly basis. In this manner the two weeks of operation could be compared.

It was found that the page channel could be monitored quite easily using queueing analysis, but the halftone/artwork camera could not be studied without modifications.

It was found that the expected time a page spent in the system was much longer than previously thought. During the first week of observation, the expected time in the system was 18.9 minutes per page. It was 11.4 minutes per page during the second week. There was also a great difference between the

two times which might indicate that something in the system had changed.

It was found that the expected number of pages in the system per half hour during the first week was 1.69 and 1.06 during the second week. It would be expected that the system could handle a greater number of pages than this. This observation was further supported by the weekly busy period probabilities determined for the system. This is the probability that the system will be busy during any half hour interval during the week. The busy period probability was .63 for the first week and .51 for the second. These figures indicated that there was a great deal of idle time in this system. In fact, there was 23 hours and 19 minutes of idle time during the first week and 30 hours and 52 minutes during the second week.

It was impossible to draw any straightforward conclusions from these results without knowing the objectives of the organization.

If management's goal was to minimize costs in this department, it was evident this objective was not being met in light of the great amount of idle time that existed. To realize this goal, management must reduce this idle time.

If management's goal was to maximize speed, the system would again be out of line with management's expectations. However, this goal may have been more closely realized. To fully satisfy this objective would require management to

reduce the time copy spends in the system.

This study demonstrates that queueing analysis can be used quite successfully and easily in determining the operating characteristics of a camera department. It was also demonstrated that even when the analysis was not successful, much could be learned about the system through the application of this tool.

Abstract approved: W. Frederick Craig thesis advisor

Assoc. Professor, Printing title and department

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I. INTRODUCTION

In the recession of the early 1970's, newspaper production costs soared. Raw newsprint, which accounts for about 30 per cent of most newspapers' total costs, rose 58 per cent in one 37 month period. Many papers have become tied by restrictive and costly labor union settlements. Newspapers have also lost circulation for the first time in forty years and advertising has fallen off.[1]

For example, in the early 1970's, the New York Times' circulation dropped 12 per cent, advertising dropped 7 per cent, and the company's stock, worth $53.00 per share in 1968, dropped to $7.50 per share.[2]

Many papers have responded to these problems with economic and/or technological changes. Papers are eagerly instituting labor saving processes such as computerized typesetting and page composition, centralized home delivery systems and have gone to smaller pages to reduce newsprint costs.

Other changes are being made in the design of the newspaper. The aim is to make the product easier and more pleasurable to read. Color pictures, wider columns, a more detailed index, prominently displayed national and international news digests and daily features placed in the same

place are some of the changes being made.[3]

The number of daily newspapers sold in the United States decreased 4.6 per cent from 1973 to 1975. The number of readers dropped 7 per cent.

Since 1960 daily newspapers have folded in New York, Chicago, Los Angeles, Boston, San Francisco, Detroit, Houston, and Cleveland.[4]

To combat this decline, newspapers have started market research studies and are trying to attract readers with new features and formats.

The American Newspaper Publishers Association and the Newspaper Advertising Bureau are engaged in a project to help newspapers cope with the problem of re-examination and planning. However, these studies are national in scope and do not take into consideration the significant differences among papers.[5]

Time is a vital and expensive factor in the production of a newspaper. The newspaper publisher wants to keep this factor to a minimum because of the inherent costs and the reader's demand for "timely" news. Presenting "timely" news is especially a problem since newspapers must compete with the seemingly "instantaneous" communications of the electronic media.6

Newspaper publishers have become more sensitive than ever to the rising costs of production. Managers and foremen are constantly pressured to reduce operating costs.

The area getting the most attention is the prepress area since it represents one of the most expensive areas of production; production managers must have a way to evaluate the operating effectiveness of this area.[7]

Page-cost indices and man-hours per page figures are aids the manager uses to collect information about the system.

The page-cost index is generally the payroll cost of producing a page in the composing room. The weekly payroll of the department is divided by the number of pages produced to yield the page cost for that week. This index is used as a barometer of unit costs.[8]

The man-hours per page figure is determined by dividing the number of hours worked per week in the composing room by the number of pages produced per week. This method is intended to give the manager an estimate of hours per unit. A running average is kept as a ready reference.[9]

These two methods can be modified for use in other areas such as the platemaking and camera departments.

The manager must also know when peak work loads occur. One way to determine this is to construct a simple graph by plotting the amount of copy received by the time it was received. This can also be done by the week or by the month. The graph will indicate load variation and whether manning changes are necessary. Manning changes often require changing personnel hours or starting and stopping times.[10]

Flow analysis is another technique used to evaluate production departments. This technique requires an examination of the path the copy travels through production. The aim is to simplify the system and save production time.[11]

Because the manager usually has little time to conduct detailed studies, the flow analysis might be very general and yield little valuable information.

A computer model that would help publishers anticipate results of proposed changes in equipment and procedures has been suggested by Dr. Robert Hacker of the Rochester Institute of Technology's School of Printing. The proposed model would allow plant changes to be evaluated under different work loads and manning conditions. The computer would simulate actual production conditions by running the job load through the equipment represented and point out the most efficient method.[12]

Dr. Hacker warns, however, large scale simulations might require a big, expensive computer. The computer capacity could be too costly for the publisher. He also points out that another consideration is the skill involved in designing, programming and validating such a computer model.[13]

Although these techniques may have drawbacks either in refinement or costs, they can be of great service to the production manager when evaluating the effectiveness of his production system.

FOOTNOTES FOR CHAPTER ONE

[1]David Shaw, "The Newspaper must be Fit to Survive," *Quill*, vol. 65, no. 2 (February, 1977), p. 13.

[2]*Ibid.*, p. 17

[3]*Ibid.*, p. 12.

[4]*Ibid.*, p. 11.

[5]*Ibid.*, p. 17.

[6]Frank W. Rucker and Herbert L. Williams, *Newspaper Organization and Management* (Iowa: Iowa State University Press, 1967), p. 132.

[7]*Ibid.*, p. 141.

[8]Alan Woods, *Modern Newspaper Production* (New York: Harper and Row Inc., 1963), p. 189.

[9]Eugene Buttrill, "Record Keeping - A Must Factor in Assuring Productivity in the Composing Room," *Newspaper Production*, vol. 5, no. 3 (March, 1976), p. 14.

[10]Frank Higgason, "Maintaining Productivity," *Graphic Arts Monthly*, vol. 45, no. 10 (October, 1973), p. 109.

[11]*Op. Cit.*, Eugene Buttrill.

[12]Robert G. Hacker, "Simulation - An Aid to Planning," *Technological Changes in Printing and Publishing* (Rochelle Park, N.J., 1973), p. 65.

[13]*Ibid.*, p. 72.

II. PROBLEM

Once all the mechanical departments of a newspaper were contained in one room. One printer was expected to be proficient at all tasks. Today the printer is a specialist and the backshop, prepress and press area, of the newspaper is divided into several departments.[1]

The camera department in many newspapers has been established over a long period of time by various supervisors, department heads, and top management. The system may have been good once but went bad because the nature of the department's operations changed without a change in the system.[2] The fact is, operating characteristics of enterprises continually change as the systems grow obsolete.[3]

The production manager must be able to detect when a system needs modifying. However, there are few tools available to the manager for evaluating the effectiveness of a production area such as the camera department.

The duties of the manager cannot be carried out in a strict orderly fashion, however. Because of the speed and complexity of the newspaper production process, he may have only a few minutes for any one task. Everything takes place concurrently, and because of the time factor, most problems are critical.[4]

The production manager's major concern, cutting costs, is a "sometime" thing. He can usually control costs only by observing closely the efforts of the individual worker and by juggling men to eliminate idle time.[5]

To further complicate the situation, the production manager is usually a man who has moved up from the ranks and probably has little detailed knowledge of more than one of the several trades in the newspaper business.[6]

Because of the time factor and skill of the manager involved, any production evaluation tool should be relatively simple and easy to work.

FOOTNOTES FOR CHAPTER TWO

[1]Allan Woods, _Modern Newspaper Production_ (New York: Harper and Row Inc., 1963), p. 3

[2]Norman Barish, _Systems Analysis for Effective Administration_ (New York: Funk and Wagnalls Co., 1951), p. 6.

[3]_Op_. _Cit_., Allen Woods, p. 7.

[4]_Op_. _Cit_., Allen Woods, p. 12.

[5]_Op_. _Cit_., Allen Woods, P. 190.

[6]_Op_. _Cit_., Allen Woods, p. 7.

III. HYPOTHESIS

If the functions of a newspaper camera department can be interpreted as service oriented, then a queueing model can be applied as a simple production tool to determine the operating characteristics of that department without the aid of a programmable computer.

Definition of Terms

Most of the terms used in the hypothesis have rather common meanings, but there are some that should be defined as they are to be used in this paper.

(1) "queueing model"

This term shall mean a series of mathematical expressions describing a system where customers (copy) arrive for service, wait for the service if it is not immediate, and leave the system after having been served.

(2) "simple"

This term shall mean the execution of the model will require no mathematical knowledge more advanced than high school algebra.

(3) "Operating characteristics"

This term refers to: (a) average amount of copy in the camera department per unit of time, (b) average amount

of copy waiting to be processed per unit of time, (c) average time for a piece of copy to enter and leave the department after being processed, (d) average time a piece of copy waits to be processed, (e) probability the department will be busy, (f) probability the system will be idle, (g) average time for a piece of copy to receive the actual service of the department.

Purpose

The purpose of this study is to demonstrate that a queueing model can be used by the newspaper production manager to monitor the operating effectiveness of the camera department.

The method proposed here is not meant to replace the previously mentioned techniques. Moreover, it is intended as a supplement to aid the production manager in his evaluation of production functions.

IV. LITERATURE REVIEW

Queueing models are descriptive models and have been developed along the lines of formal mathematics. Queueing theory is not normative since it will not tell us what we should do. Rather, it explains the behavior of a facility with respect to its capacity, configuration and load.[1] Queueing models are descriptive rather than normative because they do not provide optimum solutions to a problem. Moreover, they are explanatory models which can be used to determine the behavior of a certain arrangement of facilities.[2]

Queueing theory was originated to provide models to predict the behavior of systems that provide service for random demands. The earliest problem studied was telephone congestion.[3]

The pioneer of queueing theory was A. K. Erlang, a Danish mathematician, who, in 1909, wrote The Theory of Probabilities and Telephone Conversations. In work done later he noted a telephone system generally had either (1) Poisson input, exponential holding (service) times, and multiple channels, or (2) Poisson input, constant service times, and a single channel.[4]

Erlang was employed by the Danish Telephone Company in Copenhagen, Denmark where he worked to apply established

probability techniques to solve the problem of determining the optimum number of telephone lines to handle prescribed call frequencies.[5]

To interpret telephone conversations as queueing or waiting line problems, Erlang had to establish what would be meant by arrivals and servers. He established that the calls themselves were the arrivals, the sequence of the calls in time was the input stream, while the call duration was the service time. Therefore, the servers were the telephone circuits and lines, and the waiting line was the collection of uncompleted calls.[6]

The actual number of cables used by a telephone company is determined in this way. For example, if the company desired busy signals to occur only five per cent of the time, it would determine the number of channels or cables needed to leave customers waiting five per cent of the time.[7]

Erlang, also, is credited for the notation of stationary equilibrium, for the introduction of the balance-of-state equations, and for the first attempt at optimization of a queueing system.[8]

Work on the theory as applied to telephony continued after Erlang. Molina, in 1927, published his Application of the Theory of Probability to Telephone Trunking Problems. This was followed a year later by Thornton Fry's Probability and its Engineering Uses which expanded much of Erlang's early work. Felix Pollaczek, in the 1930's, did further

investigative work on Poisson input, arbitrary output, and single- and multiple-channel situations. At the same time, work was also being done in this area by Kolmogorov and Khintchine in Russia, by Crommelin in France, and by Palm in Sweden.[9]

Some of the recent contributions to the field of queueing theory have been made by D. R. Lindley on integral equations, N. T. Bailey, W. Lederman and G. E. Reuter on time-dependent solutions, L. Takacs on waiting time, D. R. Cox on supplementary variables, D. G. Chapernowne on the use of random walks, and S. Karlin and J. L. McGregor on birth-death processes.[10]

Telephony was the principal application of this theory until about 1950. Thereafter, numerous applications have been found. Particularly interesting is the application of queueing to aircraft landing problems. Clearly, in this case, the customers are the airplanes, the servers are the runways, and the holding pattern represents the waiting line.[11]

Other prominent applications of the theory are: (1) machine repair, (2) toll booths, (3) taxi stands, (4) inventory control, (5) loading and unloading ships, (6) production flow, (7) scheduling in hospitals, (8) and in the computer field with regard to program scheduling, time-sharing and system design.[12]

The Boeing Aircraft Company commissioned a queueing analyst to make a study involving clerks who serviced tool

cribs throughout Boeing's factory areas. There were sixty cribs scattered throughout three plants, each employing one to five clerks who carried tools to mechanics.[13]

The problem was that the company had no idea of the number of clerks that should be employed at each crib. Foremen complained there were not enough clerks, but management was under pressure to reduce overhead and, therefore, wanted to reduce the number of clerks employed.[14]

The goal of the study, then, was to establish the optimum number of clerks at each crib.

This situation also called for balancing the cost of the mechanics' idle time on the part of the clerks and no waiting time by the mechanics. The ideal solution would have been to eliminate all the idle time of the clerks and mechanics, but this would have been impossible since there was randomness in the system.[15]

The analyst set up the problem as a queueing system of multi-channel design. Next, by observation and data gathering, the basic characteristics of the system were determined; that is, input, service and queue discipline.[16]

From the data-gathering and observations, a decision was made to use a rather complex model, the M/M/c. This model assumed a Poisson arrival distribution and an exponentially distributed service rate with many channels and no limit on load capacity; hence, the designation M/M/c.[17]

Results of the analysis indicated management was correct in its decision to reduce the number of clerks.

Therefore, several clerks were fired or transferred and the analysis was made a permanent decision-making aid in the Boeing Company.[18]

Many times queueing analysis may not indicate such a clear path of action. Most times management must decide how much service capacity is required, the type facility that will provide optimum service and how to arrange the facilities. These kinds of decisions are where managers exercise the greatest control.[19]

Another example of how queueing theory has been applied is in the area of inventory control. The flow of material in and out of a store or warehouse involves variable supply and demand and is analagous, but perhaps not too obviously, to service and arrival in queueing theory. This interpretation of service and arrivals makes an inventory model different from those used in more traditional applications.

For example, orders entering the warehouse could be interpreted as arrivals and filling the requests as service. Therefore, service is regarded as instantaneous if the item requested is in stock. In this case, most service times would be rather small while a few would be quite long in the event an item must be ordered from the factory. Also, if the order is in stock, the waiting line would be zero while, on the other hand, if it is out of stock, the line would be rather long.[21]

Another view of the inventory problem could be that, perhaps, an order should be sent to the supply source each time an item is sold. If the inventory is large enough and if the average time to replace an item is less than the average time between orders by customers, then all orders would be filled instantaneously and there would be no unsatisfied customers; that is, no queues. However, the problem with this view of the situation is such a plan would involve a high cost of replenishing and carrying the inventory. The problem requires a policy of minimizing the total cost; that is, the inventory carrying cost, replenishment cost, and the cost of lost orders.[22]

Early work in the field of queueing theory gained momentum slowly, but today the trend has changed. The number of new papers in the field appearing in mathematical and engineering journals increases each year. Although much substantive work has appeared, most of the published articles are a variation of the established theme.[23]

Queueing theory was developed as a very practical subject, but most recent work has shown little practical value. Some analysts have called for theorists to become concerned about the application of the theory that has come about since 1950. In fact, Donald Gross and Carl Harris, professors at the George Washington University, contend the emphasis of the literature on exact solutions of queueing problems with elegant mathematical tricks must become secondary to the construction of models and the use of these techniques

in management decision-making. Moreover, they contend queueing theory must not be restricted by a lack of closed-form solutions, and that a problem solver cannot be frustrated by having to solve transform equations.[24]

The great advantage of queueing is the fast, efficient and precise mathematics. David Miller and Martin Starr, two management specialists, contend this is the preferred approach if the equations remain fairly simple and capable of straightforward solutions.[25]

C. F. Newell, a professor of engineering at the University of California at Berkley, contends queueing theory as a tool for practical analysis remains in a primitive state because the impetus given the theory is only in the direction of its "potential" applications. Furthermore, he states researchers have devoted "great efforts" to solving the wrong problems. The popularity of queueing theory, he contends, has centered on its mathematical aspects instead of applications, and the literature has grown from "solutions looking for a problem" instead of "problems looking for a solution".[26] Furthermore, Newell states that much of queueing theory literature has been written by probabilists who are interested in "nice mathematics and rigorous solutions".[27]

Professor Newell emphasizes the two techniques of fluid and diffusion approximations. The former technique uses graphical methods while the latter employs a mixture of graphical and elementary analysis. He does not use such

complex mathematics as generating functions, characteristic functions, or Laplace transforms which are common in other queueing theory methods.[28]

Newell suggests that, in many cases, only approximations are needed for decision-making. An industrial engineer seldom requires calculations of high precision or exactness in the mathematical sense. Many approximations operate on the assumption the queue length is longer than one (1.00) most of the time since, if the queue is not very long, no one will be concerned.[29]

When designing a queueing experiment, researchers must first recognize the detail arrival of customers will not be the same from day to day. Therefore, it is essential the researcher make observations over several days and take an average. The cumulative number of arrivals over a time long enough to contain many arrivals is the usual practice. Then the arrivals are assumed to be uniformly spaced over the time interval selected by the researcher.[30] Some researchers make observations over many arrivals but repeat the study at another time and take the average.[31]

No matter how detailed a queueing study may be, the probability distributions yielded will still contain unknown parameters, but in an approximate analysis, the effects may be disregarded.[32]

Most of the mathematics in queueing theory is concerned with equilibrium queue distribution (steady state)

on the premise of steady arrivals and departures with "the arrival rate less the maximum service rate". Under such a condition, an approximation might indicate no customers in the waiting line. However, despite the fact approximations may not account for certain factors, they do give reasonable answers to important practical problems since most problems of this type are largely concerned with the total delay in the system.[33]

The queueing analyst's job usually involves determining the measures of effectiveness (operation characteristics) or designing an optimal system. The former involves relating waiting delays, waiting line lengths, etc. to the properties of the input stream and service procedures. To design a system, however, the analyst must balance customer waiting time against the idle time of servers along the line of some "inherent cost structure". Also, in designing a system, the analyst must plan space for the waiting line or queue. In this case, he must determine the possible size of the queue and consider the space cost along with the idle time costs to establish the optimal design. In any event, the analyst will attempt to solve the problem by analytical means, but, if this method fails, simulation must be used.[34]

Finally, any review of queueing literature should touch on the notation system used by analysts. It is important to know how the notation works in order to understand the model being discussed. The shorthand notation system was

developed by analysts in the early 1950's. In most cases, only the first three symbols are used.[35] Presently, the common practice is to omit the notation for service capacity if there is no restriction and to skip the stipulation of the service discipline if it is first-in-first-out. For example, a M/D/2 model would represent a system with exponential input (M), deterministic service (D), two servers (2), no limit on service capacity, and the service discipline is first-in-first-out.[36]

A rather recent development in queueing theory is the study of the psychological factors involved in the system. For example, customers arriving at a barber shop are happy to find no waiting line, but the shop owner may not be since this may suggest he has excess capacity or has overexpanded. The owner may also be concerned with the shop's image; that is, the shop may appear unpopular since it is not crowded with customers.[37] Thus far, little work has been done in this area.

FOOTNOTES FOR CHAPTER FOUR

[1]David Miller and Martin Starr, Executive Decisions and Operations Research (Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1969), p. 193.

[2]Ibid., p. 194.

[3]Ibid.

[4]Donald Gross and Carl Harris, Fundamentals of Queueing Theory (New York: John Wiley and Sons, 1974), p. 10.

[5]Ibid., p. 12.

[6]Ibid.

[7]Ibid.

[8]Ibid., p. 11.

[9]Ibid.

[10]Ibid.

[11]Ibid., p. 13.

[12]Ibid., p. 11.

[13]Ibid., p. 436.

[14]Ibid., p. 437

[15]Ibid.

[16]Ibid., p. 451

[17]Ibid.

[18]Ibid.

[19]Op. Cit., Miller and Starr, p. 196.

[20]Clifford Spring et al., Probabilistic Models (Homewood, Illinois: Richard Irwin, Inc., 1968), Vol. 4, p. 209.

[21] *Ibid*., p. 210

[22] *Ibid*.

[23] *Op. Cit*., Gross and Harris, p. 11.

[24] *Ibid.*

[25] *Op. Cit*., Miller and Starr, p. 362.

[26] C. F. Newell, *Applications of Queueing Theory* (London: Chapman and Hall Ltd., 1971), p. vii.

[27] *Ibid*., p. 10.

[28] *Ibid*., p. iX.

[29] *Ibid*., p. 10.

[30] *Ibid*., p. 20.

[31] *Ibid*., p. 21.

[32] *Ibid*.

[33] *Ibid*., p. 22.

[34] *Op. Cit*., Gross and Harris, p. 8.

[35] *Ibid*., p. 11.

[36] *Ibid*., p. 12.

[37] *Op. Cit*., Spring *et*. *al*., p. 182.

V. THEORY

Generally, there are three classes of models: physical, schematic and analytical.

Some examples of physical models are scale models of airplanes, ships and factories.

Some examples of schematic models are organization charts, process and flow charts, Gantt charts and wiring diagrams.

Some examples of analytical models are mathematical equations used in inventory or queueing theory or flow charts used to represent the logical processes in computer simulation.[1]

These models are used to derive solutions to problems by physically or mathematically manipulating the model.

It is easy, in most cases, to use a physical model to measure things such as force, length, and time and to extrapolate the results to the real world by using established conversion factors. However, when using schematic and analytical models, conversion factors are often not readily available. For example, a researcher can not be positive conclusions derived from a small military organization such as a platoon will be accurate when applied to a battalion.[2]

When there is doubt about the validity of a model, the best course of action is to judge or observe its usefulness

to the decision-maker in conducting operations. Even if the results are not valid, many times insight gained into the problem is more valuable.[3]

There are many different queueing models designed to measure different kinds of systems and problems. It is important to use the model that best describes the system under study. Most real problems do not conform exactly to these mathematical models, but very little literature deals with approximate solutions and sensitivity analyses.[4]

Pioneered by Danish mathematician A. K. Erlang in 1909, this type of mathematical theory is a branch of applied probability theory. It is known under the names of traffic theory, queueing theory, congestion theory, the theory of mass service and the theory of stochastic service systems. Queueing is the name used to designate those theories that describe the more specialized theory of waiting lines, queues.[5]

A preliminary observation of the camera department to be studied was made and the following discussion describes the model that perhaps most effectively and simply describes the service system. A description of the camera department follows this discussion of the model.

The queueing model to be used in this study has been designated by queueing analysts as the M/M/1 model. This designation means the system to which it is applied will have a Poisson distributed arrival rate, an exponentially distributed service rate, one server, no restriction on system

capacity and the service discipline is first-in-first-out or FIFO.[6]

The mathematical theory behind this model is extremely complex and requires a knowledge of differential and integral calculus, differential equations and other "higher" mathematical topics such as transforms, difference equations and Markov processes. A discussion of the theory from this point of view is beyond the scope of this study. It is not necessary to understand the theories to intelligently evaluate queueing systems. In this case, a description of the model should suffice.[7]

This queueing model views a system in terms of customers, servers, service mechanism, number of channels and service discipline.

The person or element that needs a service is called the customer.

The element that performs a service needed by a customer is designated the server.

The server and the manner he is set up to perform the service is called the service mechanism.

A group of servers that perform the services needed by a customer is called a channel. When a channel contains only one server, as in this case, the distinction between the two is immaterial.[8]

The waiting line is all the customers waiting to be served.

The service discipline is the manner in which the customers are selected from the waiting line; for example, FIFO.[9]

The first step in evaluating a queueing system is to study the pattern of customer arrival. The Poisson distribution is used as the theoretical model. However, the arrival pattern most likely will be a crude approximation of this distribution.

The Poisson distribution can be used as a valid model for the customer arrival pattern if the following requirements are met.

(1) The arrival pattern must be random.

(2) The probability of an arrival in any small interval must not be influenced by the history of the previous arrivals.

(3) The probability of an arrival must be proportional to the length of the very small intervals.[10]

A convenient feature of making the Poisson assumption is that the entire probability distribution of the pattern of customer arrivals is automatically available once the average number of arrivals for a given time interval has been determined.[11]

Once the empirical and theoretical probability distributions of customer arrivals have been determined, there are elegant statistical procedures for testing the reasonableness of the Poisson assumptions. However, it is suggested the assumptions be evaluated by comparing graphs of the theoretical and empirical probabilities.[12]

The theoretical model for the service time is the exponential probability distribution. This is a common assumption and appropriate if a large number of customers require a shorter time to service and a small number of customers require a long service time.

Just as with the Poisson distribution and the arrival rate, the service times will not likely be exactly exponentially distributed but the difference will probably not be significant.[13]

A factor that influences the operating characteristics of a queueing system is the length of time over which the system has been in operation. But describing these operating characteristics as a function of this time span is very difficult even with the most rigorous mathematics. Usually the operating characteristics tend to stabilize as the elapsed time in question becomes longer. There is no need to be concerned about the time factor if the queueing system is assumed to have been in operation a long time. In such a case, its characteristics are not dependent on the elapsed time factor and the system is said to be in a steady state or has statistical equilibrium.

To apply this single channel model to a queueing system the following four assumptions must be satisfied.

(1) Customer arrivals must be Poisson distributed.

(2) The service time must be exponentially distributed.

(3) Customers can not leave the waiting line once they have entered.

(4) The service discipline must be first-in-first-out (FIFO).

The ratio between the average arrival rate and the average service rate is called the traffic intensity ratio. The higher this ratio becomes, the greater the chance of having a long waiting line. This ratio plays a major role in defining the operating characteristics of the system.

When a customer enters a system, the system is either busy and he must wait, or it is not busy, and he can be processed immediately. If the service mechanism is busy, the system is said to be in a busy period and the probability associated with this period is called the busy period probability.

Another convenient feature of the single channel system is the busy period probability is the same as the traffic intensity ratio. "1.00 minus the busy period probability" will yield the probability the system will be idle.[14]

After the M/M/1 model has been satisfied, several statistical formulas can be manipulated to yield the following operating characteristics per unit of time.

(1) Average number of customers in the system.

(2) Average number of customers in the waiting line.

(3) Average time required for a customer to enter and leave the system after receiving the service.

(4) Average time a customer will spend in a queue.

(5) The probability the system will be busy.

(6) The average time for a customer to receive the actual service.[15]

FOOTNOTES FOR CHAPTER FIVE

[1]John Paul Young, "A Queueing Theory Approach to the Control of Hospital Inpatient Census" (unpublished Ph.D. dissertation, School of Engineering, The Johns Hopkins University), p. 112.

[2]Ibid., p. 113

[3]Ibid., p. 114.

[4]C. M. Harris and Donald Gross, Fundamentals of Queueing Theory (New York: John Wiley and Sons, 1974), p. 11.

[5]Robert B. Cooper, Introduction to Queueing Theory (New York: The Macmillan Company, 1972), p. 2.

[6]Op. Cit., Harris and Gross, p. 9.

[7]Op. Cit., Harris and Gross, p. Viii.

[8]Chaiho Kim, Quantitative Analysis for Managerial Decisions (Reading, Mass.: Addison-Wesley Publishing Co., 1976), p. 328.

[9]Ibid., p. 329.

[10]Ibid., p. 331.

[11]Ibid., p. 332.

[12]Ibid., p. 333.

[13]Ibid., p. 334.

[14]Ibid., p. 337.

[15]Ibid., p. 339.

VI. A DESCRIPTION OF THE SYSTEM

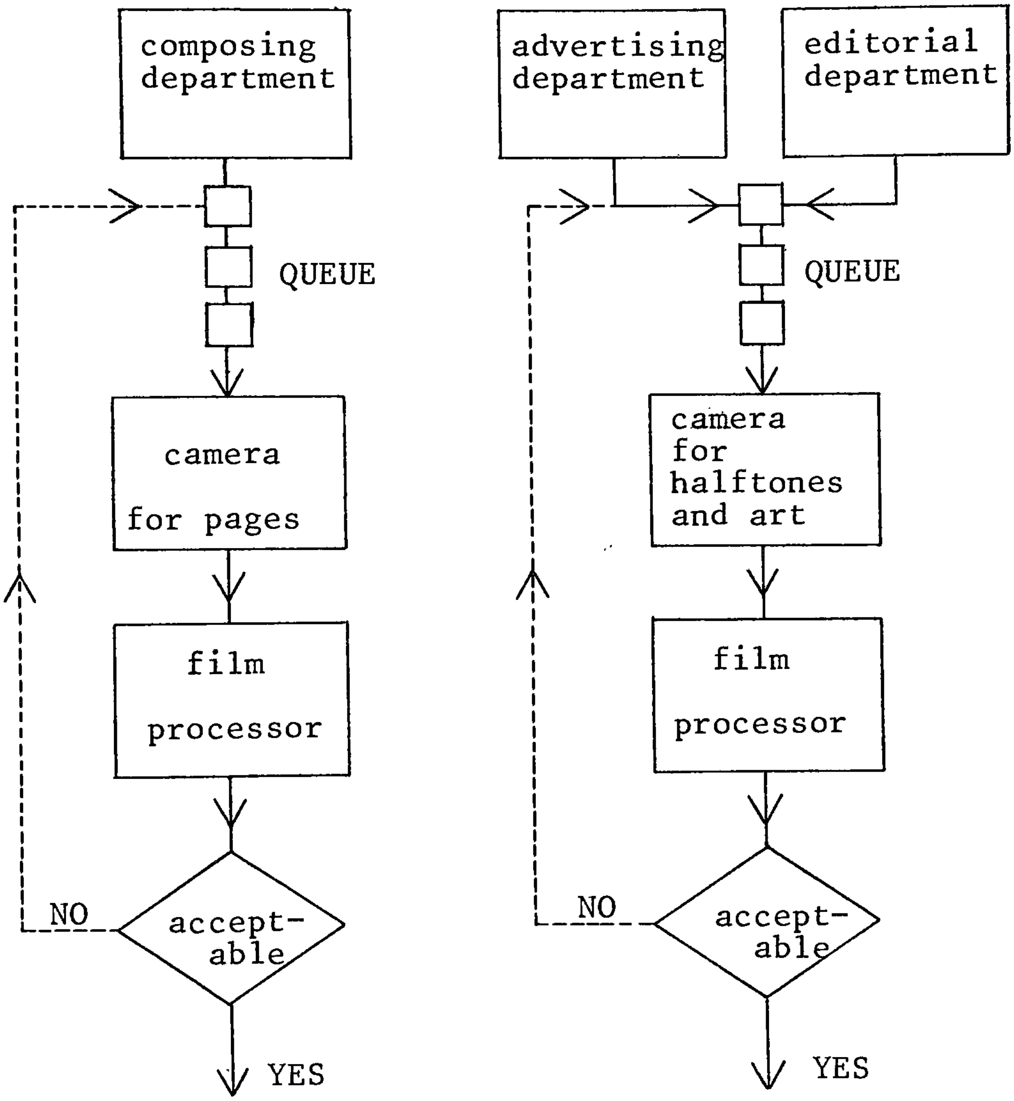


Figure 1.
Schematic of the System.

The department described above assigns specific duties to each camera. One camera is used only to reproduce art work and halftones while the other is devoted solely to handling pasted-up pages. One operator is assigned to each camera.

Both cameras are Chemco Spartan III's with their own slave processors. The processors were Log E's with Automatic film conveyors.

The goal here is to increase speed and efficiency by reducing confusion and copy backlogs.

Since each camera has its own processor and operator, the operation of each camera is independent of the other. Therefore, the system appears to contain two channels instead of one. However, to maintain simplicity, the system can be interpreted as having two one-channel queueing systems.

The department houses the camera operations of two newspapers, but the operations are not simultaneous; one is a morning paper while the other publishes evening editions. The morning paper is the one to be studied here.

The shift runs an average of nine hours from 4 p.m. to about 1:30 a.m. with staggered dinner hours.

Copy clerks deliver artwork and continuous tone copy to the camera department, and the composing department delivers its pages to the page camera queue. The copy is shot by the respective operators, and the film is passed via an automatic conveyor system into the appropriate processor. Once the film enters the processor, it is considered to be

out of the queueing system, unless, of course, it has not been serviced properly.

The negative is visually inspected for desired dot quality and a densitometer reading is taken. If the negative is judged faulty, it is sent back to the waiting line to be shot over.

A high error rate could greatly increase the size of the queue. The quality standards, also, may not be as rigorously applied if the camera operator is anxious to reduce an already large queue.

VII. METHODOLOGY AND RESULTS

This study was carried out over a two week period in the camera department of a medium size newspaper, circulation 60,000.

Before the study was begun, a meeting was held with top management of the newspaper. The purpose and methodology of the study was explained and questions were answered.

A general explanation of the study was given to the camera department personnel. An attempt was made to enlist the confidence of the personnel who were wary of the study. For example, it was explained that the information collected could be used by management to determine if faster equipment should be purchased or an extra worker hired.

Beginning on the first workday of the week, two Simplex stamp clocks were placed in the camera department. One clock was positioned at the point where copy entered the department and the other at a point where departing copy could be conveniently logged out.

The clocks were used to record the arrival and departure time on the back of the order slip that accompanied each piece of halftone/artwork copy.

Pasted-up pages were logged in and out on 4" x 5" note cards.

The pages were logged out of the system after they left the processing machine. However, since the copy was considered to be out of the system as it entered the processor, the processing time was subtracted from the total time.

Each of the cameras was treated as a separate queueing system since neither had any relationship to the other. In effect, they were separate entities (i.e., the operation of one had no bearing on the operation of the other). This interpretation also served to keep the analysis on a rather simple basis.

At the end of each day, the arrival and departure time of each piece of copy processed was tabulated. This was done each day of the week.

The shift was divided into half hour intervals and the arrival time of a particular piece of copy determined the interval into which it fell. In this manner, the arrival distribution of processed copy for both channels was determined on a weekly basis. See Tables 1 and 2 on pages 35 and 36.

The average arrival rate of the two samples for the page channel was then calculated. It was found that, on the average, 2.71 and 2.79 pages arrived during any half hour interval during the first and second week, respectively. See Tables 1 and 2.

Once the average arrival rates were determined, the theoretical distributions were readily available from a table of Poisson probabilities. The Poisson table specifies a

CALCULATION OF FIRST WEEK

PAGE AVERAGE ARRIVAL RATE

Number of pages per interval	number of intervals	Product of two columns
0	11	0
1	25	25
2	28	56
3	23	69
4	20	80
5	10	50
6	6	36
7	1	7
8	1	8
9	0	0
10	1	10
	126	$341 \div 126 = 2.71$ (average arrival rate)

Table 1.

CALCULATION OF SECOND WEEK

PAGE AVERAGE ARRIVAL RATE

Number of pages per interval	Number of intervals	Product of two columns
0	7	0
1	26	26
2	29	58
3	27	81
4	19	76
5	6	30
6	4	24
7	3	21
8	2	16
9	1	9
10	1	10
	126	$351 \div 126 = 2.79$ pages/.5 hr. (arrival rate).

Table 2.

theoretical distribution for a particular average. See Tables 3 and 4 on pages 38 and 39.

The empirical distributions of both samples from the page channel roughly approximated the theoretical Poisson distribution. See Figures 2 and 3 on pages 40 and 41.

Kim indicates that a visual comparison of the two distributions, theoretical and actual, is a legitimate method for determining whether the situation fits the model being used. This is the method recommended for busy managers who have neither the time or statistical knowledge to run goodness-of-fit tests.[1] Gross and Harris indicate that crude approximations can, indeed, be derived even if the empirical distribution is not Poisson.[2] However, these approximations should be used with great caution and never construed as true characteristics of the system.

In this case, Chi Square Goodness-of-fit tests were run to lend more credence to the assumption of Poisson distributed arrivals.[3] The tests indicated there were no significant differences between the theoretical and empirical arrival distributions of copy for the page camera channel during both weeks of observation. See Tables 5 and 6 on pages 42 and 43.

By subtracting the arrival time from the departure time of each piece of copy, the service time for that copy was derived. Once the service time for each piece of copy had been obtained, empirical distributions of the service times for the copy of both weeks' samples were constructed. See Tables 7 and 8 on pages 44 and 45.

FIRST WEEK PAGE ARRIVAL DISTRIBUTION:

EMPIRICAL VS. THEORETICAL

Number of pages per interval	number of intervals	Empirical Probability	Theoretical probability
0	11	.0873	.0672
1	25	.1984	.1815
2	28	.2222	.2450
3	23	.1825	.2205
4	20	.1587	.1488
5	10	.0794	.0804
6	6	.0476	.0362
7	1	.0079	.0139
8	1	.0079	.0047
9	0	.0000	.0014
10	1	.0079	.0004
	126		

Table 3.

SECOND WEEK PAGE ARRIVAL DISTRIBUTION:

EMPIRICAL VS. THEORETICAL

Number of pages per interval	Number of intervals	Empirical Probability	Theoretical Probability
0	7	.0556	.0672
1	26	.2063	.1815
2	29	.2302	.2450
3	27	.2143	.2205
4	19	.1508	.1488
5	6	.0476	.0804
6	4	.0317	.0362
7	3	.0238	.0139
8	2	.0159	.0047
9	1	.0079	.0014
10	1	.0079	.0004
	126		

Table 4.

FIRST WEEK'S PAGE ARRIVAL DISTRIBUTION

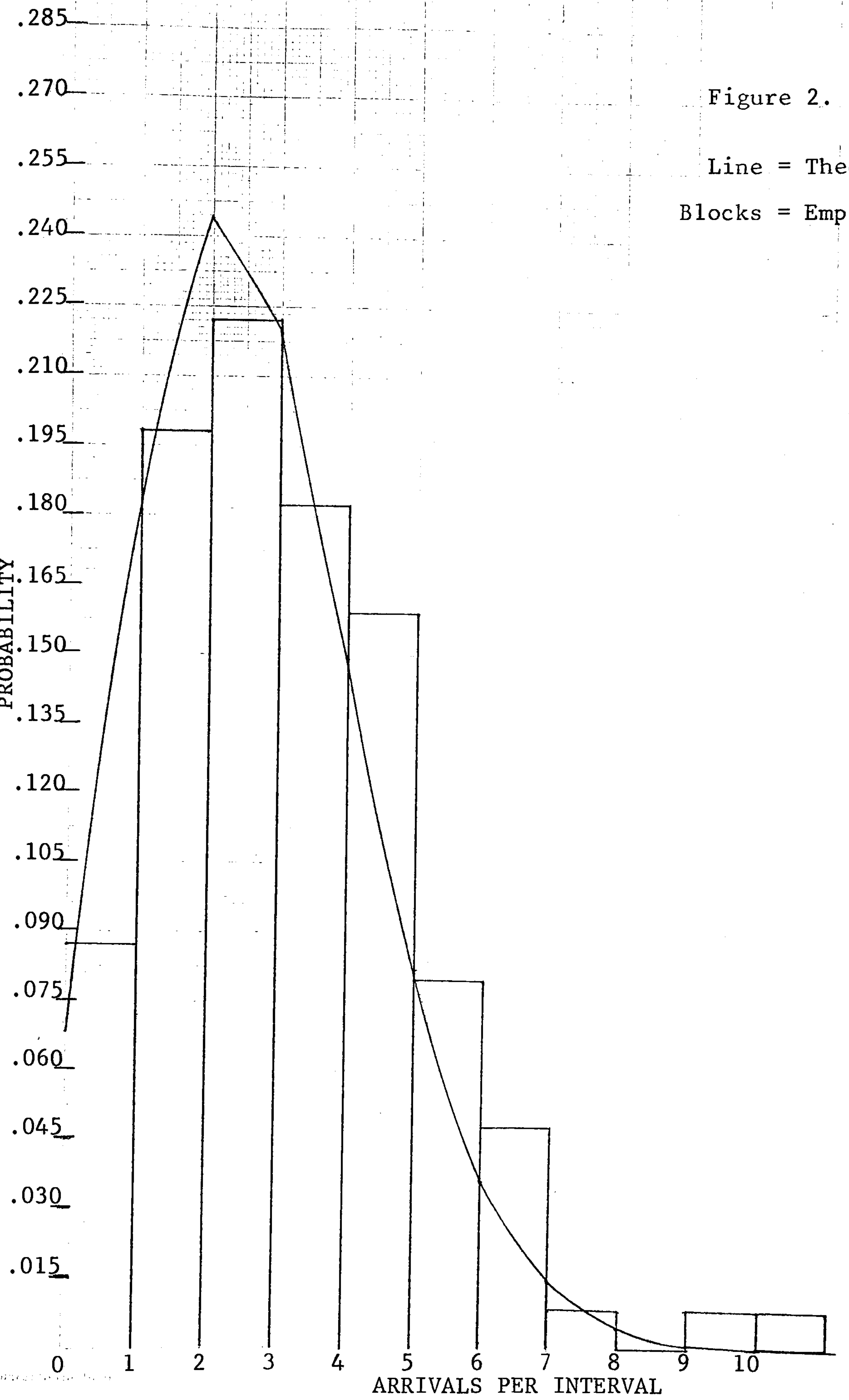
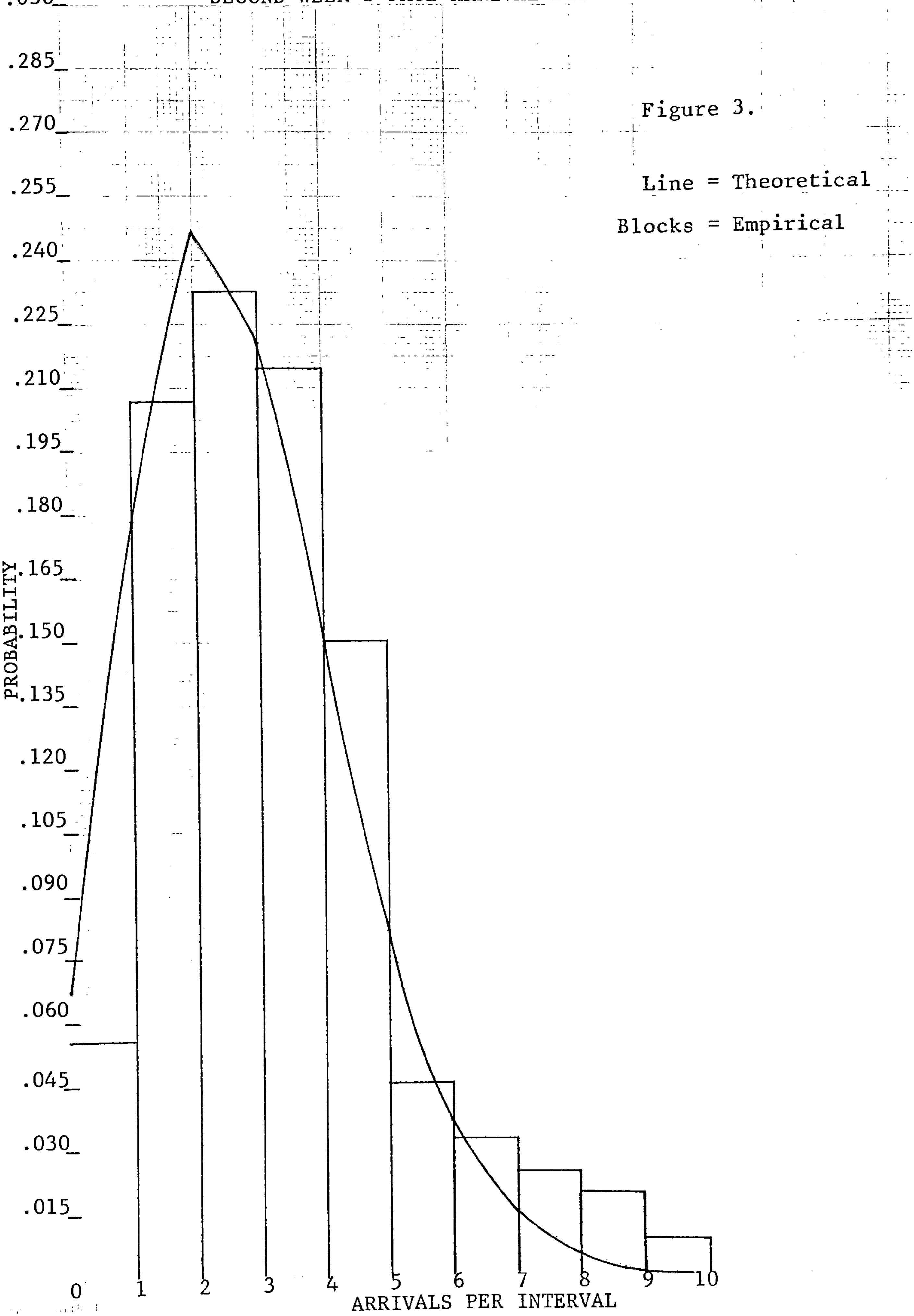


Figure 2.

Line = Theoretical

Blocks = Empirical

SECOND WEEK'S PAGE ARRIVAL DISTRIBUTION



CHI SQUARE GOODNESS-OF-FIT TEST

FOR FIRST WEEK PAGE ARRIVALS

Number of Pages per interval	Empirical distribution	Theoretical distribution	Difference
0	11	8.47	2.53
1	25	22.87	2.13
2	28	30.87	2.87
3	23	27.78	4.78
4	20	18.75	1.25
5	10	10.13	.13
6+	9	7.13	1.87
	126	126	

$(\text{Difference})^2$	$\frac{(\text{Difference})^2}{\text{Theoretical}}$
6.40	.76
4.54	.20
8.24	.27
22.85	.82
1.56	.08
.02	.002
3.50	.491
	2.623 = Calculated Chi Square value

The Chi Square table value for a 7 cell table with 1 degree of freedom at the 95% level of confidence is 12.5916. In this case, the null hypothesis that there is no difference between the two distributions should be accepted.

Table 5.

CHI SQUARE GOODNESS-OF-FIT TEST FOR

SECOND WEEK PAGE ARRIVALS

Number of Pages Per Interval	Empirical Distribution	Theoretical Distribution	Difference
0	7	8.47	1.47
1	26	22.87	3.13
2	29	30.87	1.87
3	27	27.78	.78
4	19	18.75	.25
5	7	10.13	3.13
6+	11	7.13	3.87
	126	126	

$(\text{Difference})^2$	$\frac{(\text{Difference})^2}{\text{Theoretical}}$
2.16	.26
9.80	.43
3.50	.11
.61	.02
.06	.003
9.80	.967
14.98	2.101
	3.891 = Calculated Chi Square Value.

The Chi Square table value for a 7 cell table with 1 degree of freedom at the 95 per cent level of confidence is 12.5916. Since the calculated value is less than the table value, the null hypothesis that there is no difference between the two distributions should be accepted.

Table 6.

FIRST WEEK PAGE SERVICE CALCULATIONS

Assumed average service minutes	Number of pages	Product of two columns
1	11	11
3	108	324
5	98	490
7	48	336
9	28	252
11	19	209
13	14	182
15	12	180
17	13	221
19	7	133
21	5	105
23	3	69
25	2	50
	368	2562

2562 ÷ 368 = 6.96 minutes = average service time/page

30 ÷ 6.96 = 4.31 pages per half hour = service rate

Table 7.

SECOND WEEK PAGE SERVICE CALCULATIONS

Assumed average service time	Number of pages	Product of two columns
1	3	3
3	158	474
5	112	560
7	34	238
9	28	252
11	18	198
13	10	130
15	6	90
17	2	34
19	2	38
21	1	21
23	1	23
25	1	25
	376	2077

$2077 \div 376 = 5.52$ minutes = average service time/page.

$30 \div 5.52 = 5.53$ pages per half hour = average service rate.

Table 8.

By substituting the known values, average service rate and the lower and upper limits of the time span, into the formula $e^{-u(T_1)} - e^{-u(T_2)}$, the theoretical exponential probability distributions were calculated.[4] See Tables 9 and 10 on pages 47 and 48.

This formula views the average service rate as a negative value that is multiplied by the lower limit of the time span that lies around a particular assumed average. The product of this operation is used as a negative power of the natural log, e. The second part of the formula functions in the same manner with the negative service rate being multiplied by the upper limit of the time span. When the two natural log values are determined and subtracted from one another, the difference represents the theoretical probability for that particular time span.

The theoretical exponential service distributions were then compared visually against the empirical distributions. See Figures 4 and 5 on pages 49 and 50. The two distributions appear to be dissimilar for both page channel samples. The empirical service times seem to be much longer than they theoretically should be. However, goodness-of-fit tests were run to determine if they were significantly different from the theoretical.

The Kolmogorov-Smirnov Goodness-of-fit Test for Exponential Distributions was used.[5] See Tables 11 and 12 on pages 51 and 52.

The service times were divided into two cells instead of thirteen because the probabilities, both empirical and theoretical, became extremely small as the service time increased.

DETERMINATION OF THEORETICAL EXPONENTIAL SERVICE DISTRIBUTIONS

<u>Formula</u>

Probability = $e^{-u(T_1)} - e^{-u(T_2)}$

<u>Definition of Variables</u>

(1) e = natural log (2.718)

(2) $-u$ = average service rate (expressed as a negative value).

(3) t_1 = lower limit of time span.

(4) t_2 = upper limit of time span.

<u>Distribution for page Channel - First Week Sample</u>

Service minutes required		Theoretical Distribution
0 - 2	$2.718^{-4.31(0)}-2.718^{-4.31(2)}$ =	.9998
2 - 4	$2.718^{-4.31(2)}-2.718^{-4.31(4)}$ =	.0002
4 - 6	$2.718^{-4.31(4)}-2.718^{-4.31(6)}$ =	.0000
6 - 8	$2.718^{-4.31(6)}-2.718^{-4.31(8)}$ =	.0000
8 - 10	$2.718^{-4.31(8)}-2.718^{-4.31(10)}$ =	.0000
10 - 12	$2.718^{-4.31(10)}-2.718^{-4.31(12)}$ =	.0000
12 - 14	$2.718^{-4.31(12)}-2.718^{-4.31(14)}$ =	.0000
14 - 16	$2.718^{-4.31(16)}-2.178^{-4.31(18)}$ =	.0000
16 - 18	$2.718^{-4.31(16)}-2.718^{-4.31(18)}$ =	.0000
18 - 20	$2.718^{-4.31(18)}-2.718^{-4.31(20)}$ =	.0000
20 - 22	$2.718^{-4.31(20)}-2.718^{-4.31(22)}$ =	.0000
22 - 24	$2.718^{-4.31(22)}-2.718^{-4.31(24)}$ =	.0000
24 - 26	$2.718^{-4.31(24)}-2.718^{-4.31(26)}$ =	.0000

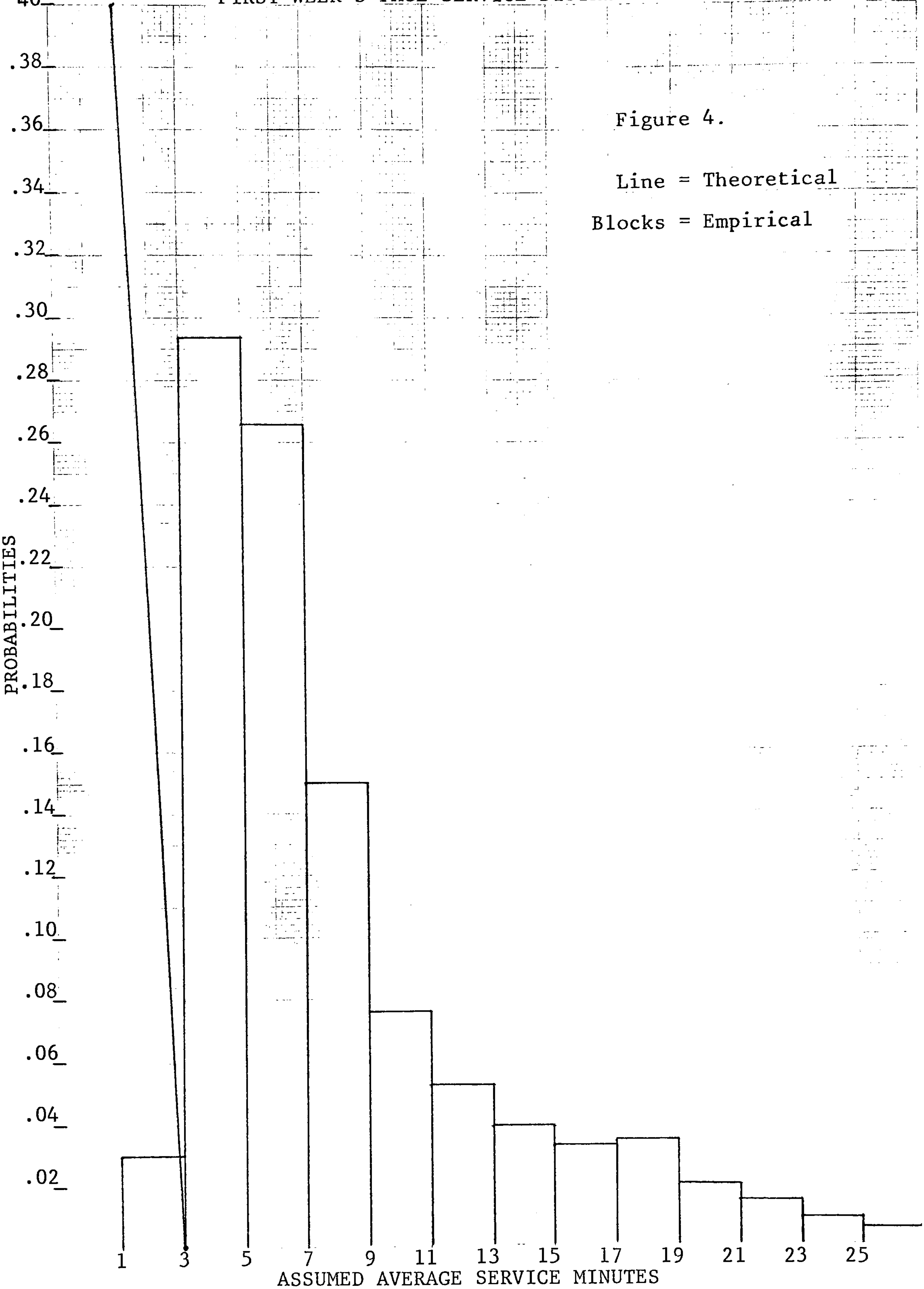
Table 9.

Distribution for Page Channel - Second Week Sample

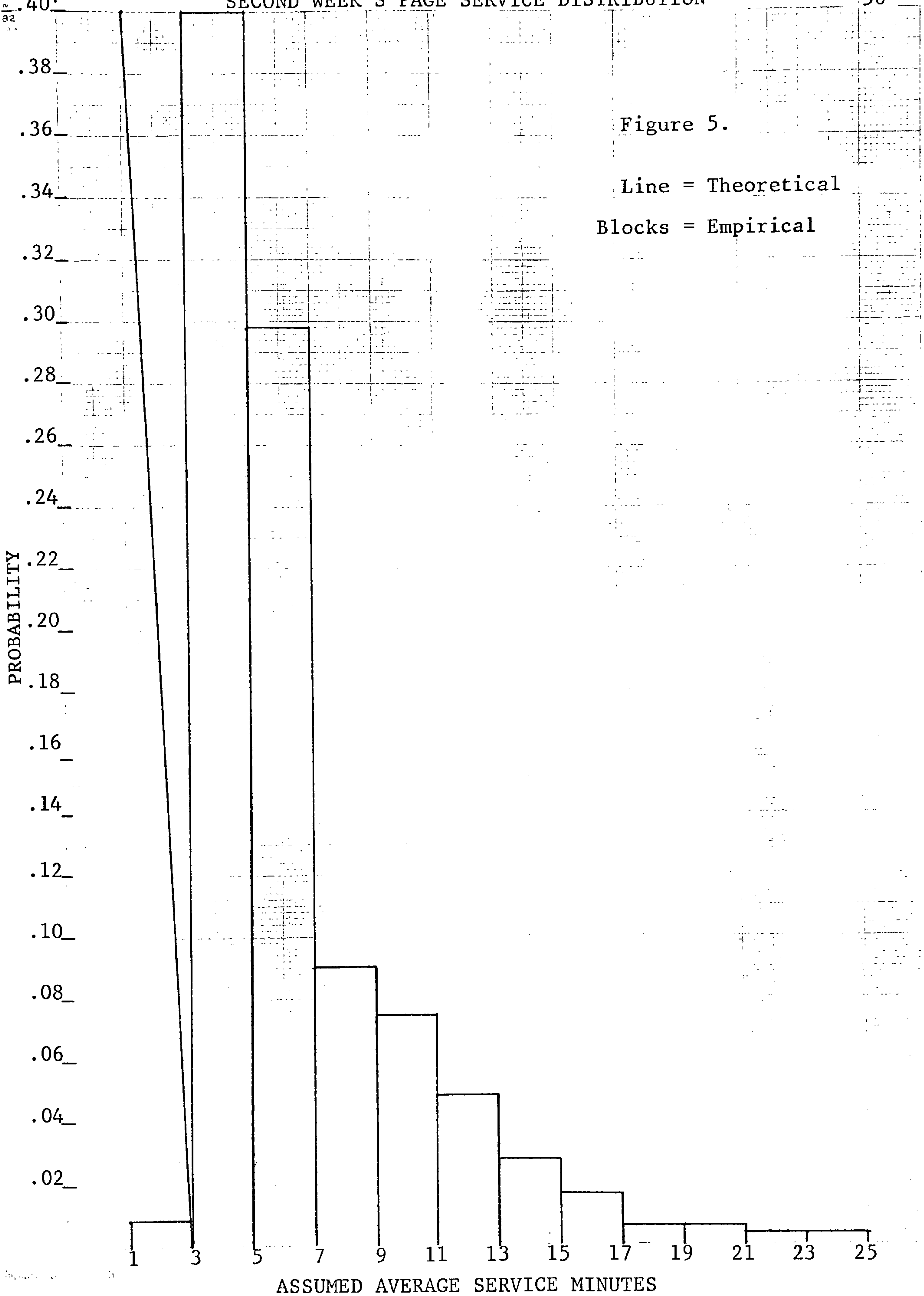
Service minutes required			Theoretical Distribution
0 - 2	$2.718^{-5.43(0)} - 2.718^{-5.43(2)}$	=	.99998
2 - 4	$2.718^{-5.43(2)} - 2.718^{-5.43(4)}$	=	.00002
4 - 6	$2.718^{-5.43(4)} - 2.718^{-5.43(6)}$	=	.00000
6 - 8	$2.718^{-5.43(6)} - 2.718^{-5.43(8)}$	=	.00000
8 - 10	$2.718^{-5.43(8)} - 2.718^{-5.43(10)}$	=	.00000
10 - 12	$2.718^{-5.43(10)} - 2.718^{-5.43(12)}$	=	.00000
12 - 14	$2.718^{-5.43(12)} - 2.718^{-5.43(14)}$	=	.00000
14 - 16	$2.718^{-5.43(14)} - 2.718^{-5.43(16)}$	=	.00000
16 - 18	$2.718^{-5.43(16)} - 2.178^{-5.43(18)}$	=	.00000
18 - 20	$2.718^{-5.43(18)} - 2.178^{-5.43(20)}$	=	.00000
20 - 22	$2.718^{-5.43(20)} - 2.178^{-5.43(22)}$	=	.00000
22 - 24	$2.718^{-5.43(22)} - 2.178^{-5.43(24)}$	=	.00000
24 - 26	$2.178^{-5.43(24)} - 2.178^{-5.43(26)}$	=	.00000

Table 10.

FIRST WEEK'S PAGE SERVICE DISTRIBUTION



SECOND WEEK'S PAGE SERVICE DISTRIBUTION



KOLMOGOROV-SMIRNOV GOODNESS-OF-FIT TEST
FOR EXPONENTIAL DISTRIBUTION OF FIRST WEEK
PAGE SERVICE TIMES

Service Minutes Required	Empirical Cumulative Distribution	Theoretical Cumulative Distribution	Absolute Difference
0 - 2	.03	.9998	.9698
2 - 26	1.00	1.0000	0.0000

Dmax. = .9698 = Calculated Kolmogorov-Smirnov value.

The Kolmogorov-Smirnov table value for a distribution with a sample size of 368 pages at the 95 percent confidence level is 1.06, therefore, the null hypothesis that there is no significant difference between the two distributions must be accepted.

Table 11.

KOLMOGOROV-SMIRNOV GOODNESS-OF-FIT TEST

FOR EXPONENTIAL DISTRIBUTION

OF SECOND WEEK PAGE SERVICE TIME

Service minutes required	Empirical cumulative Distribution	Theoretical cumulative Distribution	Absolute difference
0 - 2	.008	.99998	.99198
2 - 26	1.00	1.000	0.000

Dmax = .99198

The number of samples or pages in this case was 376. The Kolmogorov-Smirnov table value for a distribution with a sample size of 276 pages at the 95% level of confidence is 1.06. In this case, the null hypothesis that there is no significant difference between the two distributions should be accepted.

Table 12.

See Tables 13 and 14 on pages 54 and 55. By dividing both the empirical and theoretical distributions into two cells, more significance, larger differences between the two distributions, could be obtained.

This particular goodness-of-fit test requires the empirical and theoretical probabilities be tablulated in a cummulative fashion and the absolute differences between each of the distribution's values be taken for each time span. The greatest absolute difference, D_{max}, represents the calculated Kolmogorov-Smirnov value.[6] See Tables 11 and 12 on pages 51 and 52.

This difference was .9698 for the first week's page channel and .99198 for the second week.

These values were then compared with the Kolmogorov-Smirnov Exponential Table values. The table value for the first week's page channel which serviced a sample size of 368 was 1.06 at the 95 per cent level of confidence. The second week's page channel serviced a sample size of 376 and its table value was 1.06, also, at the 95 per cent level of confidence. Since the table values are greater than the calculated values, the null hypothesis that there is no significant difference between the theoretical and empirical distributions must be accepted.

Since it was then established statistically that the arrival and service distributions were, in fact, Poisson and exponential, respectively, the analysis should have yielded close approximations of the channel's operating characteristics for the two weeks.

FIRST WEEK PAGE SERVICE:

THEORETICAL VS. ACTUAL DISTRIBUTION

Service Minutes Required	Number of Pages	Empirical Probability	Theoretical Probability
0 - 2	11	.03	.9998
2 - 4	108	.294	.0002
4 - 6	98	.266	0.0000
6 - 8	48	.130	0.0000
8 - 10	28	.076	0.0000
10 - 12	19	.052	0.0000
12 - 14	14	.038	0.0000
14 - 16	12	.033	0.0000
16 - 18	13	.035	0.0000
18 - 20	7	.019	0.0000
20 - 22	5	.014	0.0000
22 - 24	3	.008	0.0000
24 - 26	2	.005	0.0000
	368		

Table 13

SECOND WEEK PAGE SERVICE:

THEORETICAL VS. ACTUAL DISTRIBUTION

Service minutes required	Number of pages	Empirical probability	Theoretical probability
0 - 2	3	.008	.99998
2 - 4	158	.42	.00002
4 - 6	112	.298	0.0
6 - 8	34	.09	0.0
8 - 10	28	.074	0.0
10 - 12	18	.048	0.0
12 - 14	10	.027	0.0
14 - 16	6	.016	0.0
16 - 18	2	.005	0.0
18 - 20	2	.005	0.0
20 - 22	1	.003	0.0
22 - 24	1	.003	0.0
24 - 26	1	.003	0.0
	376		

Table 14.

Having calculated the average arrival and service rates, the two values were then substituted into a series of equations to determine the operating characteristics. These equations represent the m/m/1 queueing model mathematically.[7] See Table 15 on page 57.

For a detailed view of the operations, see Tables 15 and 16 on pages 57 and 58. Table 15 defines the variable and lists the equations. Table 20 demonstrates how the equations were used to determine the various operating characteristics. Following is a brief summary of the results.

The ratio between the average arrival rates and average service rates yielded the busy period probabilities. This probability was .63 for the first week's page channel and .51 for the second week. See Number 1 in Table 16. These probabilities express the chance the channel will be busy in any interval during the work week. More specifically, it represents the chance the channel will be busy when a piece of copy arrives for processing.

Once the busy period probability of each sample was established, it was quite easy to determine the amount of time the channel was busy during the week by multiplying these probabilities by the number of hours in the work week. It was determined that the page channel was busy 39.69 hours (39 hours and 41 minutes) during the first week and 32.13 hours (32 hours and 8 minutes) during the second week. See Number 2 in Table 16.

DEFINITION OF VARIABLES

(1) Bp = Busy Period Probability.

(2) B_t = Time System was Busy.

(3) I_p = Idle Period Probability.

(4) I_t = Time System was Idle.

(5) $E(N_t)$ = Expected Number in the System.

(6) $E(N_w)$ = Expected Number in the Waiting Line.

(7) $E(N_s)$ = Expected Number Receiving Service.

(8) $E(T_t)$ = Expected Time in the System.

(9) $E(T_w)$ = Expected Time in the Waiting Line.

(10) $E(T_s)$ = Expected Time Receiving Service.

FORMULAS

(1) $B_p = \dfrac{\text{Average Arrival Rate}}{\text{Average Service Rate}}$

(2) $B_t = B_p$ X Hours in Work Week.

(3) $I_p = 1 - B_p$

(4) $I_t = I_p$ X Hours in Work Week

(5) $E(N_t) = \dfrac{\text{Average Arrival Rate}}{\text{Average Service Rate}} - \text{Average Arrival Rate}$

(6) $E(N_w)$ = Busy Period Probability X E (N_t)

(7) $E(N_s) = E(N_t) - E(N_w)$

(8) $E(T_w) = \dfrac{1}{\text{Average Service Rate} - \text{Average Arrival Rate}}$ X Length of Interval

(9) $E(T_w)$ = Busy Period Probability X $E(T_t)$ X Length of Interval

(10) $E(T_s) = \dfrac{1}{\text{Average Service Rate}}$ X Length of Interval

Table 15.

OPERATING CHARACTERISTICS FOR PAGE CHANNEL

First Week Sample

(1) $B_p = \frac{2.71}{4.31} = .63$

(2) $B_t = .63 \text{ X } 63 \text{ hours} = 39.69 \text{ hours}$

(3) $I_p = 1 - .63 = .37$

(4) $I_t = .37 \text{ X } 63 \text{ hours} = 23.31 \text{ hours}$

(5) $E(N_t) = \frac{2.71}{4.31 - 2.71} = 1.69 \text{ pages}$

(6) $E(N_w) = .63 \text{ X } 1.69 = 1.06 \text{ pages}$

(7) $E(N_s) = 1.69 - 1.06 = .63 \text{ pages}$

(8) $E(T_t) = \frac{1}{4.31 - 2.71} = .63 \text{ X } 30 \text{ minutes} = 18.9 \text{ minutes/page}$

(9) $E(T_w) = .63 \text{ X } 18.9 \text{ minutes} = 12.0 \text{ minutes/page}$

(10) $E(T_s) = \frac{1}{4.31} \text{ X } 30 \text{ minutes} = 6.90 \text{ minutes/page}$

Second Week Sample

(1) $B_p = \frac{2.79}{5.43} = .51$

(2) $B_t = .51 \text{ X } 63 \text{ hours} = 32.13 \text{ hours.}$

(3) $I_p = 1 - .51 = .49$

(4) $I_t = .49 \text{ X } 63 \text{ hours} = 30.87 \text{ hours}$

(5) $E(N_t) = \frac{2.79}{5.43 - 2.79} = 1.06 \text{ pages}$

(6) $E(N_w) = .51 \text{ X } 1.06 = .54 \text{ pages}$

(7) $E(N_s) = 1.06 - .54 = .51 \text{ pages}$

(8) $E(T_t) = \frac{1}{5.43 - 2.79} = .38 \text{ X } 30 \text{ minutes} = 11.40 \text{ minutes/page}$

(9) $E(T_w) = .51 \text{ X } 11.4 \text{ minutes} = 5.81 \text{ minutes/page}$

(10) $E(T_s) = \frac{1}{5.43} \text{ X } 30 \text{ minutes} = 5.52 \text{ minutes/page}$

Table 16.

The idle period probability of each week was calculated by subtracting the busy period probability from 1.00. This probability for the first week was .37 and .49 for the second week. See Number 3 in Table 16. This probability represents the chance the channel will not be busy during any interval when copy arrives.

The idle time probability for each week was then multiplied by the number of hours in the work week to determine the total idle time. It was found that the page channel was idle 23.31 hours (23 hours and 19 minutes) during the first week and 30.87 (30 hours and 52 minutes) during the second week. See Number 4 in Table 16.

The next step was to determine the expected number of pages in the system during any interval. This was calculated by subtracting the average arrival rate from the average service rate using this value to divide the average arrival rate. See Number 5 in Table 16. The expected number of pages in the system for the first and second week was 1.69 and 1.06, respectively.

Next, the expected number of pages in the waiting line was determined by multiplying the busy period probability of each week by the expected number of pages in that week's system. See Number 6 in Table 16. The expected number of pages in the waiting line was 1.06 and .54 for the first and second weeks, respectively. Since a fraction of a page cannot arrive, this fraction is always rounded up to the next whole number.

The expected number of pages actually receiving the service for both weeks was then calculated by subtracting the expected number in the waiting line from the expected number in the system. See Number 7 in Table 16. The expected number of pages being served per interval was .63 and .51 for the first and second week, respectively. Again, since a fraction of a page cannot arrive, the fraction is rounded up to the next whole number. For example, if, as in the first week, .63 page was being serviced, this would be considered as one page.

The next step was to determine the expected time a page spent in the system. This was calculated by subtracting the average arrival rate from the average service rate and using the resulting value to divide 1.00. See Number 8 in Table 16. The resulting value of this operation expresses the time as a fraction of the interval, thirty minutes. This value is easily converted to minutes by multiplying it by thirty minutes, the length of the interval. It was determined that a page spent 18.9 minutes and 11.4 minutes in the system during the first and second week, respectively.

The expected time a pasted-up page spent in the waiting line for each week was then calculated by multiplying the busy period probability by the expected time in the system. See Number 9 in Table 16. In this manner it was determined that a page spent 12 minutes waiting for service during the first week and 5.81 minutes during the second week.

The expected time a page received service during each week was determined by dividing 1.00 by the average service rate for that week. See Number 10 in Table 16. The product of this operation was then multiplied by the length of the interval, thirty minutes, to determine the time in minutes. These calculations revealed that a page was serviced in 6.9 minutes during the first week and 5.52 minutes during the second week.

After these characteristics were determined, the results were considered and conclusions were drawn about the system. These remarks are presented in the following chapter.

After the analysis of the page channel was completed, the halftone/artwork channel was studied.

The arrival for the halftone/artwork channel were compiled to construct an empirical arrival distribution and to determine the average arrival rate. See Table 17 on page 62.

It was found that, on the average, 2.65 pieces of copy arrived per half hour. Once again, by consulting a table of Poisson probabilities and finding the theoretical distribution for a sample with an average arrival rate of 2.65, the empirical and theoretical can be compared. See Table 18 on page 63 for the theoretical probabilities and Figure 6 on page 64 for the comparison.

A visual comparison would seem to indicate the two are dissimilar. Figure 16 indicates there were many intervals in which no copy arrived at this channel. In fact, there were 56 such intervals. See Table 17. This indicates the copy is

AVERAGE ARRIVAL RATE OF HALFTONE AND ARTWORK

Number of arrivals per interval	Number of intervals	Product of two columns
0	56	0
1	17	17
2	9	18
3	10	30
4	9	36
5	3	15
6	4	24
7	3	21
8	4	32
9	1	9
10	2	20
11	1	11
12	1	12
13	3	39
14	0	0
15	1	15
16	0	0
17	1	17
18	1	18
	126	$334 \div 126 = 2.65$ pieces/.5 hr. =average arrival rate

Table 17.

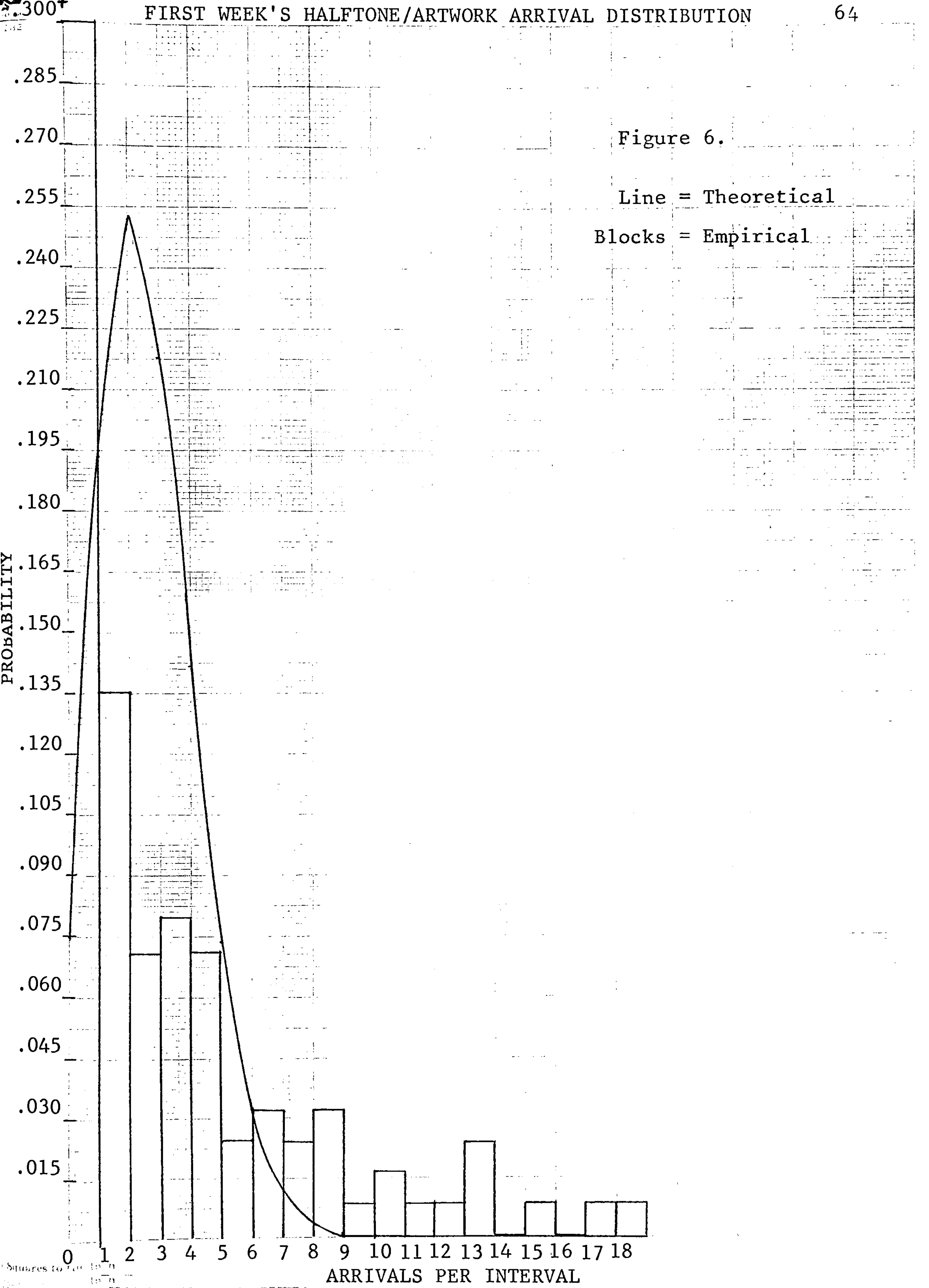
HALFTONE AND ARTWORK ARRIVAL DISTRIBUTION:

EMPIRICAL VS. THEORETICAL

Number of Arrivals per interval	Number of intervals	Empirical Probability	Theoretical Probability
0	56	.4444	.0743
1	17	.1349	.1931
2	9	.0714	.2510
3	10	.0794	.2176
4	9	.0714	.1414
5	3	.0238	.0735
6	4	.0317	.0319
7	3	.0238	.0118
8	4	.0317	.0038
9	1	.0079	.0011
10	2	.0159	.0003
11	1	.0079	.0001
12	1	.0079	.0000
13	3	.0238	.0000
14	0	.0000	.0000
15	1	.0079	.0000
16	0	.0000	.0000
17	1	.0079	.0000
18	1	.0079	.0000
	126		

Table 18.

FIRST WEEK'S HALFTONE/ARTWORK ARRIVAL DISTRIBUTION



not as evenly spaced in time as it should be to satisfy the Poisson assumption. It follows that more arrivals than would be considered optimal are arriving at the channel in fewer intervals than considered optimal.

From observations of the arrivals during the work week, it becomes apparent that copy often arrived at the channel in batches and was processed in the same manner.

Such a system of batch arrivals and batch processing, in most cases, cannot be effectively studied using this m/m/1 model because a batch system defies some of the basic assumptions of this model. Such assumptions as Poisson distributed arrivals and immediate service if the channel is idle are not followed in a batch system. If copy is processed according to batch, a piece of copy is allowed to wait for service until several pieces have been accumulated even though the system is idle.

In any case, a Chi Square Goodness-of-fit Test was run to determine statistically if the difference between the actual and theoretical distributions was significant. See Table 19 on page 66. It was found that the calculated Chi Square value greatly exceeded the table value, therefore, the null hypothesis that there was no difference was rejected. The actual arrival distribution is, in fact, not Poisson as was assumed.

In this case, Gross and Harris suggest an analysis be run anyway, if extremely crude approximations are acceptable.[6] So the analysis was continued.

By subtracting the arrival time from the departure time of each piece of copy, the service time for that piece was

CHI SQUARE GOODNESS-OF-FIT TEST

FOR HALFTONE/ARTWORK ARRIVAL DISTRIBUTION

Number of arrivals per interval	Empirical Distribution	Theoretical distribution	Difference
0	56	9.36	46.64
1	17	24.33	7.33
2	9	31.63	22.63
3	10	27.42	17.42
4	9	17.82	8.82
5+	25	15.44	9.56
	126	126	

$(\text{Difference})^2$	$\frac{(\text{Difference})^2}{\text{Theoretical}}$
2175.29	232.40
53.73	2.21
512.12	16.19
303.46	11.07
77.79	4.37
91.39	5.92

272.16 = calculated Chi Square value.

The Chi Square table value for a 6 cell table with 1 degree of freedom at the 95% level of confidence is 11.0705. In this case, the null hypothesis that there is no difference between the two distributions should be rejected since the calculated Chi Square value is greater than the table value.

Table 19.

determined. Once the service time for each piece had been obtained, an empirical distribution of the service time was constructed. See Tables 20 and 21 on pages 68 and 69.

The average service rate was then calculated by determining the average service time and dividing it by the length of the interval, thirty minutes. The average service rate was calculated and found to be .67 piece of copy per half hour. See Table 20.

The theoretical service distribution was then calculated just as the theoretical page distribution. Refer to the discussion of this procedure earlier in this chapter. Table 22 on page 70 demonstrates how the theoretical was determined for this channel.

The theoretical exponential service distribution was then compared visually with the empirical distribtuion. See Figure 7 on page 71. The two distributions seemed to be dissimilar since the empirical service time appeared to be longer than it theoretically should be.

However, a Kolmogorov-Smirnov Goodness-of-fit Test was run to test the validity of the exponential assumption. See Table 23 on page 72. The calculated Kolmogorov-Smirnov value D_{max}, was found to be .9850. The Kolmogorov-Smirnov table value was 1.06 for a sample size of 323 at the 95 per cent level of confidence. Therefore, the null hypothesis that there is no significant difference should be accepted. The empirical service distribution is, indeed, exponential despite the batch

HALFTONE/ARTWORK SERVICE CALCULATIONS

Assumed Average Service Minutes	Number of Pieces	Product of Two Columns
8	5	40
24	68	1632
40	123	4920
56	82	4264
72	30	2160
88	8	704
104	5	520
112	2	224
	323	14464

14464 ÷ 323 = 44.78 minutes = Average Service Time/Piece.

30 minutes ÷ 44.78 minutes = .67/half hour = Average Service Rate.

$$\frac{\text{Average Arrival Rate}}{\text{Average Service Rate}} = \frac{2.65}{.67} = 3.96 = \text{Infinite Waiting Line}$$

Table 20.

HALFTONE/ARTWORK SERVICE DISTRIBUTION:

EMPIRICAL VS. THEORETICAL

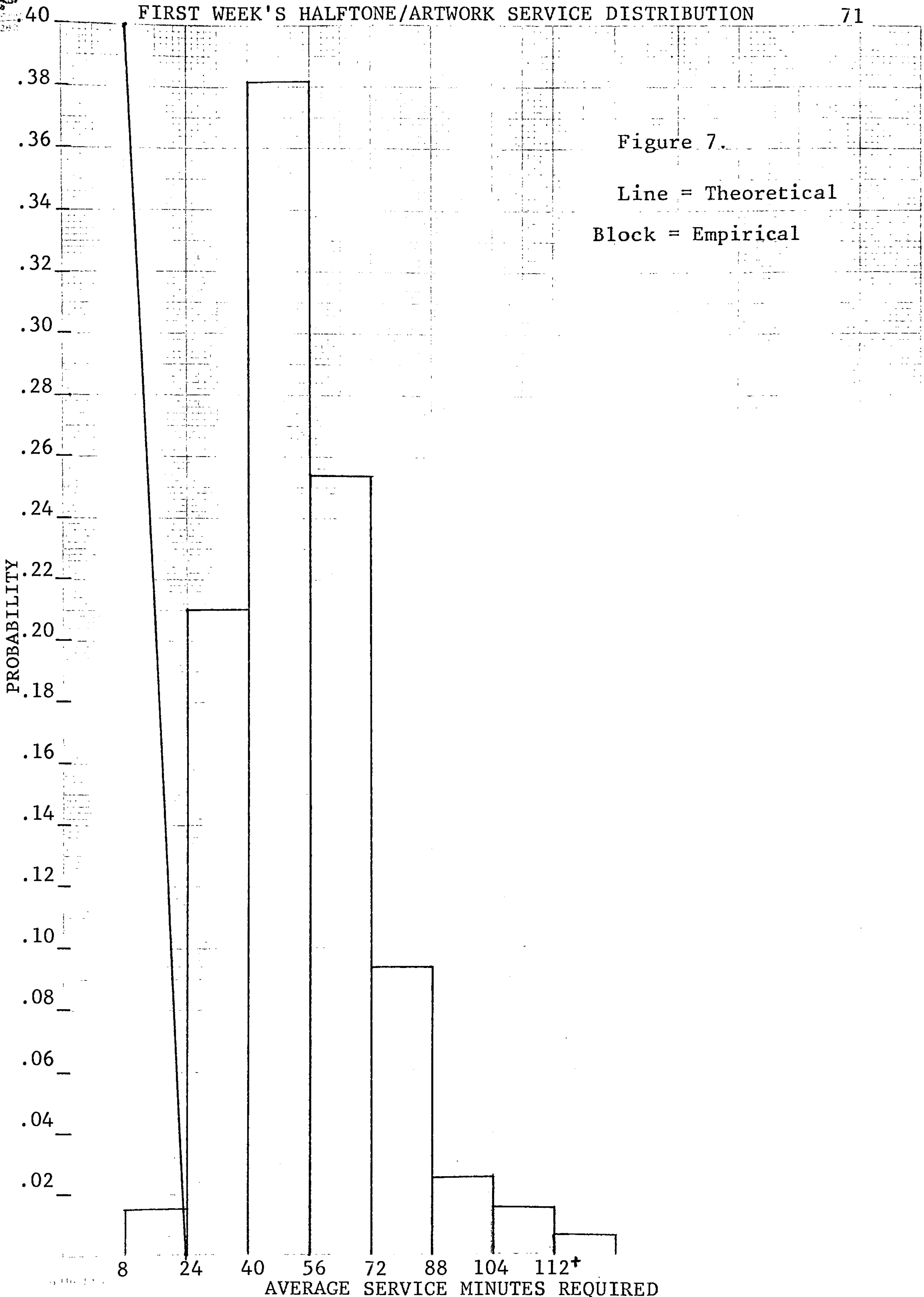
Service Minutes Required	Number of Pieces	Empirical Probability	Theoretical Probability
0 - 16	5	.015	.99998
16 - 32	68	.211	.00002
32 - 48	123	.381	.00000
48 - 64	82	.254	.00000
64 - 80	30	.093	.00000
80 - 96	8	.025	.00000
96 - 112	5	.015	.00000
112+	2	.006	.00000
	323		

Table 21.

Distribution for Halftone/Artwork Channel - First Week Sample

Service Minutes Required			Theoretical Distribution
0 - 16	$2.718^{-.67(0)} - 2.718^{-.67(16)}$	=	.99998
16 - 32	$2.718^{-.67(16)} - 2.718^{-.67(32)}$	=	.00002
32 - 48	$2.718^{-.67(32)} - 2.718^{-.67(48)}$	=	.00000
48 - 64	$2.718^{-.67(48)} - 2.718^{-.67(64)}$	=	.00000
64 - 80	$2.718^{-.67(64)} - 2.718^{-.67(80)}$	=	.00000
80 - 96	$2.718^{-.67(80)} - 2.718^{-.67(96)}$	=	.00000
96 - 112	$2.718^{-.67(96)} - 2.718^{-.67(112)}$	=	.00000
112+	$2.718^{-.67(112)} - 2.718^{-.67(140)}$	=	.00000

Table 22.


FIRST WEEK'S HALFTONE/ARTWORK SERVICE DISTRIBUTION
Figure 7.
Line = Theoretical
Block = Empirical
PROBABILITY
.40
.38
.36
.34
.32
.30
.28
.26
.24
.22
.20
.18
.16
.14
.12
.10
.08
.06
.04
.02
8
24
40
56
72
88
104
112+
AVERAGE SERVICE MINUTES REQUIRED

KOLMOGOROV-SMIRNOV GOODNESS-OF-FIT TEST
FOR EXPONENTIAL DISTRIBUTION OF HALFTONE/ARTWORK CHANNEL

First Week Halftone/Artwork Sample

Service Minutes Required	Empirical Cumulative Distribution	Theoretical Cumulative Distribution	Absolute Difference
0 - 16	.015	.99998	.985
16 - 32	.226	1.00000	.774
32 - 48	.607	1.00000	.393
48 - 64	.8610	1.00000	.139
64 - 80	.954	1.00000	.046
80 - 96	.979	1.00000	.021
96+	1.00	1.00000	.000

Dmax = .9850

The Kolmogorov-Smirnov table value for a distribution with a sample size of 323 at the 95% confidence level is 1.06. Therefore, the null hypothesis that there is no significant difference between the two distributions must be accepted.

Table 23.

processing and failure of arrivals to be Poisson distributed.

Having calculated the average arrival and service rate, the two values were substituted into queueing equations to determine the operating characteristics. The ratio between the average service rate was then calculated to determine the busy period probability

$$\frac{\text{Average Arrival Rate}}{\text{Average Service Rate}} = \frac{2.65}{.67} = 3.96$$

Since the resulting number is greater than 1.00, it is assumed that the channel has an infinite waiting line since a channel cannot be more than 100 per cent busy or have a busy period probability greater than 1.11. This situation would occur any time the arrival rate is greater than the service rate. This indicates something is seriously wrong in the system. The service rate must be increased or the arrival rate decreased.

From observations made during the data collection, it was determined that this channel was not busy 100 per cent of the time. In fact, it was idle at least two hours each day. Therefore, it was assumed that the arrival of copy in batches was responsible for such results. Since batch arrival would increase the number of pieces arriving during an interval, this appeared to be the prime factor contributing to a larger arrival rate than the system could handle.

Since the busy period probability exceeds 1.00, the analysis could not be continued. It would have been impossible to even obtain extremely crude approximations from

the analysis since the calculations would yield negative numbers in some cases because of the unrealistic busy period probability.

No data were collected from this channel during the second week of observations. Since the organization of the channel was not changed, the results would not significantly change. It was not possible for this researcher to modify the system after the first week even though it was apparent that the arrival of copy should be on a continuous basis rather than batch. Such a change would have required action by the management of the organization.

Even though the halftone/artwork channel analysis could not be successfully executed, much was learned about the system. Without such analysis, it is doubtful the problem of copy arrival would have been recognized. It is also quite helpful to know the average arrival and service rates.

FOOTNOTES FOR CHAPTER SEVEN

[1] Chaiho Kim, Quantitative Analysis for Managerial Decisions (Reading, Mass.: Addison - Wesley Publishing Co., 1976), p. 333.

[2] Donald Gross and C. M. Harris, Fundamentals of Queueing Theory (New York: John Wiley and Sons, 1974), p. 452.

[3] Albert D. Rickmers and Hollis N. Todd, Statistics, an Introduction (New York: McGraw Hill Book Co., 1967), p. 140.

[4] Op. Cit., Chaiho Kim, p. 336.

[5] J. A. White et. al., Analysis of Queueing Systems (New York: Academic Press, 1975), p. 330.

[6] Ibid., p. 331.

[7] Op. Cit., Chaiho Kim, p. 339.

VIII. CONCLUSIONS

The purpose of this study was to determine the operating characteristics of the camera department. It has been demonstrated that queueing analysis can do this quite effectively if the arrivals and service distributions roughly approximate the theoretical distributions and if the other assumptions (random arrival, FIFO with the stipulation that customers cannot leave the waiting line once they have entered) are satisfied.

The characteristics of the halftone/artwork channel failed to satisfy these assumptions so the analysis could not adequately describe the system. The one important assumption this channel did not satisfy was the assumption that the arrival of customers was random. Batch delivery influenced the rate of arrivals, preventing it from being a random process. However, valuable information was obtained. For example, it was found the arrival and service discipline were batch, a situation very undesirable if quick service is the objective.

With a few modifications, this channel could be monitored also by queueing analysis. For example, if the method of transporting halftone/artwork copy could be switched to a more continuous system such as a conveyor or pneumatic

tube system, the copy could be sent to the camera department as soon as the artists or editors completed their tasks of sizing, etc. This system would eliminate the need for the clerk who could not possibly deliver copy on a continuous basis. Even if it were physically possible for a clerk to carry one piece of copy to the camera department as the editor or artist finished his work with it, another piece may be ready for delivery before the clerk returns.

Batch processing could be eliminated by simply instructing the camera operator to shoot copy as soon as it arrives instead of waiting to collect several pieces. Although, in some situations, there may be a slight economical disadvantage to this procedure. For example, if ten inches of film is required to get the film through the processor and there is only one piece of copy with a maximum depth of five inches, there will be some wastage of film, particularly with a roll film camera. However, in many newspaper production situations, the added speed could offset the waste.

At any rate, this researcher did not have the freedom to make such modifications since this would largely be an upper management decision.

Although the purpose of this study was not to design an optimal system, several conclusions can be drawn from the results of the page channel analysis, given the various possible objectives of the organization.

If the objective of the organization is to maximize speed, attention should be given to the system with the

goal of decreasing the expected time a page spends in the system by decreasing the service time and, thereby, increasing the rate of service and decreasing the busy period probability and/or decreasing the expected number of pages in the system per interval. Increasing the service rate would diminish the size of the queue, but the worker might slow his work pace when confronted with little work to do.

Decreasing the service time of copy becomes a matter of studying the system and replacing time consuming methods and machinery with faster methods and machinery. In this case, it was found that a page could actually be serviced in one minute from the time it was picked up and loaded on the copy-board to the time it was unloaded and placed in the "processed" bin. Of course this time would change with the length of exposure required. At any rate, this indicated that the average service time of 6.96 minutes per page for the first week page channel operation could be lowered, thereby, increasing the service rate and so decreasing the expected time for a page to receive the actual service. It was found that the cause of this longer service time was the frequency of mistakes in shooting the pages. In fact, twenty-four pages had to be shot two or more times to correct original shooting errors during the first week.

The camera operator also tended to increase service times by talking with visitors in his work area. In the case of this department, the system could be improved to provide faster service if the work habits and skill of the operator were improved.

If the busy period probability were decreased, there would be a greater chance of the channel being idle when a page arrived, and, therefore, the page could be processed immediately. Theoretically, this would decrease the time a page would spend in the system, but it was found that, as fewer pages arrived for service, the service time increased. For example, during the first week 368 pieces of copy arrived at the page channel. This is eight fewer pages than arrived during the second week, but the expected time in the system is 7.5 minutes longer than that of the second week. This is largely due to the psychology of the worker and the need of the worker to appear busy. This may also be attributed to the worker's desire to take extra time and care to make sure work was done correctly during slow work periods.

In this case, reducing the weekly amount of work coming to the channel may not decrease the busy period probability and increase the service rate, though logically it should.

The speed of the system can be increased by decreasing the number of pages arriving per interval. As demonstrated in the results of this study, it is possible to have fewer pages in the system per interval during the week that has a total of more customers than another week with more pages per interval. This can be attributed to a larger service rate (faster service time) and/or arrival rate. For example, during the second week which had eight more customers than

the first week, 1.12 customers (5.43 - 4.31) more were serviced per interval than during the first week. There was a significant increase in the rate of customer arrival, also.

The rate of shooting errors could have significantly affected the rate of service. This may have been the case during the second week. A shooting error will more than double the service time for a particular page. The manager must keep this factor to an absolute minimum.

A high error rate would significantly increase the size of the queue and might indicate that a system is much too slow to handle a particular workload during a specified time. However, a closer look might show that the system's organization and components are efficiently arranged, and that, indeed, it is the worker's errors that is the problem. A poorly trained worker can make any system look bad.

By improving the efficiency of the method used to process the pages, more pages can be processed per half hour, thereby reducing the expected number of pages in the system per half hour.

The following are more specific methods by which the queue could be modified:

(1) Spread make-up of advanced sections over a longer time period.

(2) Dump Sunday classified earlier so the paste-up artist can regulate the flow of pages to the camera department over more intervals of time.

(3) Schedule release times for daily classified, editorial and other pages not containing hard news.

(4) Establish a strict priority system of handling halftones based on expected release times of each halftone's respective page. This would eliminate the waiting of the pages for halftones or artwork. There is a need for coordination of such specifics from copy chief to composition to paste-up.

(5) The size of the waiting line is also dependent, to some extent, on the skill of the camera operator. Sufficient education of camera operators in sound camera techniques could effectively reduce the queue size in some instances.

(6) Since the arrival of copy to the camera department is random, it is imperative that camera operators remain at their work stations during slack periods. Closer supervision may be required.

If the organization's goal is to minimize costs, attempts should be made to reduce the idle time or increase the busy period probability.

Any idle time is considered a loss of revenue since the organization is paying for a service not rendered. The amount of idle time management will tolerate will vary with the nature of the work and the goals of a particular organization. For example, it is desirous for a mobile medical unit to be idle as much as possible so it will be alert and waiting when an emergency life-or-death situation occurs. If the busy period probability of such a medical unit is very

high, there will be a very high probability that a critically injured accident victim will have to wait for medical attention.

One way to increase the busy period probability is to increase the number of customers coming to the system. An increase in the arrival rate of copy will increase the busy period probability proportionally, if the service rate remains fairly constant. This is highly unlikely since an increase in arrivals may cause the camera operator to work faster, thereby increasing the service rate or he might work slower and decrease the rate of service.

If the busy period probability is not as high as management desires, the worker could be assigned extra duties. These extra duties could take the form of "low priority" jobs to be carried out in the worker's immediate area. A cross-training program could be implemented, also.

Assigning extra "low priority" duties to a worker can be a rather delicate matter requiring great diplomacy since, naturally, a worker does not want to do more work with no pay increase.

A cross-training program might be more practical. This program would train camera operators in plate-making procedures and plate-makers in camera procedures. An arrangement could be made requiring camera operators to burn plates when they are idle and the plate-makers could help in the camera department when they are not busy. Such a program not

only helps eliminate idle time, but also provides extra manpower in both departments when workers are sick or vacationing.

Action should not be taken, however, to modify a system simply on the results of a one or two week queueing study of the system. The operating characteristics may change drastically from week to week. Defective machinery, vacationing workers, disabled workers and the work load will affect the results. Ideally, the system should be monitored continuously to determine if patterns exist in the results.

Continuously monitoring the system will also provide a basis for comparing the characteristics from week to week and for comparing the effects of changes in the system against the results obtained before the changes were made.

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