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13. ABSTRACT The dentists working in the restorative section of the Dental Clinic at the Wright-Patterson AFB Medical Center were frequently incurring large amounts of idle time. The Dental Clinic utilized an Individual appointment system with patients scheduled for either a 45 minute or a 90 minute appointment. The inflexibility of this type appointment scheduling system contributed to the amount of dentist idle time incurred. Two different simulation models (which utilized patient arrival time, restorative service time and the dentists' estimate of the service time required for each patient) were developed to enable experimentation with several different type appointment systems. Appointment system D, which provides available appointment lengths of 30, 45, 60, 75 and 90 minutes, is recommended for all follow-up appointments. This is an individual appointment system which will allow each patient to be serviced by the same dentist until all required work has been completed. Appointment system Y, which schedules a specific number of 30, 45 and 60 minute appointments during each clinic session, is recommended for patients scheduled for their first appointment. This is a Mixed Block-Individual appointment system in which each patient's first appointment length is based on the examining dentists' estimate of the service time required for the patient's first appointment. The patients are not scheduled with a specific dentist and are serviced on an earliest arrival time basis. Initiating these two systems requires scheduling patients for follow-up appointments during different clinic sessions than those scheduled for their initial appointment. Initiation of these two appointment systems will result in approximately a 25 increase in the number of patients scheduled with an associated average patient waiting time and average dentist idle time of less than 17 minutes.

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DENTAL CLINIC SCHEDULING

A SIMULATION APPROACH

THESIS

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DENTAL CLINIC SCHEDULING
A SIMULATION APPROACH

THESIS

Presented to the Faculty of the School of Engineering

of the Air Force Institute of Technology

Air University

in Partial Fulfillment of the

Requirements for the Degree of

Master of Science

by

William H. Glendenning, B.S.
Major USAF

Graduate Systems Analysis

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Preface

This thesis is my attempt to analyze the problem of dentist idle times created by an inflexible appointment scheduling system and to structure an appointment scheduling system which is both flexible and provides a more efficient use of available resources. Due to the limited amount of time available for data collection and analysis, this research was confined to the restorative appointment scheduling section of the Wright-Patterson Air Force Base Dental Clinic. A number of assumptions were necessary which may not satisfy all readers of this thesis; however, the resulting simulation models can easily be altered to test the effects of different assumptions.

During the past several months, my frequent contact with the various staff members of the hospital clinics has confirmed my feelings of respect and admiration for the dedicated personnel of our military hospitals. I wish to apologize to those medically knowledgeable individuals, who find reason to read this study, for my limited understanding of the medical profession which in several circumstances may result in my flagrant use of medical terminology. Writing a thesis that is easily comprehensible to both the physician with little formal analysis background and the analyst with little medical background, presents a problem of finding a suitable balance between the two fields. This report

tends toward my personal preference as a systems analyst.

I am grateful for the assistance and guidance provided by Major Ronald J. Quayle, thesis advisor, and Lieutenant Colonel David L. Belden, thesis reader. I am also indebted to Mr. Robert F. Bachert for his invaluable assistance in writing and debugging the simulation programs. I also wish to thank Colonel John J. Tarsitano and his entire Dental Clinic Staff, without whose assistance the collecting of data would not have been possible. Lieutenant Colonel J. M. Snider was especially helpful in monitoring the data collection.

Finally, I am indebted to my wife for typing this thesis and for her encouragement and understanding through the months of preparing this research.

William H. Glendenning

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Abstract

The dentists working in the restorative section of the Dental Clinic at the Wright-Patterson AFB Medical Center were frequently incurring large amounts of idle time. The Dental Clinic utilized an Individual appointment system with patients scheduled for either a 45 minute or a 90 minute appointment. The inflexibility of this type appointment scheduling system contributed to the amount of dentist idle time incurred. Two different simulation models (which utilized patient arrival time, restorative service time and the dentists' estimate of the service time required for each patient) were developed to enable experimentation with several different type appointment systems. Appointment system D, which provides available appointment lengths of 30, 45, 60, 75 and 90 minutes, is recommended for all follow-up appointments. This is an individual appointment system which will allow each patient to be serviced by the same dentist until all required work has been completed. Appointment system Y, which schedules a specific number of 30, 45 and 60 minute appointments during each clinic session, is recommended for patients scheduled for their first appointment. This is a Mixed Block-Individual appointment system in which each patient's first appointment length is based on the examining dentists' estimate of the service time required for the patients first appointment. The patients

are not scheduled with a specific dentist and are serviced on an earliest arrival time basis. Initiating these two systems requires scheduling patients for follow-up appointments during different clinic sessions than those scheduled for their initial appointment. Initiation of these two appointment systems will result in approximately a 25% increase in the number of patients scheduled with an associated average patient waiting time and average dentist idle time of less than 17 minutes.

I. INTRODUCTION

In general, the hospital industry has been rather slow in utilizing computers. In 1965 there were more than seven thousand hospitals in the United States and it was estimated that only about 250 of these were utilizing computers (Ref 7:312). Since 1965 this number has increased rapidly, with approximately one thousand computers in use by 1970.

The United States Air Force is currently in the process of combining the capabilities of computer science with medical center operations in the hope of developing a more timely and integrated medical service. The Medical Center at Wright-Patterson Air Force Base (WPAFB) is one of the first military hospitals to utilize these capabilities. In the past year a computer terminal has been installed in the hospital laboratory and computer programs have been developed to initiate some automation into the hospital laboratory procedures. Programs are also being developed for the other clinics throughout the hospital. Specific studies have been accomplished in the pharmacy, food services and the blood bank donor center.

One of the first steps toward the development of a hospital information system for the Medical Center was a pilot project to schedule outpatient appointments. Since that time a specific study has been accomplished concerning the scheduling of patients at the Obstetrics-

Gynecology clinic (Ref 4). At the present time there is a time series study being conducted concerning the central appointment scheduling system for all outpatients. Due to the interest and emphasis placed on analyzing the present outpatient appointment scheduling systems, this facet of the hospital complex was chosen as the subject for this thesis. Specifically, this thesis is concerned with the outpatient appointment scheduling system for the Dental Clinic.

Definitions

The following terms, several of which were taken from Elements of Queueing Theory (Ref 11) and Outpatient Scheduling, A Simulation Approach (Ref 4), are defined for the purpose of this thesis.

Arrival Pattern - The statistical distribution of patient arrival times. The arrival rate is the average number of arrivals per unit time and the interarrival time is the time between two arrivals (Ref 4:3).

Block Appointment System - System whereby groups of patients are scheduled at different times throughout the clinic period. This system may vary from having all patients scheduled at the beginning of the clinic to having groups of patients scheduled at various time intervals throughout the Clinic period (Ref 4:3).

Broken Appointment - A scheduled appointment for which the patient does not arrive.

Dental Clinic - Refers to the Dental Clinic located at the WPAFB Medical Center.

Dentist Idle Time - For a block appointment system, this is the sum of time between the dentist's first

appointment time and his last appointment time in which there are no patients available to be seen. For an individual appointment system, this is the sum of time between the dentist's first appointment time and the end of the clinic session in which his next scheduled patient is not available to be seen.

Emergency Patient - A dental patient requiring immediate attention.

Estimated Minus Actual Service Pattern - The statistical distribution of the difference between the dentist's estimated service time and the actual service time required to complete each patient.

Estimated Minus Actual Service Time - The difference between the estimated service time and the actual service time for each patient.

Estimated Service Pattern - The statistical distribution of the dentist's estimate of the time required to service a patient.

Estimated Service Time - The dentist's estimate of the time required to service a patient.

Individual Appointment System - System whereby each

patient is given a separate appointment time with a specific dentist. The length of each appointment may vary from clinic to clinic and is usually associated with the average service time required for each patient.

Mixed Block - Individual Appointment System - System whereby each patient is given a separate appointment time, but not with a specific dentist. The length of each appointment may vary and is usually associated with the average service time required for each patient.

Outpatient - "A person given general or emergency diagnostic, therapeutic, or preventive health services provided through a hospital facility and who, at the time, is not registered in the hospital." (Ref 4:5)

Patient Waiting Time - Period of time between a patient's arrival time at the clinic and the time he is called to the dentist's office.

Queue - A waiting line. To have a queue, one must have arrivals at a service facility where they often wait (Ref 11:VII).

Queue Discipline - The manner in which the next patient to be served is selected.

Restorative Dentistry - Dentistry concerned primarily with tooth preservation. Also includes preventive dentistry counseling.

Service Pattern - The statistical distribution of the time required to service a patient. The service rate is the average number of patients which the clinic is capable of serving per unit time (Ref 4:6).

Service Time - The time from the patient initially being called to the dentist's office until he departs the dentist's office.

Simulation - A method of studying systems. "It is the process of conducting experiments on a model of a system in lieu of either (1) direct experimentation with the system itself, or (2) direct analytical solution of some problem associated with the system." (Ref 8:1)

Walk-in Patient - A patient arriving at a clinic without having a scheduled appointment (Ref 4:6).

WPAFB - Wright-Patterson Air Force Base.

Statement of the Problem

The restorative section of the WPAFB Dental Clinic presently experiences varying amounts of dentist idle time throughout the day. After completing each patient, the dentist cannot start work again until his next scheduled patient arrives. Although the amount of time the dentist is required to wait varies from patient to patient, a contributing factor appears to be the inflexibility of the appointment scheduling system being used. This can result in large amounts of dentist idle time and a resultant inefficient use of available resources. This is the problem which will be investigated in this thesis.

Objective

The objective of this research is to develop and analyze alternative methods of appointment scheduling for the restorative section of the WPAFB Dental Clinic. The technique of computer simulation is utilized in simulating alternative appointment systems for a six hour clinic session. The simulated results are analyzed with the objective of finding a suitable balance between the number of patients scheduled and the amount of average dentist idle time and average patient waiting time incurred during each clinic session.

Scope of Research

The Medical Center at WPAFB has a variety of

specialized clinics, each with varying characteristics and potentially different personnel being served. The problem of designing an efficient outpatient appointment scheduling system varies from clinic to clinic. Therefore, due to the time constraint and to allow a more thorough analysis of the variables which affect appointment scheduling systems, this research is limited to the Dental Clinic at the WPAFB Medical Center. The results of this study may not apply to all other clinics; but should be applicable to all similar clinics, especially those within the military medical system.

The Dental Clinic itself is divided into a variety of different specialties. The cleaning and restorative sections use an individual appointment scheduling system which is controlled at a central desk. All other sections also use the individual appointment scheduling system, but maintain their own appointment books and do their own scheduling. Thus, this research is further limited to the restorative appointment scheduling system within the Dental Clinic.

Method of Research

The problem of patient appointment scheduling at a clinic can be analyzed in terms of the following queueing process:

Queue - Patients occupying the clinic waiting room and awaiting dental service.

Service discipline - Manner in which the next patient to be serviced is selected.

Service mechanism - Dentist performing restorative work.

System input - The dental patient arriving with a scheduled appointment or desiring an immediate appointment.

In order to accomplish the objective of developing and analyzing alternative methods of appointment scheduling, a search of the current literature concerning queueing theory was accomplished. Although this search did not result in a specific queueing model which was applicable to the present conditions existing at the Dental Clinic, it did provide a better understanding of the many different methods and problems associated with the analysis of a queue. Direct experimentation with the present appointment scheduling system at the Dental Clinic did not seem feasible due to the risk of compounding any problems which might already exist. Thus, various scheduling methods are simulated under the conditions that currently exist at the Dental Clinic.

Patient arrival patterns and dentist service patterns are developed from information collected at the Dental Clinic during an eight week period from 9 August 1971 through 30 September 1971. A distribution for the dentists' estimate of the time required to complete each patient is also developed from the data collected during

this period. An additional distribution is developed for the difference between the dentists' estimated service time and the actual service time required for each patient.

Two different computer simulation programs are used for this study. The first program utilizes patient arrival time and actual service time to simulate a Dental Clinic session of six hours duration. The number of dentists available is fixed at four; however, a sensitivity analysis is accomplished which considered scheduling patients when the number of dentists available is either three or five. The number of patients to be scheduled is fixed at twenty-eight (seven per dentist); however, a sensitivity analysis is also accomplished on this factor with varying numbers of patients being considered. Various methods of scheduling patients are then introduced and results of the simulated clinic sessions using each method of scheduling are tabulated and analyzed.

The second computer simulation program utilized patient arrival time, estimated service time and estimated minus actual service time to simulate a Dental Clinic session of six hours duration. This program simulates one dentist scheduling patient appointment times according to his estimate of the service time required to complete each patient. Various lengths of time available for each appointment are then

introduced and the results of the simulated clinic sessions are tabulated and analyzed.

A discussion of the characteristics of appointment scheduling systems is presented in Chapter II. Also included is a brief summary of some past studies concerning scheduling systems.

The WPAFB Dental Clinic procedures and the scheduling system being used during this study are described in Chapter III. The method of collecting information used in this research and a detailed analysis of this information is also presented. A brief summary of these statistics is provided at the end of the chapter.

In Chapter IV the computer simulation models used in this research are explained with respect to the variables used, basic assumptions, time-flow mechanism, output format and other specific characteristics of each program.

The alternative appointment scheduling systems simulated during this study are presented in Chapter V. Each scheduling system is followed by an analysis of the simulated results for that system. Chapter VI is a summary of the findings of this study and also includes recommendations based on these findings.

II. ANALYZING APPOINTMENT SYSTEMS

The problem of designing an appropriate appointment scheduling system is centered around the idea of reducing the waiting time for the patients while still allowing for the fullest use of the physicians' time. Past studies clearly indicate that one cannot hope to reduce either the patient waiting time or the dentist idle time without sacrificing one for the other (Ref 2:198). However, these studies do indicate that a desirable balance between patient waiting time and dentist idle time can be achieved with an adequately designed appointment scheduling system.

Appointment systems can be classified into three general types: (1) Pure Block Appointment Systems, (2) Individual Appointment Systems, and (3) Mixed Block-Individual Appointment Systems (Ref 14:389).

A Pure Block Appointment System assigns a common appointment time at the beginning of the clinic session for all the patients scheduled to be seen on any given day. This system would minimize the dentists' idle time but would result in extremely long patient waiting times. A direct result of this system is the regular occurance of congestion in waiting rooms.

An Individual Appointment System assigns each patient an appointment time with a specific dentist. From the patient's point of view, this system is highly desirable. It tends to minimize the waiting time of the patient, which in turn helps to reduce congestion in the waiting

rooms. The disadvantage of this system is that the amount of dentist idle time can become very large due to broken appointments, varying lengths of service time required for each patient and patients arriving late for their scheduled appointments.

A Mixed Block-Individual Appointment System integrates aspects of both the individual and the block appointment systems. This system schedules an initial group of patients to arrive at the beginning of the clinic session with others scheduled to arrive at intervals throughout the session. The patients are not scheduled with a specific dentist and are serviced on an earliest arrival time or earliest appointment time basis. The optimum scheduling system for most clinical situations falls somewhere within this Mixed Block-Individual Appointment System.

Past Studies of Scheduling Systems

Probably the first scientist to analyze the problem of scheduling patients analytically was D. V. Lindley (Ref 6). His study considered the problem of a single server with customers arriving singly, where the intervals between arrivals and service time were distributed according to general distributions. This study was mainly concerned with the waiting times of the customers and the development of the waiting time distribution for any

customer.

A study of the problem of scheduling patients was accomplished by N. T. J. Bailey (Ref 2). He studied the effect of changing the size of the initial group in the case of a Mixed Block-Individual Appointment System. A Monte-Carlo simulation technique was used to obtain the average patient waiting time and the average doctor idle time as a function of the size of the initial group of patients scheduled. As was expected, the results indicated that the patient waiting time is an increasing function of the size of the initial group, while the doctor idle time is a decreasing function of the size of the initial group. Bailey also concluded that the average waiting times are rather sensitive to small changes in the appointment interval.

A. Soriano made a comparison of two appointment scheduling systems (Ref 14). He compared the Individual Appointment System with a new system referred to as the "Two-at-a-Time Appointment System." This latter system merely schedules two patients at each appointment time, while doubling the length of the appointment interval. The comparison was accomplished in terms of the waiting time distribution for the two systems.

Other studies have been accomplished in the area of appointment scheduling, but they all seem to point toward the same two previously mentioned factors: (1) an efficient system requires a balance between patient

waiting time, physician idle time and the number of patients scheduled and (2) this balance can be achieved with an adequately designed appointment scheduling system.

III. DESCRIPTION OF PRESENT DENTAL CLINIC OPERATIONS

The Dental Clinic is located within the USAF Medical Center, WPAFB, Ohio. The primary mission of the clinic is to provide dental care for all active duty military personnel stationed at WPAFB. They also provide x-ray service for dependents, a children's preventive dentistry service and dental care for retired military personnel on an availability basis. All active duty military personnel stationed at WPAFB are required to have an annual dental examination. If specific dental care is found to be required as a result of this examination it is accomplished on subsequent appointments.

The Dental Clinic itself has several specialized sections; such as oral hygiene, restorative dentistry, periodontics, etc. During the data collection period the clinic staff was made up of the following numbers of personnel:

22	Staff Dentists
6	Interns
4	Resident Dentists
5	Dental Hygienists
1	Civilian Dental Hygienist
25	Dental Technicians
5	Dental Laboratory Technicians
1	Civilian Laboratory Technician
1-3	Red Cross Volunteers

Appointment Scheduling and Clinic Routine

Each section in the Dental Clinic uses an individual appointment system. The appointment scheduling for oral hygiene and restorative dentistry is controlled at a central desk. All other sections keep their own appointment books and do their own scheduling of appointments. This research is limited to an analysis of the appointment scheduling system for restorative dentistry.

Scheduled appointments for restorations are acquired either as a result of a dental examination or as a follow-up appointment. A patient flow chart for the annual dental examination is depicted in Fig. 1. If restorative work is required, the patient is given a 45 minute appointment. Occasionally, a double appointment (90 minutes) is given when extensive work will be required to complete the first appointment. A restorative patient flow chart is depicted in Fig. 2. If further restorative work is required following the patient's initial appointment, the patient receives another 45 or 90 minute appointment as specified by the dentist completing the initial appointment. No other choice for length of appointment is considered under the present system. Clearly, if the time required to complete a patient is less than the scheduled appointment length (45 or 90 minutes), it may result in large amounts of dentist idle time throughout the day. This may also be

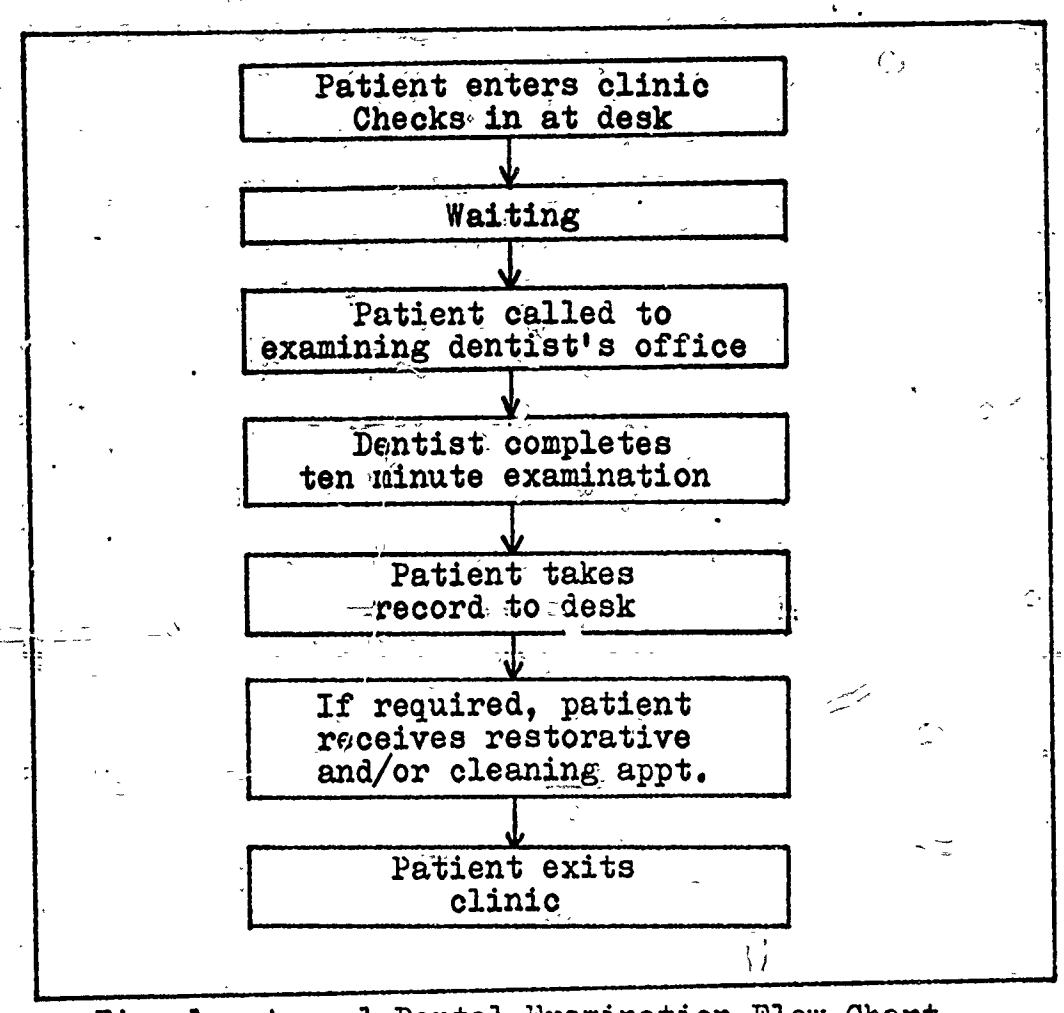

Fig. 1. Annual Dental Examination Flow Chart

compounded by the fact that even though the dentist completes a patient early, he must await the arrival of his next scheduled patient. Patients arriving prior to their scheduled appointment time will normally be called as soon as the dentist completes his present patient. Occasionally the clinic desk attendants may become very busy and fail to inform the dentist of an early patient arrival. This could result in additional dentist idle time even though the patient is available.

During this study the restorative section of the

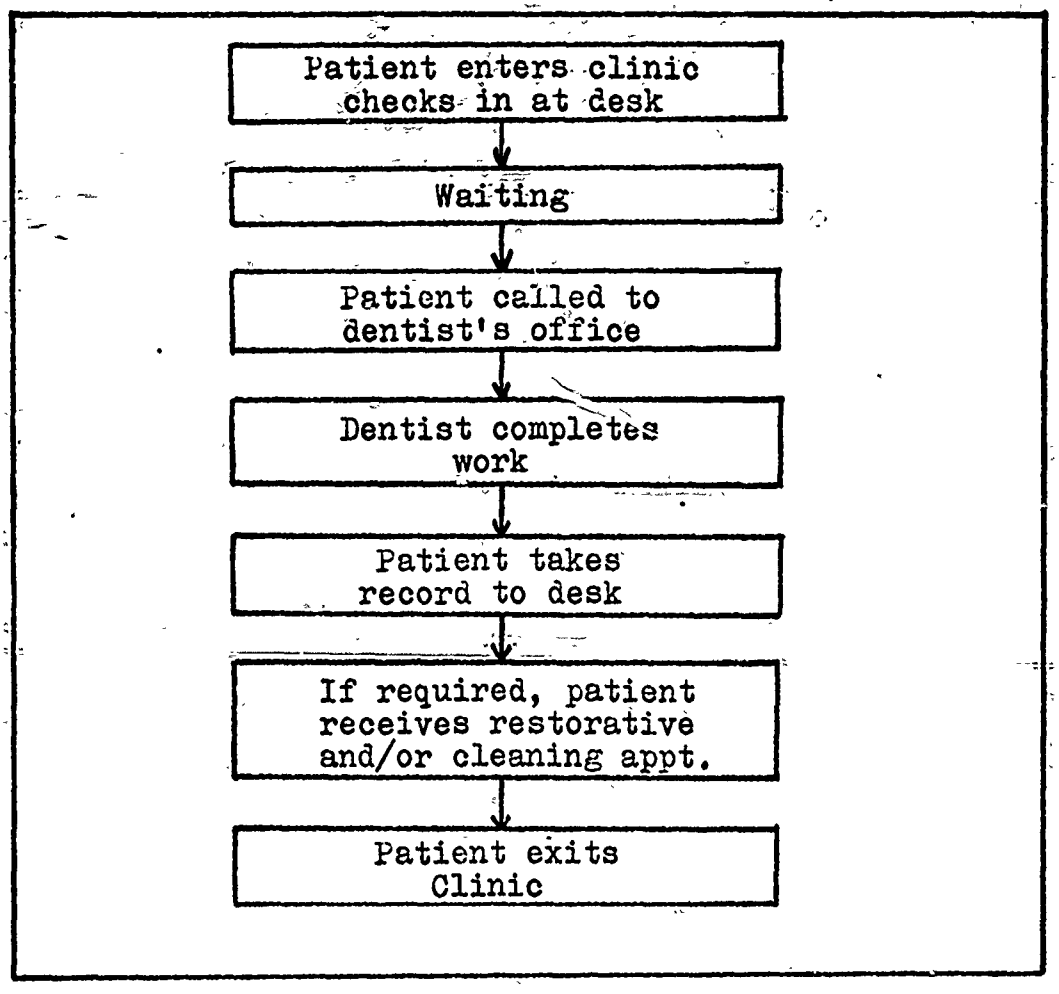

Fig. 2. Restorative Flow Chart

Dental Clinic was staffed with eight staff dentists, two interns, and eight dental technicians. This number may vary from time to time as a result of newly assigned personnel, personnel being transferred, leaves, sickness, etc. Four dentists, one intern and four dental technicians work from 0700 to 1300 hours each day. The remainder of the staff works from 1300 to 1900 hours each day. This provides each dentist with eight 45 minute time blocks with patients scheduled on an individual basis. The restorative section is divided into two separate work shifts due to the lack of facilities to accommodate more

than seven restorative dentists at one time.

The individual appointment system is used by the Dental Clinic for several reasons. This system allows each patient to be scheduled with the same dentist until all required work has been completed. This is desirable from a dentist's point of view since it provides each dentist with the opportunity to monitor his previously completed work. Since each patient's reaction to dental treatment is slightly different, most of the dentists at the Dental Clinic consider that subsequent appointments with the same patient are advantageous for a variety of reasons; such as the dentist is better able to anticipate the patient's reaction to treatment and the patient is familiar with the dentist's method of treatment. It is also assumed by the Dental Clinic staff that a patient would prefer to be treated by the same dentist rather than to see a different dentist on each appointment.

Data Collection and Analysis

During an eight week period from 9 August 1971 through 30 September 1971, information concerning patient arrival time, patient waiting time, restorative service time, dentists' estimate of time required to complete each patient, and other characteristics of the Dental Clinic was collected at the Dental Clinic through the use of two questionnaires (See Appendix A). The first

questionnaire was completed during each patient's ten minute required annual examination. The second questionnaire was completed during the patient's scheduled restorative appointment. There was approximately a three to four week wait between these two activities, which contributed to the large amount of time required to complete the data collection.

Patient arrival times depend on a large number of independent random variables and were assumed to be normally distributed with respect to the scheduled appointment times. Patient mean arrival time for 45 minute appointments was 10.2 minutes before appointment time with a standard deviation of 8.7 minutes. Patient mean arrival time for 90 minute appointments was 11.8 minutes before appointment time with a standard deviation of 11.1 minutes. The combined arrival pattern is depicted in Fig. 3. A Chi Square goodness of fit test (Ref 1:109) confirmed the assumption of a normally distributed arrival pattern for each of these cases. The test for the combined arrival pattern is included in Appendix B. The mean and standard deviation for the combined sample were 10.4 minutes and 9.0 minutes respectively.

The dentist service time was assumed to have a gamma distribution based on previous studies conducted by the Nuffield Provincial Hospitals Trust, the University of Bristol and Bailey (Ref 2:187). This assumption was

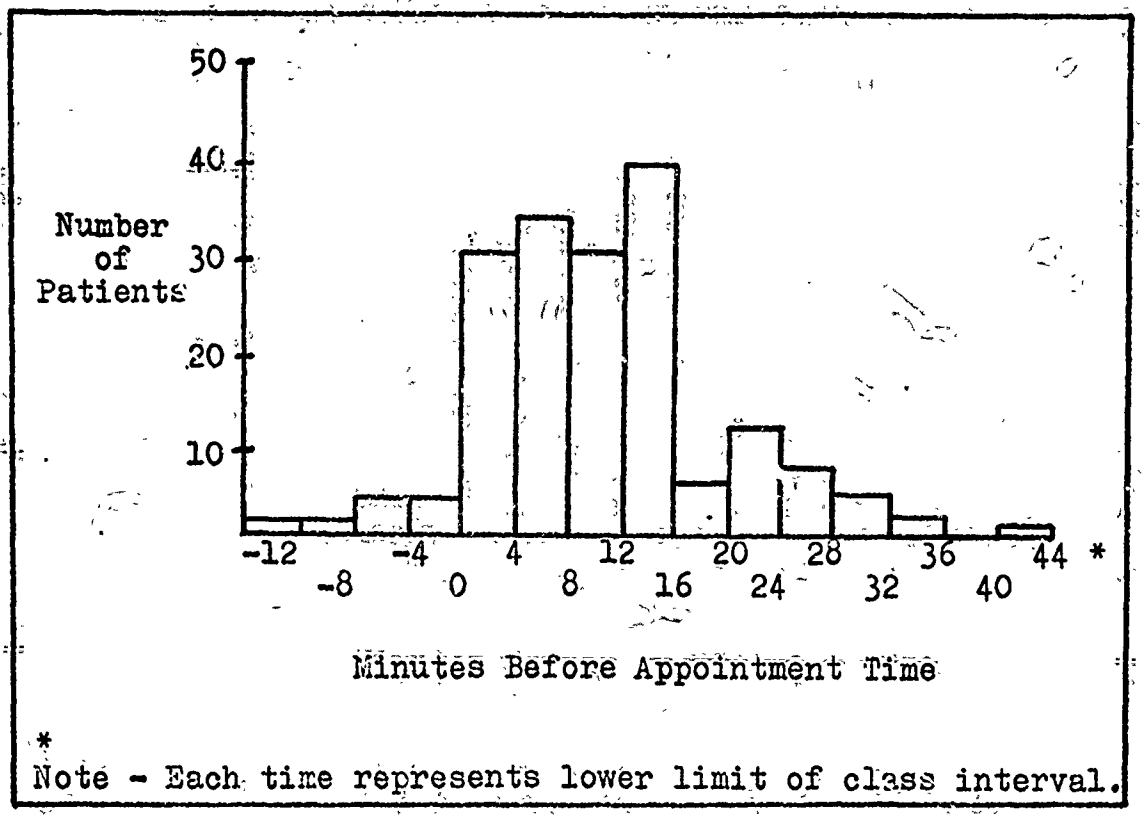

Fig. 3. Patient Arrival Pattern

verified by use of a computer program to conduct a Kolmogorov-Smirnov (K-S) goodness of fit test (Ref 12:47) on the combined service times for 45 minute and 90 minute appointments. A reference for the computer program and results from the test are presented in Appendix C. The combined dentist service time distribution is depicted in Fig. 4.

The dentists' estimated service time was also assumed to have a gamma distribution. The results from a Kolmogorov-Smirnov goodness of fit test are also contained in Appendix C. Although the hypothesis was not accepted at the .01 level of significance, the results were considered to be satisfactory to justify the use of this assumption

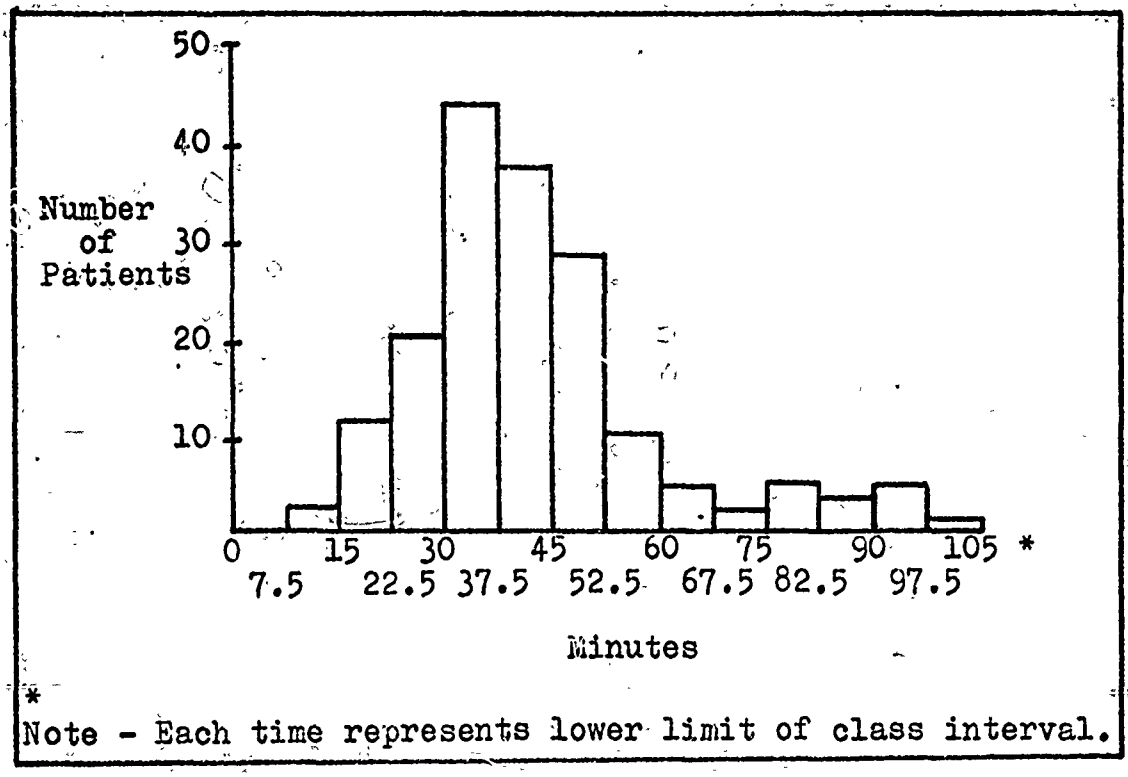

Fig. 4. Actual Restorative Service Time To Complete Each Patient

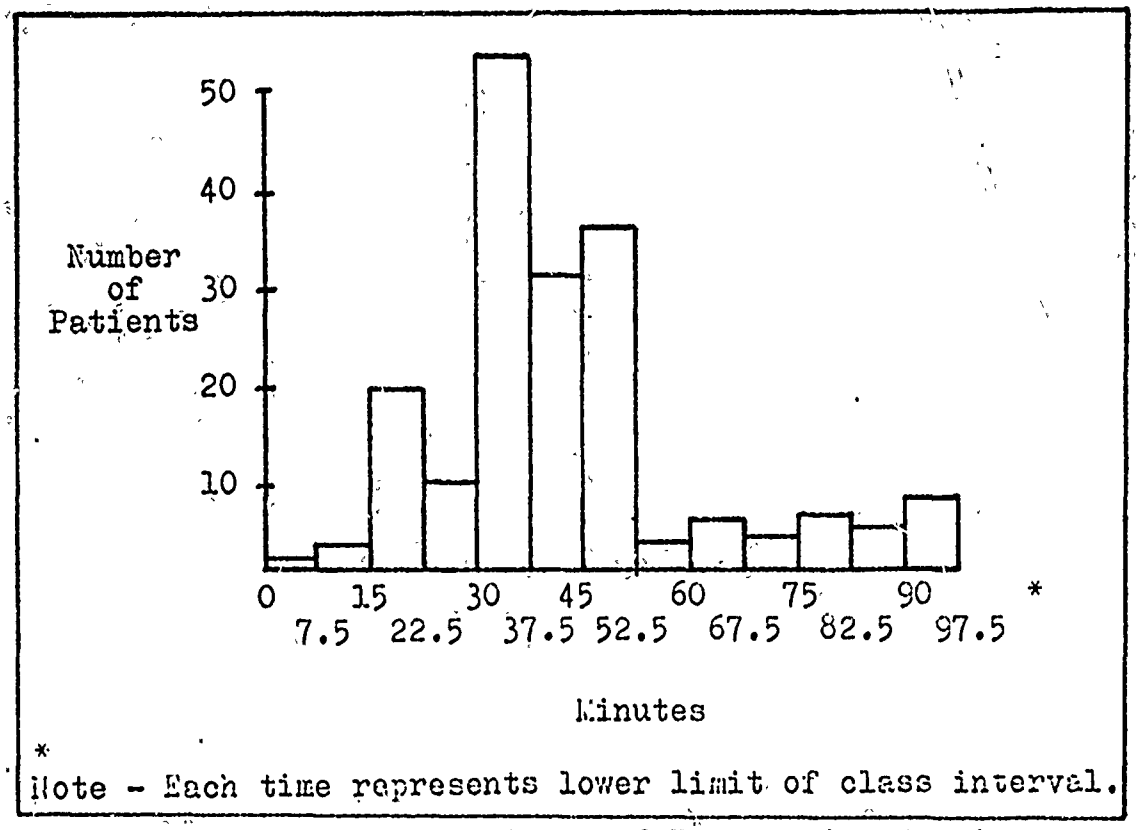

Fig. 5. Dentists' Estimate of Restorative Service Time To Complete Each Patient

in the simulation model. The dentists' estimated service time distribution is depicted in Fig. 5. With a mean of 40.8 minutes, the large number of estimates at the 30 minute and 45 minute levels (shown in Fig. 5) could cause a large difference between the actual distribution and the gamma distribution at these points. The results from the computer program for the K-S test verified this fact since the only difference statistics which exceeded the maximum allowable K-S statistic were those associated with estimates at the 30 minute and 45 minute levels. A possible reason for this may have been a tendency on the part of the dentists to round their estimates towards the 30 minute and 45 minute levels. Although the results from the gamma distribution are used, the actual distribution of the dentists' estimated service times is also introduced into the simulation model and used to better understand the differences produced. An analysis of the data from the simulations indicated that the gamma distribution gave the most realistic results.

Data was also collected concerning the examining dentists' estimate of the time required for each patient's first restorative appointment. This required additional work on the part of the examining dentist in that he was required to indicate the specific work to be accomplished and to estimate how long it would take another dentist to complete the work. These estimates were compared with the actual service time required for each patient and with

the estimates made by the dentist actually completing the work. Examining dentists' estimates were acquired in 58 out of a total of 178 observations. In those cases where the work accomplished was the same as had been indicated by the examining dentist (30 out of the 58 observations), the average estimate of the service time required to complete each patient was the same for both the examining dentist and the dentist actually accomplishing the work (mean = 35.1 minutes). This compared quite favorably with the average service time required for each patient (37.2 minutes). Although in approximately fifty per cent of the cases the work actually accomplished was not the same as had been indicated by the examining dentist, the examining dentists' average estimate for the 58 observations (mean = 37.4 minutes) compared quite favorably with the actual service time (mean = 38.1 minutes) for these patients. A K-S goodness of fit test verified each of these to have a gamma distribution and the test results are included in Appendix C.

The dentists actually accomplishing the restorations did not always accomplish the work indicated by the examining dentist. Therefore, in order to allow complete flexibility to the dentists actually accomplishing the restorations, scheduling patient appointments on an individual basis (based on the dentists' estimates) will be simulated for follow-up appointments only. The examining dentists' estimates will be utilized in scheduling initial

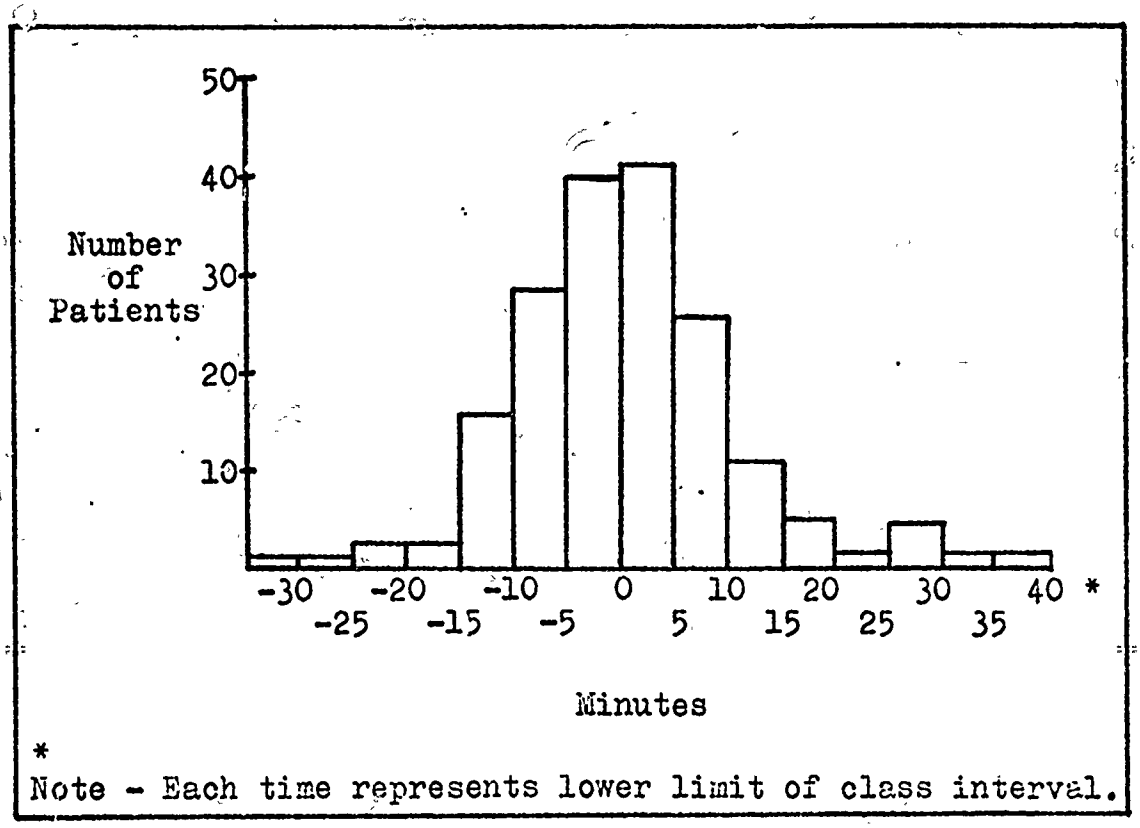

Fig. 6. Difference Between Dentists' Estimate of Restorative Service Time and Actual Restorative Service Time For Each Patient

patients into a mixed block-individual type system. This would require scheduling patients for their initial appointment during different clinic sessions than those scheduled for follow-up appointments and will be discussed further in Chapter V.

The final distributions considered were the difference between the dentists' estimated service time and the actual service time for each patient. The distribution for the dentists' actually accomplishing the restorations is depicted in Fig. 6. It was assumed to be normally distributed and this assumption was confirmed by a Chi Square goodness of fit test. The test is included in

Appendix D. The mean and standard deviation was -1.3 minutes and 10.1 minutes respectively. The distribution for the difference between the examining dentists' estimated service time and the actual service time for each patient was also normally distributed with a mean of -.8 minutes and a standard deviation of 14.5 minutes. Thus, the dentists underestimate slightly the service time required for each patient.

Summary of Dental Clinic Statistics

A brief summary of the data collected at the Dental Clinic is presented in Table I. The choice of appointment length for each patient is restricted to either 45 minutes or 90 minutes. As can be seen from Table I, the mean patient service time is less than the scheduled appointment length. During a six hour clinic, this difference could result in large amounts of dentist idle time. It can also be seen from Table I that the mean service time and the mean estimated service time (made by the dentist actually accomplishing the work) are fairly close. While in most cases this is true (76% of the estimates were within ten minutes), it should be pointed out that some estimates were off by as much as thirty minutes or more (see Fig. 6). Since this factor can cause large variations in the simulation results, it will be considered in the analysis of the simulation results.

Table I

Dental Clinic Statistics *

Distribution	Length of Appointment		
	45 Minutes	90 Minutes	Combined 45 & 90 Minutes
Patient Arrival Time	Mean 10.2min. S.D. 8.7min. n=153	Mean 11.8min. S.D. 11.1min. n=25	Mean 10.4min. S.D. 9.0min. n=178
Patient Waiting Time	Mean 14.2min. S.D. 10.1min. n=153	Mean 12.5min. S.D. 8.0min. n=25	Mean 14.0min. S.D. 9.8min. n=178
Actual Service Time	Mean 37.2min. S.D. 10.1min. n=153	Mean 71.8min. S.D. 19.3min. n=25	Mean 42.1min. S.D. 17.8min. n=178
Dentist Estimated Service Time	Mean 35.1min. S.D. 11.1min. n=153	Mean 75.8min. S.D. 13.7min. n=25	Mean 40.8min. S.D. 18.2min. n=178
Examining Dentist Estimated Service Time			Mean 37.4min. S.D. 12.8min. n=58
Actual Service Time For Examining Dentist Estimates			Mean 38.1min. S.D. 12.3min. n=58

* Results from data collected at Dental Clinic from 9 August 1971 to 30 September 1971. Each statistic is based on the number of observations denoted by n.

As can be seen from Table I, the average patient waiting time is approximately 14 minutes. Since the patients' mean arrival time is ten minutes prior to their scheduled appointment time, this indicates that on the average each patient is called four minutes after his scheduled appointment time. This waiting time is considered quite small in comparison with the waiting time of other clinics at the WPAFB Medical Center. This factor is considered in analyzing the simulation results and it is not expected to increase without either an increase in the number of patients being served or a decrease in the dentists' idle time.

IV. THE SIMULATION MODELS

Two different computer simulation programs were used in this study and will be referred to as simulation model A and simulation model B. Each was written in FORTRAN IV (rather than in a simulation language) in order to facilitate understanding by any individual with a basic computer programming background. Both computer programs were written for use on the IBM 360/40/G computer and may require some conversions if a different computer is used. The computer simulation programs were developed and debugged over a period of approximately four weeks. Although there are many possible alternative appointment scheduling systems which could be tested by the simulation models, the actual number of systems tested was limited by the time available for simulation. Should it become necessary to simulate additional systems, both simulation program packages can be obtained from Mr. Robert Bachert, WPAFB (AMRL/HES), ext. 54343.

The following is a brief explanation of the simulation models.

Simulation Model A

Simulation model A simulates a Dental Clinic session of six hours duration. It simulates one dentist scheduling patient appointment times according to his estimate of

the time required to complete each patient. A computer flow diagram and complete program are included in Appendix E. Since an individual appointment system schedules each patient with a specific dentist, this simulation is of a single-server type queueing system. Alternative available appointment lengths were introduced into the computer simulation model and the results were analyzed.

Basic Assumptions

Most simulation problems involve assumptions about certain aspects of the problem. The following assumptions were required in the development of simulation model A:

(1) The waiting room has sufficient space for an unlimited buildup of the queue.

(2) The patient arrival distribution is not affected by the queue length, i.e., patients don't turn away when the queue length is long.

(3) Patients will be selected from the queue on an earliest appointment time basis.

(4) Dentists will not intentionally overestimate the service time required for each patient in order to insure more than sufficient time to complete each patient.

(5) Service time does not vary between dentists. Although this factor probably does not hold, the small number of patients seen (from 5 to 10 per clinic session) will allow some variance without adversely affecting

the results of the simulation.

(6) The IBM 360 pseudorandom number generator generates perfectly random numbers.

Starting Conditions

The simulation model starts at time = 0 minutes and the first appointment is scheduled for time = 60 minutes. The dentist is considered to be available and begins service at time = 65 minutes. This provides five minutes at the beginning of each clinic session to prepare for the first patient or for the possibility of a late dentist arrival.

Time-Flow Mechanism

The computer program must be written in such a way that it moves the model through simulated time, causing events to occur in the proper order and with a proper time interval between successive events. The method used in this simulation is a form of the variable increment method (Ref 8:158). Total time available for scheduling patient appointments is 360 minutes. Each patient's appointment length is subtracted from the time available. The simulated day ends when there is no more time available to schedule more patients or when the remaining time is less than the smallest available appointment length.

Process Generators

The process generators are the mechanisms by which the variables involved in a simulated system are represented. The variables used in this model were estimated service times, patient arrival times and estimated minus actual service times.

Estimated service times. The method of generating random estimated service times utilized the uniform distribution of numbers between 0 and 1. A computer subroutine computes the cumulative distributions of 100 points between 5 minutes and 95 minutes of a gamma probability density function with shape parameter = 5.0143 and scale parameter = 8.1374. The cumulative distribution and associated times are presented in Table II. A random number was generated and the appropriate estimated service time was determined from the associated cumulative distribution interval. The distribution was limited to values between five minutes and ninety-five minutes since there were no observed estimates less than five minutes or greater than ninety-five minutes. The actual distribution of estimated service times was also introduced into the simulation model and the results from each of these distributions were compared and analyzed. The actual distribution and associated times are presented in Table III. The dentists' estimates were to the nearest five minutes. The large intervals at the 30 minute and 45 minute levels are an indication of the large number of

Table II

Estimated Service Time (Gamma) Distribution

Service Time (min.)	Cum. dist.	Service Time (min.)	Cum. dist.	Service Time (min.)	Cum. dist.
5.00	.0004	35.91	.4486	65.91	.9049
5.91	.0009	36.82	.4699	66.82	.9109
6.82	.0017	37.73	.4909	67.73	.9165
7.73	.0029	38.64	.5116	68.64	.9218
8.64	.0046	39.55	.5319	69.55	.9268
9.55	.0069	40.45	.5519	70.45	.9316
10.45	.0100	41.36	.5714	71.36	.9360
11.36	.0138	42.27	.5905	72.27	.9402
12.27	.0186	43.18	.6091	73.18	.9441
13.18	.0243	44.09	.6272	74.09	.9478
14.09	.0311	45.00	.6447	75.00	.9513
15.00	.0390	45.91	.6618	75.91	.9546
15.91	.0479	46.82	.6783	76.82	.9577
16.82	.0580	47.73	.6942	77.73	.9605
17.73	.0692	48.64	.7097	78.64	.9632
18.64	.0815	49.55	.7245	79.55	.9658
19.55	.0949	50.45	.7388	80.45	.9681
20.45	.1093	51.36	.7525	81.36	.9703
21.36	.1247	52.27	.7657	82.27	.9724
22.27	.1410	53.18	.7784	83.18	.9743
23.18	.1583	54.09	.7905	84.09	.9761
24.09	.1763	55.00	.8021	85.00	.9778
25.00	.1951	55.91	.8132	85.91	.9794
25.91	.2145	56.82	.8238	86.82	.9809
26.82	.2345	57.73	.8339	87.73	.9822
27.73	.2549	58.64	.8435	88.64	.9835
28.64	.2758	59.55	.8526	89.55	.9847
29.55	.2971	60.45	.8613	90.45	.9858
30.45	.3185	61.36	.8696	91.36	.9869
31.36	.3402	62.27	.8774	92.27	.9878
32.27	.3620	63.18	.8849	93.18	.9887
33.18	.3837	64.09	.8919	94.09	.9895
34.09	.4055	65.00	.8986	94.99	.9903
35.00	.4271				

Table III

Estimated Service Time (Actual) Distribution

Service Time (min.)	Cum. dist.	Service Time (min.)	Cum. dist.	Service Time (min.)	Cum. dist.
10	.0112	40	.6467	70	.9040
15	.0337	45	.8152	75	.9217
20	.1180	50	.8486	80	.9383
25	.1573	55	.8593	85	.9619
30	.3876	60	.8711	90	.9943
35	.4724	65	.8875	95	.9999

estimates at these times. Also, these estimates may be biased toward a forty-five minute and ninety minute appointment scheduling system since they were made while this type of scheduling system was in effect. From a comparison of Tables II and III (especially at the thirty minute and forty-five minute levels), a random number would be expected to generate smaller values from Table III than from Table II. These factors were considered in analyzing the simulation results.

Patient arrival times. Each patient's arrival time was determined by subtracting a normally distributed variate with an expected value of 10.4 minutes and a standard deviation of 9.0 minutes from the patient's scheduled appointment time. The IBM 360 subroutine GAUSS was used to generate this variate. The normal distribution was truncated at - 20 minutes and + 45 minutes, which assured that more than 99% of the possible arrival times

(from theoretical distribution) were being included in the simulation model. These limits compare favorably with the data collected at the Dental Clinic since there were no patient arrivals earlier than 45 minutes before appointment time or later than 20 minutes after appointment time.

Service times. The service time required for each patient was determined by subtracting a normally distributed variate with an expected value of - 1.3 minutes and a standard deviation of 10.1 minutes from the estimated service time for that patient. As before, the variate was generated through the use of the subroutine GAUSS.

Output Format

The computer output format for the results of each simulated schedule is depicted in Fig. 7. Five alternative appointment scheduling systems were simulated and are designated by the appointment system. The specific available appointment lengths for each simulated run are designated by the "schedule". The following abbreviations were used in the output format and are explained in Appendix E:

NP	-	Number of patients.
DIT	-	Dentist idle time.
DBT	-	Dentist busy time.
PWT	-	Patient waiting time.
DAVAL	-	Dentist availability time.

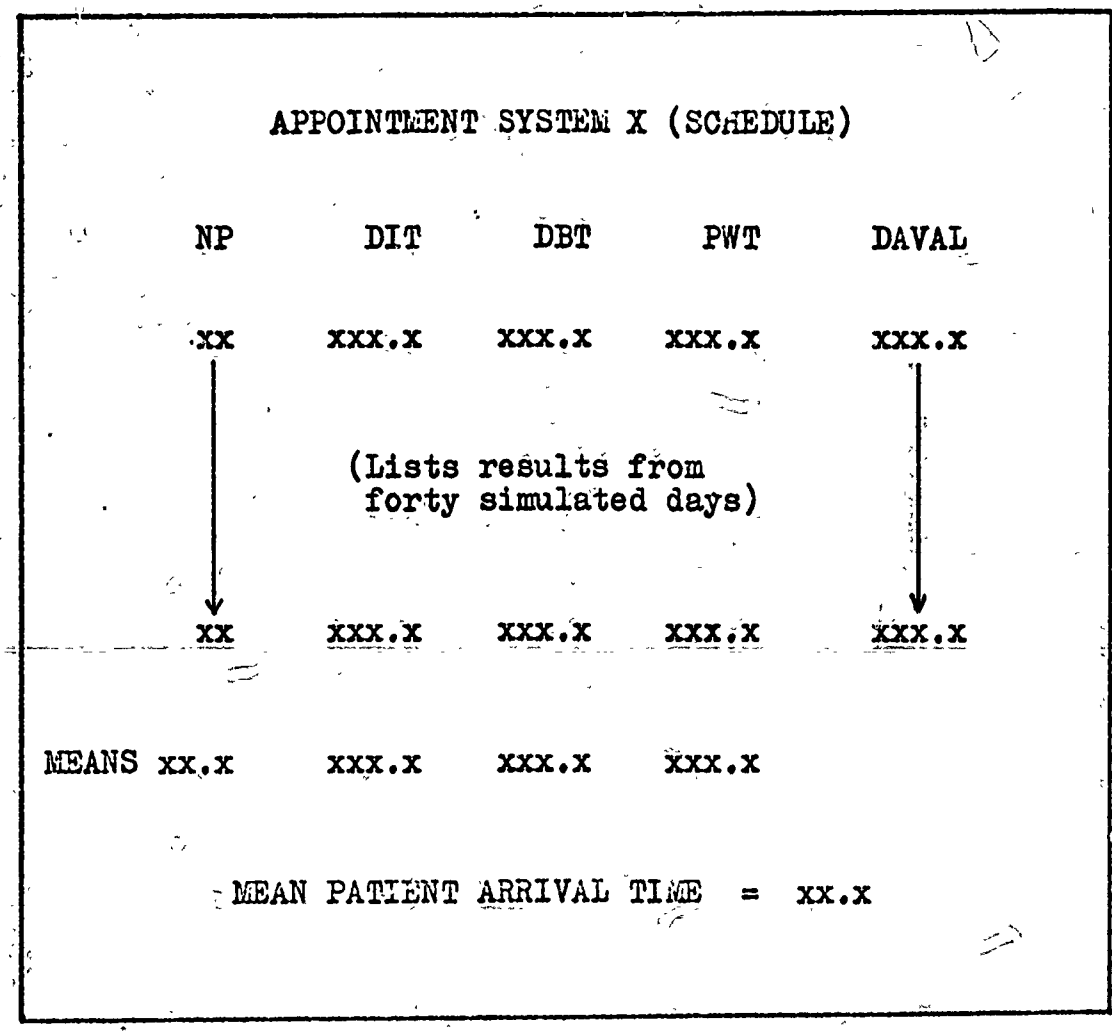

Fig. 7. Output Format For Simulation Model A

Each alternative appointment scheduling system was simulated for both 20 and 40 clinic sessions. Although the results from the forty runs were used, a comparison of the average results for the different sized runs showed little difference in the average figures. The average number of patients scheduled was within one tenth, the average patient waiting time within one minute and the average dentist idle time within three minutes. The total for each of the above variables are listed for each of the simulated days.

Following the last day the average figures for the forty runs are printed out.

Also included in the output is the mean patient arrival time for the forty simulated clinic sessions. This was used as an aid in validating the simulation model and compared quite favorably with the expected value of the patient arrival time distribution. As was stated by Mize and Cox (Ref 8:164), "A computer simulation model is considered valid if it produces results that are very close to the results that would be produced by the real-world system the computer model is supposed to represent." Further validation was accomplished by checking the results for each simulated day to assure that the model did not schedule more or fewer patients than the time period would allow, i.e., if the simulated schedule was for 45 minute and 90 minute appointments the number of patients scheduled should not be fewer than four or more than eight for any given day. This minimum or maximum number of patients scheduled was not exceeded for any of the simulated days. These validation results assured that simulation model A was acceptable for the purpose of this thesis.

Simulation Model B

Simulation model B was originally written and used in a study of the appointment scheduling system for the OB-GYN Clinic at the WPAFB Medical Center (Ref 4). A complete computer flow diagram and program can be found

in Appendix C of Outpatient Scheduling, A Simulation Approach (Ref 4). Two changes in the computer simulation program were necessary to allow for its use in this study. The first change was to allow no walk-in patients during the simulated period. This was necessary since the Dental Clinic treats walk-in patients on an availability basis only. The second change was concerned with the number of dentists available during the simulated clinic sessions. In the original model a random number of doctors (from one to six) was generated every thirty minutes. The program was changed so that a fixed number of dentists (from one to ten) would be available throughout the entire simulated clinic session. Both changes required only minor corrections to the original program. Simulation model B was also modified so that patients scheduled for their initial appointment received an appointment length based on the examining dentists estimate of the service time required to complete each patient. A copy of this modified program is included in Appendix F.

Simulation model B utilizes the patient arrival times and service times developed in Chapter III to simulate the conditions existing at the Dental Clinic during this study. By fixing the number of dentists at one and varying both the number of patients and the time interval between appointments, the simulated results can be compared with the actual results (developed in Chapter III)

from the appointment scheduling system being used during this study. The model also has the capability of simulating a Mixed Block-Individual appointment scheduling system. The number of dentists can be fixed at greater than one and again the number of patients and the time interval between appointments can be varied. With this system the patients are not scheduled with a specific dentist and are seen on an earliest arrival time basis. The Dental Clinic could utilize this type appointment scheduling system by scheduling patients for their initial appointment on different days than those scheduled for follow-up appointments. This should not cause any particular scheduling problems and actually would be desirable if all follow-up appointments were to be scheduled according to the dentist's estimate of the service time required to complete each patient. An Individual appointment system would be used for all follow-up appointments and either an Individual or a Mixed Block-Individual appointment system could be used for all patients on their initial appointment.

Basic Assumptions

The following list of assumptions was required in the development of simulation model B. Several of these assumptions (in quotation marks) are the same as were required in the original model (Ref 4:33) and others coincide with the assumptions used in simulation model A.

(1) "The waiting room has sufficient space for an unlimited buildup of the queue."

(2) "Arrival distribution is not affected by the queue length, i.e., patients don't turn away when the queue length is long."

(3) Service time does not vary between dentists. As was discussed in model A, a small variance will not adversely affect the simulation results because of the small number of patients seen by each dentist during a clinic session.

(4) When the number of dentists being simulated is greater than one, patients will not refuse to see a particular dentist in order to wait for another.

(5) "Patients will be selected from the queue on an earliest arrival time basis."

(6) "The IBM 360 pseudorandom number generator generates perfectly random numbers."

Starting Conditions and Time Increment

As with model A, simulation model B starts at time = 0 minutes and the first appointments are scheduled for time = 60 minutes. All dentists are considered to be available and begin service at time = 65 minutes. This provides five minutes at the beginning of each clinic session to prepare for the first patient or for the possibility of a late dentist arrival. In regard to the scheduling systems simulated in Chapter V, time = 60

minutes simulates 0700 hours.

A form of the variable increment method is again used for the advancement of simulation time. Simulation model B advances from one event to the next on the basis of the earliest event time. As soon as a dentist completes one patient, the next patient to be serviced is the one with the earliest arrival time.

Process Generators

The variables used in simulation model B were patient arrival times, examining dentists' estimated service times, actual restorative service times and examining dentists' estimated minus actual service times. Patient arrival times were generated in the same manner as was utilized in simulation model A.

Examining dentists' estimated service times. The method of generating random examining dentists' estimated service times utilized the uniform distribution of numbers between 0 and 1. A computer subroutine computes the cumulative distributions of 100 points between 15 minutes and 90 minutes of a gamma probability density function with shape parameter = 8.4772 and scale parameter = 4.4135. The cumulative distribution and associated times are presented in Table IV. The distribution was limited to values between fifteen minutes and ninety minutes since there were no estimates less than fifteen minutes or greater than ninety minutes.

Table IV

Examining Dentists' Estimated Service Time (Gamma) Distribution

Estimated Service Time (min.)	Cum. dist.	Estimated Service Time (min.)	Cum. dist.	Estimated Service Time (min.)	Cum. dist.
15.00	.0143	40.75	.6431	65.75	.9726
15.75	.0188	41.51	.6635	66.51	.9751
16.51	.0241	42.27	.6831	67.27	.9773
17.27	.0305	43.03	.7021	68.02	.9794
18.03	.0380	43.78	.7202	68.78	.9813
18.78	.0466	44.54	.7377	69.54	.9830
19.54	.0564	45.30	.7544	70.30	.9846
20.30	.0674	46.06	.7703	71.06	.9860
21.06	.0796	46.81	.7854	71.82	.9874
21.81	.0932	47.57	.7999	72.57	.9886
22.57	.1079	48.33	.8135	73.33	.9897
23.33	.1239	49.09	.8265	74.09	.9906
24.09	.1410	49.84	.8387	74.84	.9916
24.84	.1593	50.60	.8503	75.60	.9924
25.60	.1787	51.36	.8612	76.36	.9931
25.36	.1990	52.12	.8714	77.12	.9938
27.12	.2202	52.87	.8810	77.87	.9944
27.87	.2422	53.63	.8900	78.63	.9950
28.63	.2650	54.39	.8985	79.39	.9955
29.39	.2883	55.15	.9064	80.15	.9959
30.15	.3121	55.90	.9137	80.90	.9963
30.90	.3363	56.66	.9206	81.66	.9967
31.66	.3609	57.42	.9270	82.42	.9970
32.42	.3855	58.18	.9329	83.18	.9973
33.18	.4103	58.93	.9384	83.93	.9976
33.93	.4350	59.69	.9435	84.69	.9979
34.69	.4596	60.45	.9483	85.45	.9981
35.45	.4841	61.21	.9526	86.21	.9983
36.21	.5082	61.96	.9567	86.96	.9985
36.96	.5319	62.73	.9604	87.72	.9986
37.72	.5553	63.48	.9638	88.48	.9988
38.48	.5781	64.24	.9670	89.24	.9989
39.24	.6004	64.99	.9699	89.99	.9990
39.99	.6221				

Service times. The method of generating random service times utilized the uniform distribution of numbers between 0 and 1. This is the same method used to generate estimated service times in simulation model A. A computer subroutine computes the cumulative distributions of 100 points between 10 minutes and 100 minutes of a gamma probability density function with shape parameter = 5.5836 and scale parameter = 7.5381. The cumulative distribution and associated times are presented in Table V. A random number was generated to determine the appropriate service time. The distribution was limited to values between 10 minutes and 100 minutes since there were no observed service times less than 10 minutes or greater than 100 minutes.

The service time for each patient (whose appointment length was based on the examining dentists' estimate) was determined by subtracting a normally distributed variate with an expected value of -.8 minutes and a standard deviation of 14.5 minutes from the examining dentists' estimated service time for that patient.

Table V

Service Time (Gamma) Distribution

Service Time (min.)	Cum. dist.	Service Time (min.)	Cum. dist.	Service Time (min.)	Cum. dist.
10.00	.0048	40.91	.5299	70.91	.9312
10.91	.0070	41.82	.5503	71.82	.9358
11.82	.0100	42.73	.5703	72.73	.9402
12.73	.0137	43.64	.5898	73.64	.9443
13.64	.0182	44.54	.6088	74.54	.9481
14.54	.0237	45.45	.6273	75.45	.9517
15.45	.0301	46.36	.6453	76.36	.9551
16.36	.0376	47.27	.6628	77.27	.9582
17.27	.0461	48.18	.6797	78.18	.9612
18.18	.0558	49.09	.6960	79.09	.9640
19.09	.0666	50.00	.7118	80.00	.9665
20.00	.0784	50.91	.7269	80.91	.9689
20.91	.0914	51.82	.7415	81.82	.9712
21.82	.1054	52.73	.7556	82.73	.9733
22.73	.1204	53.64	.7690	83.64	.9752
23.64	.1364	54.54	.7819	84.54	.9771
24.54	.1533	55.45	.7942	85.45	.9788
25.45	.1711	56.36	.8060	86.36	.9803
26.36	.1897	57.27	.8173	87.27	.9818
27.27	.2089	58.18	.8280	88.18	.9832
28.18	.2288	59.09	.8382	89.09	.9844
29.09	.2493	60.00	.8479	90.00	.9856
30.00	.2702	60.91	.8572	90.91	.9867
30.91	.2915	61.82	.8659	91.82	.9877
31.82	.3131	62.73	.8742	92.73	.9887
32.73	.3350	63.64	.8821	93.64	.9895
33.64	.3570	64.54	.8895	94.54	.9903
34.54	.3790	65.45	.8966	95.45	.9911
34.45	.4011	66.36	.9032	96.36	.9918
36.36	.4231	67.27	.9095	97.27	.9924
37.27	.4449	68.18	.9154	98.18	.9930
38.18	.4666	69.09	.9210	99.09	.9936
39.09	.4880	70.00	.9262	99.99	.9941
40.00	.5091				

Output Format

The computer output format for the results of each simulation run is depicted in Fig. 8. Each alternative appointment system was simulated over 25 clinic sessions.

APPOINTMENT SYSTEM X (RUN Y)

AVERAGE PATIENT WAITING TIME	=	xx.xx
AVERAGE LENGTH OF IDLE TIME	=	xx.xx
AVERAGE DENTIST IDLE TIME	=	xx.xx
MEAN EARLY AT* OF PATIENT	=	xx.xx
MEAN SERVICE TIME	=	xx.xx
LENGTH OF CLINICAL SESSION	=	xx.xx
NUMBER OF WALK-IN PATIENTS	=	xx
NUMBER OF DENTISTS AVAILABLE	=	xx.xx

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ.	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.			
	10.			
	15.			
	20.			
	25.			
	30.			
	35.			
	40.			
	45.			
	50.			
	55.			
	60.			
OVER	60.			

*AT = Arrival Time

Fig. 8. Output Format For Simulation Model B

The run number designates the particular clinic session being simulated. A combined output is produced at the end of the 25 runs with each appointment system. The combined output presents average figures from the previous 25 runs and the individual waiting times are cumulative figures combining the results of the individual runs. Entries for patient arrival time and service time are recorded as zeros in the combined output. The cumulated output for each of the simulated appointment systems (1-27) utilized by simulation model B are contained in Appendix G.

Each output contains the mean value for both the patient arrival times and the service times. These were used as an aid in validating the simulation model and compared quite favorably with the expected values of the patient arrival time distribution and the service time distribution. Also, each output was checked to assure that no walk-in patients were considered and that the number of dentists available during each of the 25 simulated clinic sessions was the same as had been specified for that particular appointment system. The final test of validation was the simulation of the appointment system being used during this study. This system is approximated by appointment system 5 in Chapter V. The simulation results revealed an average patient waiting time of 13.7 minutes for the 25 simulated runs. This compared quite favorably with the 14 minute

average patient waiting time developed in Chapter III. This system was expected to produce large amounts of dentist idle time and the simulated results indicate an average dentist idle time of 56 minutes for the 25 simulated runs. The above validation results assured that the simulation model was acceptable for the purpose of this thesis.

V. ALTERNATIVE APPOINTMENT SCHEDULING SYSTEMS

An "ideal" appointment scheduling system would be one in which each patient's arrival time coincided exactly with the completion time of the previous patient. Due to the varying lengths of service time required for each patient and the unpunctuality of patient arrivals, this "ideal" system is impossible to attain. Assuming a dentist can service only a specified number of patients within a given amount of time, the search for an efficient appointment scheduling system is centered around the objectives of scheduling the maximum number of patients while attempting to minimize both dentist idle time and patient waiting time. It should be recognized that these are conflicting objectives and that a balance between each must be sought.

Individual Appointment System

Scheduling patients for their initial appointment during a particular clinic session poses the problem of how many patients to schedule and at what time intervals. With an individual appointment scheduling system, each dentist works individually with a specified number of patients. This type of system can be simulated using simulation model B and fixing the number of dentists at one. There are an infinite number of alternative appointment systems which could be tested by the simulation model. The choice of appointment systems to be

tested was based on knowledge of the characteristics of the Dental Clinic, practicality of administering the appointment system and personal judgment.

The following abbreviations are used as an aid in presenting some of the simulation results in conjunction with the various appointment systems being simulated.

PWT - Patient waiting time. The number of minutes a patient would be required to wait before being called for his appointment. The number presented with each simulated appointment system is the average patient waiting time for the 25 simulated clinic sessions.

DIT - Dentist idle time. The number of minutes during a clinic session in which a dentist must await the arrival of his next patient. The number presented with each simulated appointment system is the average dentist idle time for the 25 simulated clinic sessions.

Clinic Length - The total number of minutes from the start of a clinic session until the last patient is completed. The number presented with each simulated appointment system is the average clinic length for the 25 simulated sessions.

Although there are 360 minutes available during a six hour clinic session, the simulated clinic lengths varied from thirty to forty minutes from one simulated session to the next. There are three main reasons why a particular clinic session might exceed 360 minutes.

One reason would be scheduling more patients than can be serviced during a six hour clinic. Such a system would usually result in an increase in PWT and a decrease in DIT. A second reason would be a combination of late patient arrival times and greater than average service time required for each patient. This could cause the time to build up during the clinic session and very likely exceed 360 minutes. The third reason pertains to the scheduled appointment time for the last patient or patients. Whenev ne or more patients is scheduled for an appointment within one hour from the end of the clinic session, several of the 25 simulated clinic sessions will exceed 360 minutes in length. This results from the simulation model accepting patient arrivals as late as twenty minutes after scheduled appointment times and generated service times as long as 100 minutes. Thus, an average clinic length of approximately 360 minutes or less would be desirable in order to assure that all scheduled patients can be completed during the clinic session.

The number of patients to be scheduled for one dentist during a six hour clinic is nearly deterministic. With a mean service time of 42 minutes and a standard deviation of approximately 18 minutes, the average service time for each patient may vary by several minutes. Even so, the maximum number of patients which can be expected to be serviced during a six hour clinic should not exceed

nine. Table VI outlines the first eight appointment systems that were simulated. The number of patients scheduled varied from nine to six and various appointment intervals were used. Presented below Table VI are the average results from the 25 simulated runs for each appointment system.

Appointment system one scheduled nine patients at 40 minute intervals and was clearly unsatisfactory. As was expected the average clinic length far exceeded the 360 minutes available. Appointment system two scheduled eight patients at 45 minute intervals and resulted in an average clinic length of 372 minutes. Although the Dental Clinic would rather not schedule eight patients with a dentist during a six hour clinic, a check of the Dental Clinic records for the months of October and November (1971) indicated that some dentists had been scheduled with eight patients. Most of the dentists in the restorative section of the Dental Clinic consider eight patients to be more than can be efficiently served during a six hour clinic. The figures appear to substantiate this claim since an average clinic length of 2 minutes was required to service the eight patients simulated for appointment system two. Appointment system three also scheduled eight patients but decreased the appointment interval to 40 minutes. The simulated results indicated an average clinic length of 356 minutes, however the average patient waiting time increased to

Table VI
(1 Dentist)
Alternative Appointment Systems (1-8)

	Number of Patients Scheduled							
	Appointment System							
Time	1	2	3	4	5	6	7	8
0700	1	1	1	1	1	1	1	1
0740	1		1					
0745		1		1	1			1
0750						1		
0820	1		1					
0830		1		1	1		1	
0840						1		
0900	1		1					
0915		1		1	1		1	1
0930						1		
0940	1		1					
1000		1		1			1	1
1020	1		1			1		
1045		1		1	1			1
1100	1		1					
1110						1		
1130		1		1	1		1	
1140	1		1					
1200						1		
1215		1			1		1	1
1220	1							
	9	8	8	7	7	7	6	6

	Minutes							
PWT	28.5	21.1	31.1	18.5	13.7	12.3	7.3	7.4
DIT	14.6	24.5	7.7	19.7	55.8	41.2	105	97
Clinic Length	397	372	356	328	364	349	356	347

31 minutes. This is more than twice the amount of waiting time experienced by patients during the data collection period.

Appointment systems four and five each schedule seven patients at 45 minute intervals, with one patient scheduled for a 90 minute appointment. The total service time of 308 minutes required to complete all patients is the same for both of these systems and can be obtained by subtracting the DIT from the clinic length. Appointment system four clearly provides the greatest assurance of completing all seven patients within the six hour clinic session. This system schedules the last patient for a 90 minute appointment and the simulated results indicate an average clinic length of 328 minutes. Although the patient waiting time is slightly higher with this system, the average DIT and average clinic length are much less than those associated with appointment system five. Appointment system five is approximately the system being used during this study. When seven patients were scheduled, the appointment interval was 45 minutes with one patient scheduled for a 90 minute appointment. The simulated results indicate an average PWT of approximately 14 minutes and an average DIT of 56 minutes. The average clinic length of 364 minutes resulted from scheduling the last patient 45 minutes from the end of the clinic session. Appointment system six also scheduled seven patients but increased the appointment interval to fifty minutes be-

tween each patient. The average results for this system show a decrease in each of the areas being considered and indicates a definite improvement over appointment system five.

Appointment systems seven and eight each schedule six patients at 45 minute intervals, with two patients receiving a 90 minute appointment. The average results from the 25 simulated runs indicate no problem in completing six patients during a six hour clinic session. In comparison with the first six systems, the PWT for these systems decreased while the DIT increased substantially. The results from the first eight simulated systems appear to indicate that seven patients per dentist can easily be serviced during a six hour clinic session. Eight patients scheduled at forty minute intervals can also be seen, however an average patient waiting time of approximately 31 minutes would be expected. While this may be true for an individual appointment scheduling system (in which each patient is scheduled for his initial appointment), it may not hold for a completely different type of scheduling system. This topic will be discussed in the next section.

Mixed Block-Individual Appointment System

Patients scheduled for their initial appointment would not necessarily have to be scheduled on an individual

basis with a specific dentist. During those clinic sessions in which each patient is scheduled for his initial appointment, a Mixed Block-Individual appointment system could be used. This type appointment scheduling system can be simulated using simulation model B. Although each patient has an appointment time, he does not have a specific appointment length. Patients are then serviced on an earliest arrival time basis. The number of dentists available will be fixed at three, four, or five. The number of patients and the appointment intervals will be varied and the simulation results analyzed.

Table VII outlines appointment systems nine through thirteen. Each of these systems schedules 32 patients with four dentists. The average results from the 25 simulated runs for each of the appointment systems are presented below Table VII. The efficiency of the Mixed Block-Individual system over the Individual system is brought out by a comparison of the results for appointment systems nine and two. Each of these systems schedule one patient per dentist at 45 minute intervals. The average results from system nine show a decrease in both the patient waiting time and the dentist idle time of approximately 9 minutes compared with the results for the individual system. Although the average clinic length is slightly longer (4 minutes) for appointment system nine, it should be pointed out that this represents the

Table VII
(4 Dentists)
Alternative Appointment Systems (9-13)

	Number of Patients Scheduled				
	Appointment System				
Time	9	10	11	12	13
0700	4	4	4	4	6
0740		4			
0745	4		5	5	
0800					5
0820		4			
0830	4		4	4	
0900		4			6
0915	4		5	5	
0940		4			
1000	4		4	4	5
1020		4			
1045	4		5	4	
1100		4			6
1130	4		5	4	
1140		4			
1200				2	4
1215	4				
	32	32	32	32	32

	Minutes				
PWT	12.5	24.1	25.1	22.0	22.6
DIT	15.2	2.9	3.2	4.1	6.1
Clinic Length	376	363	364	365	366

completion time for the last patient and does not represent the time required for each dentist to complete his last patient (which is characteristic of the Individual system).

The results for appointment system nine indicate an average clinic length of 376 minutes which is slightly longer than desirable. The average results for appointment systems ten through thirteen indicate the last patient would be completed in slightly more than 360 minutes, however, the average patient waiting time would be between 22 and 25 minutes. Although this is not an excessive amount of patient waiting time, it is higher than the 14 minutes being encountered by each patient during the data collection period. Thus, appointment system fourteen through nineteen schedule four dentists with either 30 patients or 28 patients. These systems are outlined in Table VIII along with the average results indicated. The average results indicate that each of these systems would be acceptable in regard to the average clinic length, since each is approximately 360 minutes or less. Appointment systems fourteen and fifteen each schedule 30 patients with system fourteen clearly showing the "best" balance between patient waiting time and dentist idle time. This system schedules four patients every 45 minutes, with the last two scheduled one hour from the end of the clinic session.

Appointment systems sixteen through nineteen each schedule 28 patients with four dentists and the results

Table VIII
(4 Dentists)
Alternative Appointment Systems (14-19)

	Number of Patients Scheduled					
	Appointment System					
Time	14	15	16	17	18	19
0700	4	4	4	4	4	4
0740		4				3
0745	4		4		3	
0750				4		
0820		4				4
0830	4		4		4	
0840				4		
0900		4				3
0915	4		4		3	
0930				4		
0940		4				4
1000	4		4		4	
1020		4		4		3
1045	4		4		3	
1100		4				4
1110				4		
1130	4		4		4	
1140		2				3
1200	2			4		
1215					3	
	30	30	28	28	28	28
	Minutes					
PWT	12.6	22.4	12.9	7.5	6.6	12.0
DIT	15.7	3.2	13.4	34.9	42.2	16.5
Clinic Length	361	348	332	353	363	335

present several possible trade-offs. Appointment systems sixteen and nineteen provide the "best" balance between PWT and DIT, however, the average clinic length for each of these systems indicate that the last patient would be completed approximately 25 minutes before the end of the clinic session. Should it be a specific objective of the Dental Clinic, these two systems would provide each dentist with approximately 25 minutes or more at the end of each clinic session to see emergency patients or walk-in patients. With a specific objective of decreasing PWT, appointment system seventeen schedules four patients every fifty minutes and the average results indicate a PWT of 7.5 minutes with an associated DIT of 35 minutes. A comparison of the average results for system sixteen with those of system four and for system seventeen with those of system six will again point out the efficiency of the Mixed Block-Individual appointment scheduling system over the Individual system. Each of these comparative systems schedules the same number of patients per dentist at the same time intervals, with both the average PWT and DIT being approximately six minutes less with the Mixed Block-Individual system.

The number of dentists available at the Dental Clinic may vary from time to time due to newly assigned personnel, leaves, sickness, etc. The above type appointment scheduling system was also simulated for both five dentists

Table IX
(5 Dentists)
Alternative Appointment Systems (20-23)

	Number of Patients Scheduled			
	Appointment System			
Time	20	21	22	23
0700	5	5	5	5
0740		5		
0745	5		5	
0750				5
0820		5		
0830	5		5	
0840				5
0900		5		
0915	5		5	
0930				5
0940		5		
1000	5		5	
1020		5		5
1045	5		5	
1100		5		
1110				5
1130	5		5	
1140		5		
1200	5			5
1215				
	40	40	35	35

	Minutes			
PWT	13.3	22.6	10.0	5.9
DIT	15.5	4.5	15.0	38.7
Clinic Length	377	365	331	354

Table X
(3 Dentists)
Alternative Appointment Systems (24-27)

	Number of Patients Scheduled			
	Appointment System			
Time	24	25	26	27
0700	3	3	3	3
0740		3		
0745	3		3	
0750				3
0820		3		
0830	3		3	
0840				3
0900		3		
0915	3		3	
0930				3
0940		3		
1000	3		3	
1020		3		3
1045	3		3	
1100		3		
1110				3
1130	3		3	
1140		3		
1200	3			3
1215				
	24	24	21	21

	Minutes			
PWT	17.9	25.4	13.6	8.8
DIT	13.0	2.7	16.4	37.9
Clinic Length	376	366	327	347

and three dentists. These systems are outlined in Tables IX and X. The results again indicate that eight patients per dentist can be seen by scheduling one patient per dentist every forty minutes, however, an average PWT of 22 to 25 minutes would be expected and the average clinic length would slightly exceed 360 minutes. Scheduling seven patients per dentist will substantially reduce the patient waiting time with the result that the last patient would be completed approximately 20 minutes before the end of the clinic session.

Scheduling Initial Appointments By Examining Dentists' Estimate

Each of the previous systems scheduled patients with an appointment time, but not with a specific appointment length. Since the results from Chapter III indicate that the examining dentists' may be able to estimate the approximate amount of time required for each patients initial appointment, simulation model B was utilized to sirulate scheduling each patients initial appointment length based on the examining dentists' estimate. Table XI outlines the alternative appointment systems to be simulated. The available appointment lengths and the associated per cent of patients to be scheduled for these appointment lengths are presented with each system. For example, scheduling twenty-four

Table XI

Alternative Appointment Systems (W,X,Y,Z)

Appointment System	Available Appointment Lengths (min.)	Per Cent of Total Patients Scheduled
W	20	16%
	30	30%
	40	30%
	50	15%
	60	9%
X	30	46%
	40	30%
	50	15%
	60	9%
Y	30	46%
	45	40%
	60	14%
Z	20	16%
	40	60%
	60	24%

patients with appointment system Y would result in eleven 30 minute appointments, nine 45 minute appointments and four 60 minute appointments. These numbers are acquired by multiplying the associated per cent by the total number of patients to be scheduled.

The percentages used for each of these appointment systems are based on the cumulative distribution for the examining dentists' estimates (see Table IV). A five minute increment was added to each of the available appointment lengths and the percentage associated with this number was taken from the cumulative distribution.

Thus, the percentages for appointment system X indicate that 46% of the examining dentists' estimates were equal to or less than 35 minutes, 30% were between 35 and 45 minutes, 15% were between 45 and 55 minutes and 9% were greater than 55 minutes. The five minute increment used with each appointment system was based on the judgment of the dentist in charge of the restorative section of the Dental Clinic as to what would be the most realistic and on personal knowledge of the characteristics of the Dental Clinic. Since less than six per cent of the examining dentists' estimates exceeded 60 minutes, this was utilized as the largest appointment length with each of the alternative systems. Although many other alternative appointment systems could have been simulated, the results from these four should provide adequate information to judge the most efficient type system.

Each of these systems was simulated with from three to six dentists and the number of patients to be scheduled was varied from six to ten per dentist. The average results from the 25 simulated runs for each of the simulated schedules are presented in Tables XII through XV and represent the results for three to six dentists, respectively. As was expected, the average clinic length increased as the number of patients per dentist was increased. Scheduling the total number of patients based on eight per dentist resulted in an average clinic length of less than 360 minutes with each of the alternative systems simulated.

Table XII
(3 Dentists)

Results From Scheduling Initial Appointments By Examining Dentists' Estimate

Appt. System	Number of Patients Scheduled	Average Patient Waiting Time	Average Dentist Idle Time	Average Clinic Length
W	18	15.7	8.8	243
X	18	13.4	12.1	246
Y	18	11.8	15.8	246
Z	18	12.4	16.2	253
W	21	18.0	10.2	288
X	21	14.7	13.6	293
Y	21	12.2	18.3	299
Z	21	11.7	18.9	304
W	24	22.6	7.5	334
X	24	16.0	16.3	345
Y	24	15.7	17.2	351
Z	24	15.2	19.4	348
W	27	21.3	9.7	371
X	27	16.2	16.4	376
Y	27	14.0	19.3	386
Z	27	12.6	26.7	394
W	30	25.4	7.8	408
X	30	18.9	14.2	409
Y	30	17.7	17.5	420
Z	30	17.3	25.5	430

Table XIII
(4 Dentists)

Results From Scheduling Initial Appointments
By Examining Dentists' Estimate

Appt. System	Number of Patients Scheduled	Average Patient Waiting Time	Average Dentist Idle Time	Average Clinic Length
W	24	18.1	5.0	245
X	24	15.7	7.3	247
Y	24	12.8	10.9	250
Z	24	10.7	14.1	261
W	28	19.9	4.0	291
X	28	15.7	6.2	293
Y	28	13.7	9.4	299
Z	28	13.1	15.3	307
W	32	19.7	5.4	335
X	32	16.2	9.1	338
Y	32	12.5	16.8	343
Z	32	11.4	21.0	354
W	36	19.3	9.1	357
X	36	18.4	11.0	368
Y	36	14.3	19.3	380
Z	36	11.7	22.1	395
W	40	21.6	9.1	412
X	40	17.2	9.7	414
Y	40	12.9	21.6	420
Z	40	10.5	31.3	432

Table XIV
(5 Dentists)

Results From Scheduling Initial Appointments
By Examining Dentists' Estimate

Appt. System	Number of Patients Scheduled	Average Patient Waiting Time	Average Dentist Idle Time	Average Clinic Length
W	30	19.0	3.3	255
X	30	16.5	5.2	261
Y	30	13.9	7.3	261
Z	30	11.5	9.6	262
W	35	19.7	4.6	285
X	35	14.6	9.1	288
Y	35	11.3	14.0	293
Z	35	12.0	14.0	299
W	40	22.8	4.5	333
X	40	18.0	7.1	334
Y	40	14.8	12.7	338
Z	40	11.9	17.7	353
W	45	23.5	3.9	368
X	45	19.1	6.4	374
Y	45	14.1	12.5	378
Z	45	10.9	22.1	397
W	50	19.5	6.0	403
X	50	15.3	10.9	404
Y	50	11.1	16.5	413
Z	50	9.3	23.9	426

Table XV

(6 Dentists)

Results From Scheduling Initial Appointments
By Examining Dentists' Estimate

Appt. System	Number of Patients Scheduled	Average Patient Waiting Time	Average Dentist Idle Time	Average Clinic Length
W	36	18.8	2.5	249
X	36	16.2	4.1	249
Y	36	12.8	6.5	252
Z	36	11.1	10.6	265
W	42	19.7	2.1	282
X	42	17.3	3.7	284
Y	42	13.9	6.3	287
Z	42	12.2	9.8	297
W	48	20.7	1.3	333
X	48	15.5	4.6	338
Y	48	12.6	8.5	343
Z	48	10.1	13.2	346
W	54	24.1	2.7	371
X	54	18.6	5.4	372
Y	54	14.7	11.2	377
Z	54	12.7	13.8	391
W	60	20.3	4.8	402
X	60	15.1	9.1	403
Y	60	13.2	17.3	421
Z	60	9.4	20.4	424

In only one case (Table XIII, Appointment System W, and 36 total patients) did scheduling nine patients per dentist result in a clinic length of less than 360 minutes. Thus, based on an average clinic length of 360 minutes or less, the maximum number of patients to be scheduled with each of these systems during a six hour clinic should be between 8 and 9 per dentist.

As an aid in analyzing the efficiency of each of the four alternative systems (W,X,Y and Z), Fig. 9 presents the possible trade-offs between average clinic length and the number of patients scheduled per dentist for four dentists. For a given number of patients, appointment system W would be expected to result in the shortest clinic length with systems X, Y and Z each slightly longer. Fig. 9 indicates an average clinic length of approximately 360 minutes would result from scheduling 8.1 patients per dentist with system Z, 8.4 patients per dentist with system Y, 8.7 patients per dentist with system X and approximately 9 patients per dentist with system W. Fig. 10 presents the possible trade-offs between average clinic length and the number of patients scheduled per dentist for five dentists.

The average patient waiting time versus the number of patients scheduled per dentist is depicted in Fig. 11 for four dentists. System W has the largest amount of average PWT and this was consistent with each of the

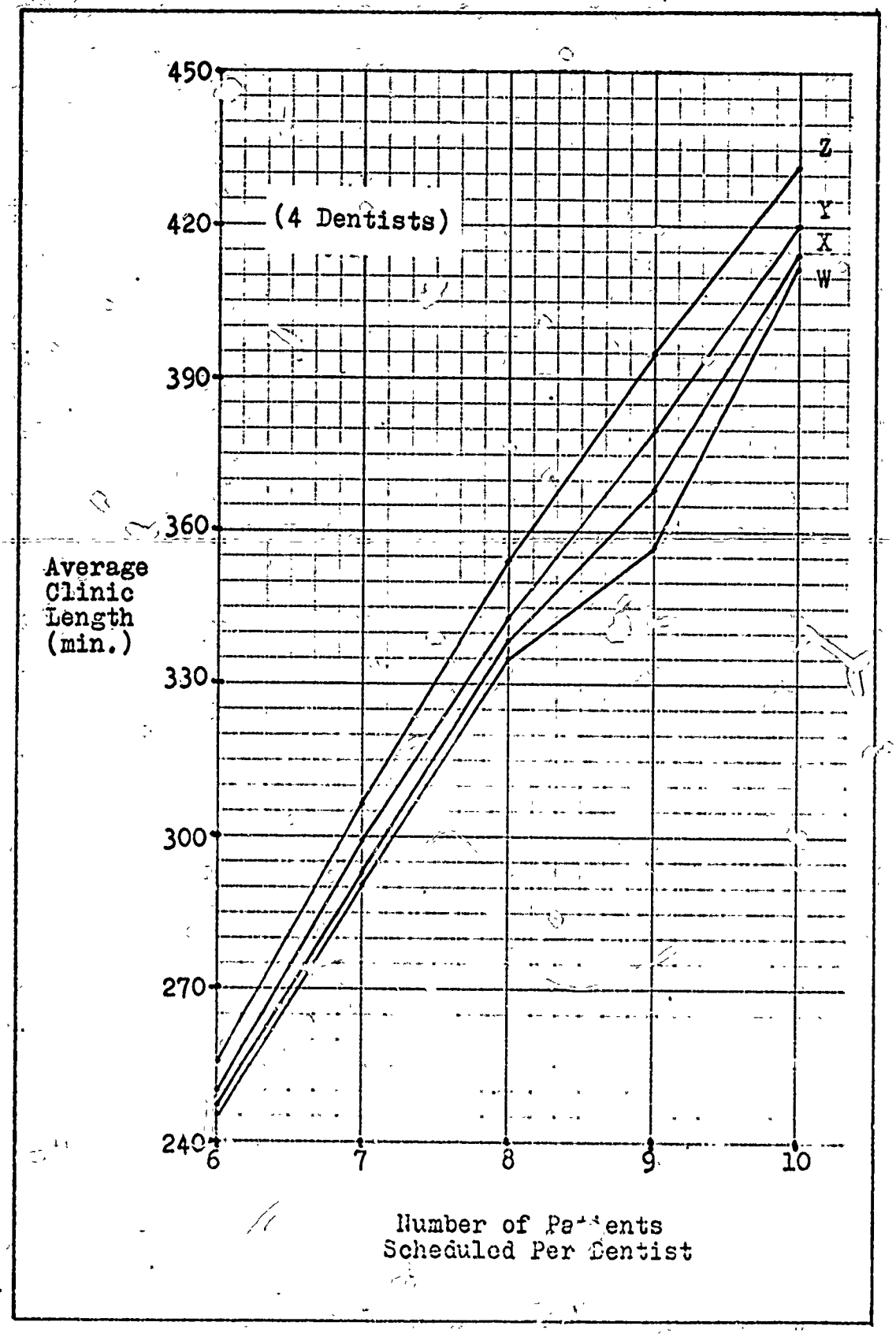

Fig. 9. Trade-offs Between Clinic Length, Number of Patients Scheduled (Appt. System W, X, Y, Z)

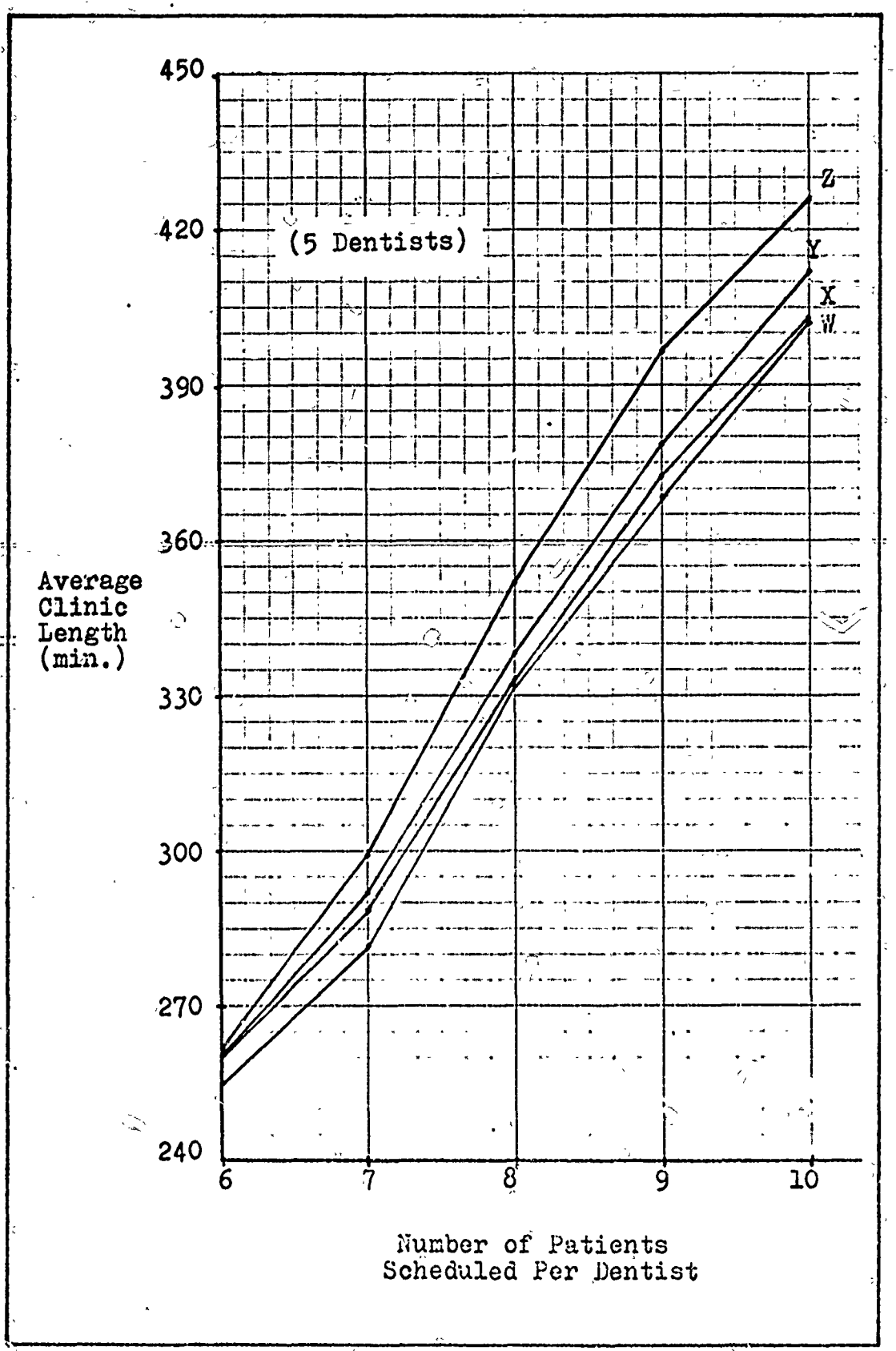

Fig. 10. Trade-offs Between Clinic Length & Number of Patients Scheduled (Appt. System W,X,Y,Z)

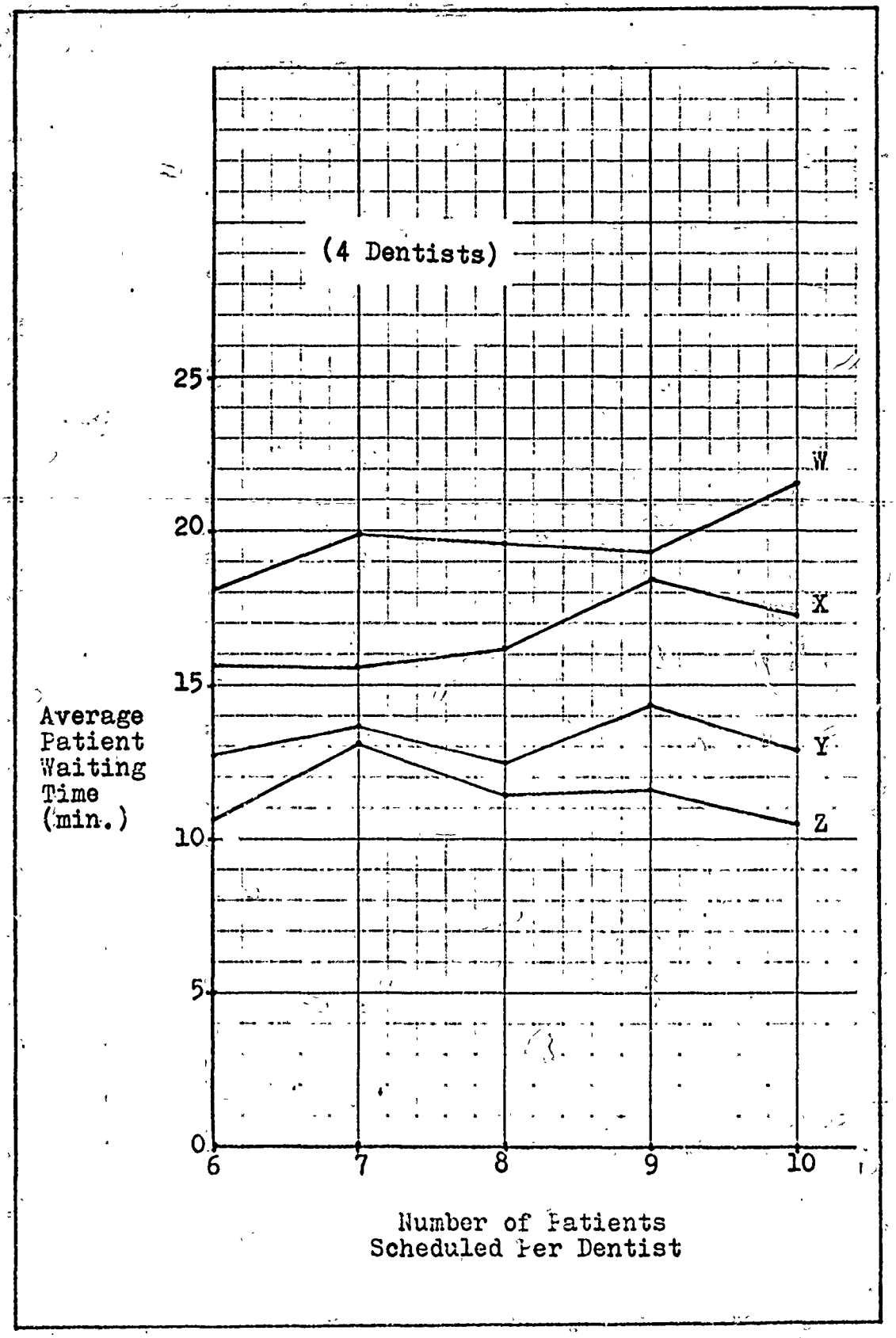

Fig. 11. Trade-offs between Patient Waiting Time/Number of Patients Scheduled (Appt. System W,X,Y,Z)

different schedules simulated. The results indicate system Z has the least amount of PWT and this was usually the case with each of the different schedules simulated. Although there was a slight variance, systems Y and Z resulted in an average patient waiting time of less than 15 minutes while systems X and W resulted in waiting times greater than 15 minutes.

Fig. 12 depicts average dentist idle time versus the number of patients scheduled per dentist for four dentists. The results indicate system W has the least amount of average DIT with systems X, Y and Z resulting in increasingly larger amounts. This trend was quite consistent with each of the different schedules simulated. Trade-offs between average PWT and average DIT with eight patients per dentist are presented in Fig. 13. Each point represents the system and number of dentists. Systems X and Y show the "best" balance between PWT and DIT, with system X having the least amount of dentist idle time and system Y having the least amount of patient waiting time.

Choosing the most efficient system requires subjective judgment concerning the desired balance between PWT, DIT, and average clinic length. The practicality of administering the alternative systems must also be considered. Appointment systems Y and Z may require less judgment on the part of the examining dentists since only three alternative appointment lengths need be considered

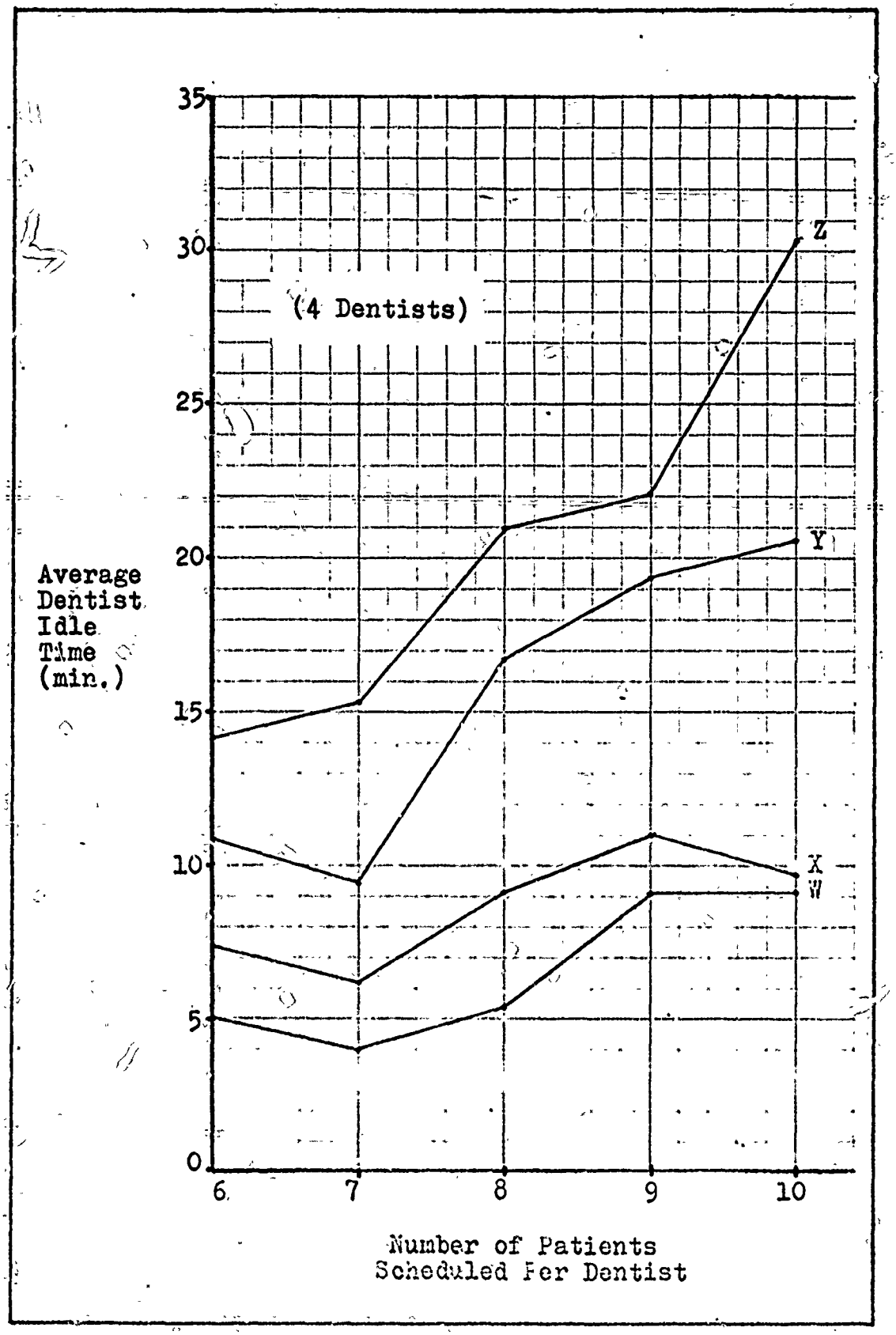

Fig. 12. Trade-offs Between Dentist Idle Time/Number of Patients Scheduled (Appt. Systems W,X,Y,Z)

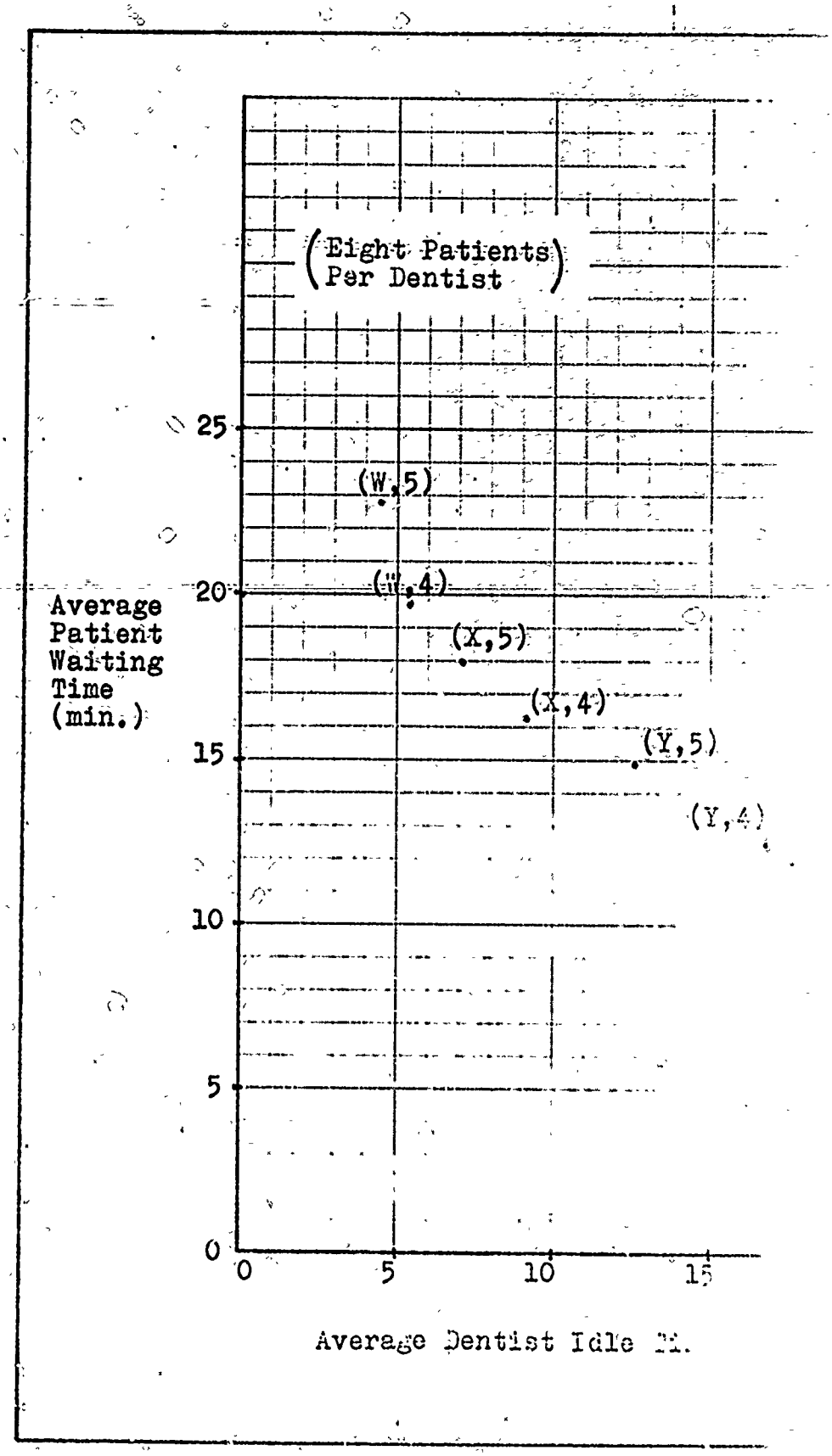

Fig. 13. Trade-offs Between Patient Waiting Time Dentist Idle Time Appt. System And Number Of Dentists)

for each patient. Once the desired system and total number of patients to be scheduled has been chosen, the number of each different appointment length can be determined. These appointment lengths are then arranged at random throughout the clinic session (based on the number of dentists available) so that all the shortest or longest appointments do not occur during one part of the clinic session. Although there are many different ways of arranging the appointment lengths throughout the clinic session, the simulation program utilized the same method with each simulated run. A copy of the modified program and two sample schedules are presented in Appendix F.

Once the appointment schedule has been determined (by appointment system, total number of patients to be scheduled and number of dentists available), it is used during those clinic sessions in which each patient is scheduled for his initial appointment. This would change only when the number of available dentists changed. The Dental Clinic has been provided with schedules ranging from fifteen patients scheduled with three dentists to sixty patients scheduled with six dentists. These provide schedules for clinic lengths ranging from approximately four to seven hours. Since the Dental Clinic schedules approximately one to two weeks in advance, matching patients with specific appointment lengths should not cause any administrative scheduling problems.

To assure that each of these systems would be administratively feasible, the simulation model scheduled patients on a daily basis. One days schedule was completed before scheduling patients for the next day, even though this might occasionally result in a patient receiving an appointment length greater than or smaller than the examining dentists' estimate.

The results from scheduling patients initial appointments based on the examining dentists' estimate of the time required to complete each patients first appointment indicate this type appointment scheduling system to be more efficient than either the Individual appointment system or the Mixed Block-Individual system. Eight patients can be seen in less than 360 minutes and a variety of trade-offs between patient waiting time and dentist idle time are available.

Scheduling Follow-up Appointments By Dentists' Estimate

An Individual appointment scheduling system would be necessary in order to schedule each patient with the same dentist until all required work had been completed. The system in use by the Dental Clinic during this study allowed each dentist to schedule follow-up appointments for 45 minutes or 90 minutes. The Dental Clinic appointment records for the month of November (1971) indicate more than 1200 patients were scheduled for restorative appointments with an average of 6.3 patients scheduled

per dentist during each six hour clinic. Although the number of patients scheduled with each dentist varied from four to eight, more than half were scheduled with either six or seven patients. The results for appointment systems five, seven and eight pointed out the possibility of incurring large amounts of dentist idle time with this type appointment system.

The results from Chapter III indicate the dentists' may be able to estimate the approximate amount of time required for each follow-up appointment. Thus, simulation model A was utilized to simulate one dentist scheduling appointment lengths according to his estimate of the time required to complete each patient. The five alternative appointment systems to be simulated are outlined in Table XVI. The available appointment lengths ranged from 20 minutes to 100 minutes and the interval between available appointment lengths varied from 10 minutes to 45 minutes. The selection of these systems was based on knowledge of the characteristics of the Dental Clinic, practicality of administering the system and personal judgment. Although many other alternative appointment systems could have been simulated, the results from these five systems should provide adequate information to judge the most efficient type system.

The following decision rules were utilized by the simulation model in assigning appointment lengths for the five alternative appointment systems. A ten minute

Table XVI

Alternative Appointment Systems (A through E)

Appt. System	Available Appointment Lengths (in minutes)
A	45, 90
B	30, 60, 90
C	20, 40, 60, 80, 100
D	30, 45, 60, 75, 90
E	30, 40, 50, 60, 70, 80, 90

increment was utilized with appointment systems A and B. The closest available appointment length to each estimated service time was assigned provided the estimate did not exceed that available appointment length by more than ten minutes. Otherwise, the first available appointment length larger than the estimated value was assigned. A five minute increment was utilized with appointment systems C, D and E. For example, an estimated service time of 46 minutes would result in a 45 minute appointment with systems A and D, a 60 minute appointment with systems B and C, and a 50 minute appointment with system E. Any estimate greater than the largest available appointment length received the largest available appointment length. These decision rules were based on the judgment of the dentist in charge of the restorative

section of the Dental Clinic as to what would be the most realistic and on personal knowledge of the characteristics of the Dental Clinic.

The average results from the forty simulated runs for each of these systems are presented in Table XVII. These results were obtained using the estimated service times from the gamma distribution. Complete results (utilizing the gamma distribution) for each of the simulated systems are contained in Appendix H. Each system was also simulated utilizing the estimated

Table XVII

Results From Scheduling Follow-up Appointments Based On Dentists' Estimate (Gamma Distribution)

Appt. System	Average Number of Patients Scheduled	Average Patient Waiting Time * (min.)	Average Dentist Idle Time (min.)	Average Clinic Length (min.)
A	6.8	9.3	48.7	340.1
B	8.0	15.0	23.5	357.5
C	8.3	15.2	21.0	358.7
D	8.3	16.1	16.3	355.5
E	8.3	19.8	11.2	363.0

* Waiting times are based on patient's arrival time not on patient's appointment time. The mean arrival time was approximately 10 minutes before the scheduled appointment time.

service times from the actual distribution and the average results are presented in Table XVIII. As was expected, the large number of estimates at the 30 minute and 45 minute levels resulted in a greater number of patients being scheduled. The large number of estimates at these levels would not be expected with each of the different systems being simulated, thus the results from Table XVII were used in analyzing the alternative appointment systems.

Table XVIII

Results From Scheduling Follow-up Appointments Based On Dentists' Estimate (Actual Distribution)

Appt. System	Average Number of Patients Scheduled	Average Patient Waiting Time * (min.)	Average Dentist Idle Time (min.)	Average Clinic Length (min.)
A	7.3	11.1	40.5	354.4
B	8.5	20.0	16.9	366.9
C	9.0	22.5	9.8	372.5
D	8.3	18.7	12.1	359.9
E	8.9	23.7	8.4	369.5

* Waiting times are based on patient's arrival time not on patient's appointment time. The mean arrival time was approximately 10 minutes before the scheduled appointment time.

The results from Table XVII indicate an average clinic length of less than 360 minutes for systems A through D and an average clinic length of 363 minutes with system E. These clinic lengths were obtained by adding the idle time and the service time associated with each of the systems. Thus, completing all scheduled patients during the clinic session would not appear to be a problem with any of these appointment systems.

The possible trade-offs between average patient waiting time, average dentist idle time and average number of patients scheduled (for appointment systems A through E) are presented in Fig. 14. Although appointment system A has the smallest amount of patient waiting time, it is by far the least efficient in regard to the number of patients scheduled and the average dentist idle time. The 48 minute average dentist idle time is more than twice that of any of the other systems and would clearly be less efficient than the other systems. Although appointment system E has the least amount of dentist idle time, it incurs the largest amount of patient waiting time (four to five minutes more than systems B, C and D) and also slightly exceeds the 360 minute length. This system provides available appointment lengths at ten minute intervals and would probably be the most difficult to administer. For these reasons, appointment system E would be considered less efficient than system B, C or D. Appointment system C is slightly better than system B

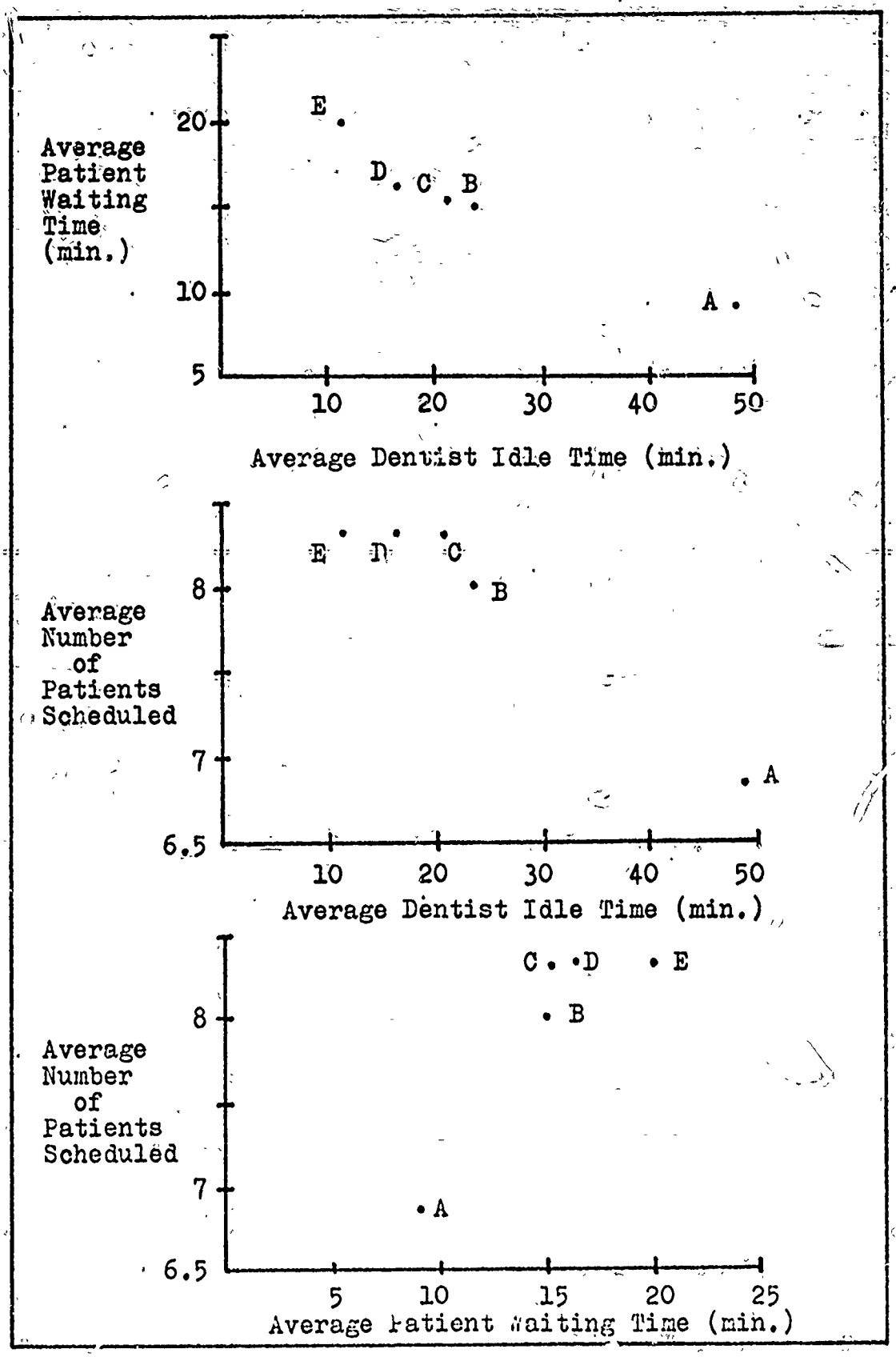

Fig. 14. Trade-offs Between Patient Waiting Time, Dentist Idle Time and Number of Patients Scheduled (Appt. Systems A-E)

since it schedules more patients and incurs less dentist idle time while having approximately the same amount of average patient waiting time. Choosing between systems C and D requires subjective judgment concerning the desired trade-off between patient waiting time and dentist idle time. System D incurs five minutes less idle time during each clinic session while requiring each patient to wait approximately one minute longer.

As a further aid in choosing between systems B, C and D, the variation in the results of the 40 simulated runs was analyzed. This refers to how the average figures were attained, i.e., were the results of all runs fairly consistent or did the average for each run fluctuate high and low seldom approaching the cumulated average. Table XIX presents the range of the individual run averages for waiting time, idle time and clinic length for systems B, C and D.

Table XIX

Waiting Time/Idle Time/Clinic Length Ranges
(Appt. Systems B, C, D)

Appt. System	Waiting Time Range (min.)	Idle Time Range (min.)	Clinic Length Range (min.)
B	2 to 40	0 to 81	321 to 398
C	1 to 35	0 to 69	305 to 415
D	5 to 34	0 to 69	302 to 399

Although system B is more stable in regard to average clinic length, it shows less stability in regard to waiting time and idle time. Appointment system D has slightly more stability than system C, however, the difference does not appear to be overwhelmingly significant. Thus, both systems C an D would appear to be the least sensitive to the random variables that influence the Dental Clinic operations.

In choosing between the alternative appointment systems, the practicality of administering the different systems should be considered. Appointment systems A and B closely resemble the system being used by the Dental Clinic during this study and should not present any particular scheduling problems. Appointment systems C through E provide available appointment lengths at intervals of 20, 15 and 10 minutes respectively and may cause some administrative scheduling problems. Although an analysis of these "possible" problems will not be attempted in this study, they should be considered in choosing the most efficient system. Thus, the choice between appointment system C and appointment system D would require subjective judgment concerning the trade-offs between patient waiting time and dentist idle time and the practicality of administering the particular system.

VI. CONCLUSIONS AND RECOMMENDATIONS

Based on the research accomplished during this study, the following conclusions were reached concerning the outpatient appointment scheduling system for the restorative section of the Dental Clinic at the WPAFB Medical Center:

(1) The appointment scheduling system used by the Dental Clinic during this study results in short patient waiting times (mean = 14 minutes) and large amounts of dentist idle time (45 minutes or more) which is characteristic of an Individual appointment scheduling system.

(2) The average estimated service times for both the examining dentists and the dentists actually accomplishing the restorations were quite close to the actual average service time for each patient. Therefore, the dentists' estimate of the service time required for each patient's next appointment should be used as an aid in assigning the appropriate appointment length for each patient.

(3) The use of a Mixed Block-Individual appointment system is more efficient than an Individual appointment system since it results in a decrease in both the patient waiting time and dentist idle time for the same number of patients scheduled.

Specific Recommendations

Based on the results from the alternative appointment systems simulated during this study, the practicality of administering the different appointment systems and personal judgment concerning the characteristics of the Dental Clinic; the following actions are recommended. A future date should be chosen (such as the first week of the next month) beyond which patients have not yet been scheduled for appointments. Patients scheduled for their first appointment should then be scheduled during different clinic sessions than those scheduled for follow-up appointments. It is recommended that three days a week (Monday, Wednesday and Friday) be utilized for follow-up appointments and the other two days be utilized for scheduling initial appointments. This is based on results from the data collection period which indicated approximately 45% of the patients were scheduled for their first appointment.

Appointment system D should be utilized in scheduling patients for their follow-up appointments. This system provides the dentists with the following choice of appointment lengths (30, 45, 60, 75 and 90 minutes) for each patient's follow-up appointment. The appointment books would be blocked in 15 minute increments and each patient's scheduled appointment length would be based on the dentists' estimate. Each patient would be scheduled

on an Individual basis with a specific dentist, which will allow each patient to be scheduled with the same dentist until all required work has been completed. This system would result in an average patient waiting time and average dentist idle time of approximately 16 minutes during each clinic session. It also shows a 1.5 increase in the number of patients scheduled per dentist compared with the present system (appt. system A). Thus, with five dentists available this system would average scheduling 41 patients during a six hour clinic session compared to 34 patients scheduled with the present system. This is an increase of 22%.

Scheduling patients for their initial appointment should be based on the examining dentists estimate of the time required for each patients first appointment and appointment system Y is recommended. This system requires the examining dentist to estimate each patients initial appointment length at either 30, 45 or 60 minutes. It is recommended that 32 patients be scheduled when four dentists are available and 40 patients when five dentists are available. The specific daily schedules to be used in each of these cases are included at the end of Appendix F. Each patient is scheduled with a specific appointment time and appointment length. The patients are not scheduled with a specific dentist and are serviced on an earliest arrival time basis. The average patient waiting time would be less than fifteen

minutes and the average dentist idle time less than seventeen minutes.

The number of patients recommended to be scheduled with system Y during each clinic session (eight per dentist) will result in an average clinic length of slightly less than 345 minutes. Although the simulation results indicate that one or two additional patients could be seen during a 360 minute clinic, the recommended number of patients provides greater assurance that all patients can be completed prior to the end of each clinic session and provides additional flexibility to the dentists actually accomplishing the restorations. The dentist idle time incurred will also provide a few additional minutes between each patient. The appointment length should be used as a guide, however, the dentists are not restricted to that amount of time and should accomplish that work which they consider appropriate. The results from Chapter V indicate the two recommended systems (D and Y) will increase the average number of patients scheduled per dentist by at least 1.7 (compared with the 6.3 patients per dentist presently being scheduled). This represents approximately a 25% increase in the number of patients scheduled or more than 300 additional patients scheduled each month.

As with any new system, caution should be used in judging the recommended appointment systems after only a few days operation. One to two months will probably

be required to allow both patients and staff to adjust to the new systems. If the results from the new appointment systems are unsatisfactory or additional improvements are desired, a follow-up study should be accomplished. The new systems may need only a slight adjustment, the simulation models may require a change to reevaluate the appointment systems or new input data may be required in order to evaluate additional appointment systems.

Current Trends in Dentistry

Although this thesis was concerned with scheduling dental patients into a system where each dentist services only one patient at a time, the current trends in dentistry are in other directions. Results from a recent study of dentistry in the United States (Ref 18) indicate a large imbalance between the population's dental needs and the number of available dentists. In 1970 it was estimated that the ratio of people qualified to perform dental care was one to every 1900 people who need it. This situation is not expected to improve in the next few years and has resulted in revisions to the traditional concepts of dentistry so that the dentist can provide more services in the same amount of time.

This need for increased productivity on the part of the dentist has brought about the following general trends in dentistry (Ref 18:3-162):

1. "To treat the patient from a seated rather than a standing position."
2. "To practice four-hand dentistry in the treatment of the supine patient."
3. "To redesign equipment to meet the needs of four-handed dentistry."
4. "To increase productivity through effective utilization of auxiliary personnel."
5. "To design effective multiple operatories."
6. "To improve dental radiography."
7. "To improve operatory illumination."
8. "To improve dental sterilization."
9. "In the military to provide comprehensive dental care to service personnel and their dependents."
10. "To establish preventive dental care facilities."

The practice of four-handed dentistry represents an advancement in the utilization of auxiliary personnel. The duties of qualified assistants are expanded to include certain routine treatment procedures usually performed by the dentist, such as rubber dam application, exposure of X-ray film, suture removal, the placement of restorative materials, etc. Experiments have been conducted using two, three, or four assistants per dentist, serving in various roles at from one to four chairs. "Studies by the Navy and the Public Health Service indicate that the most efficient team consists of one

dentist, three assistants, and one roving assistant serving three operators." (Ref 18:3-167)

Although the military ratio of dentists to patients is more favorable than the civilian ratio, a constant turnover of personnel makes it possible to provide only a small portion of the treatment needed. "A survey taken by the Air Force in 1962 showed that 36 percent of the officers and 50 percent of the enlisted personnel questioned said that the provision of dependents' dental care would affect their decision as to extending their periods of service." (Ref 18:3-175) Dental care for military dependents is presently authorized only in emergency cases or for dependents overseas or in remote areas. Although several of the current trends in dentistry are apparent at the WPAFB Dental Clinic, the clinic does not have the available equipment or the required number of qualified assistants to allow each dentist to service more than one patient at a time. Since dental care for all military dependents may become a requirement in the next few years, a future study is recommended concerning the requirements for space, equipment, number of dentists and assistants, etc. needed to allow each dentist to service more than one patient at a time.

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APPENDIX A

QUESTIONNAIRES USED IN DATA COLLECTION

GSA/SM/72-5

DENTAL CLINIC
USAF MEDICAL CENTER
Wright-Patterson AFB, Ohio

1. Examining dentist's estimate of time required for 1st appointment

_____ (Nearest 5 Min.) _____ (Tooth Number)

2. Name _____ (Last) (First)

3. SSAN _____

4. Today's Date _____ (Month) (Day)

5. Appointment Date _____ (Month) (Day)

6. Scheduled length of appointment

_____ 45 Minutes

_____ 1 Hour. 30 Minutes

_____ Other (Specify)

GSA/SM/72-5

PATIENT INFORMATION

1. Name _____ (Last) (First)
2. SSAN _____
3. Today's Date _____ (Month) (Day)
4. Time of arrival at clinic _____ (Nearest Minute)
5. Scheduled appointment time _____
6. This is my _____ (1st, 2nd, etc.) appointment in the series of appointments required after my dental check.
7. Scheduled length of appointment
   _____ 45 Minutes
   _____ 1 Hr. 30 Min.
   _____ Other (Specify)
8. Name of Dentist _____
9. Time called to Dentist's office _____ (Nearest Minute)
10. Time departed Dentist's office _____ (Nearest Minute)
11. Future appointment required
    _____ Yes
    _____ No

DENTIST INFORMATION

1. Estimated time required for this appointment

   _____ (Nearest 5 Min.) _____ (Tooth Number)

2. Was a dental assistant available for this appointment?

   _____ Yes _____ Full Time _____ Half Time
   _____ No _____ Other

3. Estimated time required for next appointment

   _____ (Nearest 5 Min.) _____ (Tooth Number)

APPENDIX B

CHI SQUARE GOODNESS OF FIT TEST

(ARRIVAL PATTERN)

Chi Square Test

Classes*	Observed Freq's (f_o)	Normal Prob.	Expected Freq's (f_e)	$\frac{(f_o-f_e)^2}{f_e}$
Less than -12	1	.0068	1 }	2.50
-12 to - 4	4	.0491	9 }	
- 4 to + 4	34	.1841	33	.03
+ 4 to +12	67	.3626	65	.06
+12 to +20	44	.2723	48	.33
+20 to +28	20	.1039	19 }	
+28 to +36	7	.0195	3 }	1.63
over +36	1	.0017	0 }	
	178		178	4.55

Computed Chi Square value = 4.55

Since 4.55 is less than 5.99, the Chi Square value with 5-2-1 or 2 degrees of freedom at the .05 level of significance, the arrival pattern is assumed to be normally distributed with mean = 10.4 and standard deviation = 9.0

* Positive values represent minutes arrived before appointment time. Negative values represent minutes arrived after appointment time.

APPENDIX C

KOLMOGOROV-SMIRNOV GOODNESS OF FIT TEST.

(ESTIMATED AND ACTUAL SERVICE TIMES)

The computer program used to conduct a Kolmogorov-Smirnov goodness of fit test (Ref 12:47) on the data obtained from the Dental Clinic was written by William B. Askren and Thaddeus L. Regulinski. A copy of the program can be found in Mathematical Modeling of Human Performance Errors for Reliability Analysis of Systems, AMRL-TR-68-93, dated January 1969.

Final Results of K-S Test (Gamma Distribution)

Dentist Service Times:

Shape parameter = 5.5836
Scale parameter = 7.5381
Mean = 42.09
Variance = 317.279
Mode = 34.55

Largest difference is 0.1178
Maximum K-S statistic allowable is 0.1222
K-S TEST ***PASSED***

Dentist Estimated Service Time

Shape parameter = 5.0143
Scale parameter = 8.1374
Mean = 40.80
Variance = 332.034
Mode = 32.66

Largest difference is 0.1699
Maximum K-S statistic allowable is 0.1222
K-S TEST ***FAILED***

Examining Dentist Estimated Service Time

Shape parameter = 8.4772
Scale parameter = 4.4135
Mean = 37.41
Variance = 165.125
Mode = 33.00

Largest difference is 0.2039
Maximum K-S statistic allowable is 0.2140
K-S TEST ***PASSED***

Actual Service Time For Examining Dentist Estimates

Shape parameter = 9.5657
Scale parameter = 3.9834
Mean = 38.10
Variance = 151.779
Mode = 34.12

Largest difference is 0.1127
Maximum K-S statistic allowable is 0.2140
K-S TEST ***PASSED***

APPENDIX D

CHI SQUARE GOODNESS OF FIT TEST

(ESTIMATED MINUS ACTUAL SERVICE TIME)

Chi Square Test

Classes*	Observed Freq's (f_o)	Normal Prob.	Expected Freq's (f_e)	$\frac{(f_o-f_e)^2}{f_e}$
Less than -30	1	.0023	0	
-30 to -25	1	.0073	1	4.57
-25 to -20	2	.0226	4	
-20 to -15	2	.0563	9	
-15 to -10	15	.1064	19	.84
-10 to - 5	29	.1645	29	.00
- 5 to 0	40	.1923	34	1.06
0 to + 5	41	.1807	32	2.53
+ 5 to +10	26	.1362	25	.04
+10 to +15	10	.0777	14	1.14
+15 to +20	4	.0358	7	
+20 to +25	1	.0132	2	.10
+25 to +30	4	.0047	1	
over +30	2	.0010	0	
	178			10.28

Computed Chi Square value = 10.28

Since 10.28 is less than 11.07, the Chi Square value with 8-2-1 or 5 degrees of freedom at the .05 level of significance, the difference in estimated and actual service time is assumed to be normally distributed with mean = -1.3 and standard deviation = 10.1

* Positive values represent minutes overestimated of service time required. Negative values represent minutes underestimated.

APPENDIX E

SIMULATION MODEL A

COMPUTER FLOW DIAGRAM AND PROGRAM

Listing of Program Variables

AAL - Actual appointment length. Service time to complete each patient.

AVV - Accumulates patient arrival times.

DAVAL - Dentist availability time. The total of DBT and DIT plus 65 minutes initial availability time.

DBT - Dentist busy time. Total of all AAL's for each day.

DIT - Dentist idle time.

ESTA - Shape of estimated service time gamma distribution.

ESTB - Scale of estimated service time gamma distribution.

GEE - Dentist estimated time (gamma distribution).

J - Number of different length of appointments available for each NSET.

K - Number of the specific NSET being simulated.

NEA - Dentist estimated minus actual service time (normal distribution).

NEAM - Mean of normally distributed estimated minus actual service time.

NEASTD - Standard deviation of normally distributed estimated minus actual service time.

NP - Number of patients. Accumulates total number of patients scheduled each day.

NSETS - Number of appointment scheduling systems to be simulated.

PAT - Patient arrival time.

PATM - Mean of normally distributed patient arrival times.

PATSTD - Standard deviation of normally distributed patient arrival times.

PWT - Patient waiting time. Accumulates total patient waiting time for each day.

SAL - Scheduled appointment length.

SAT - Scheduled appointment time.

SCH(L) - List of appointment lengths for each NSET. (L=1,J)

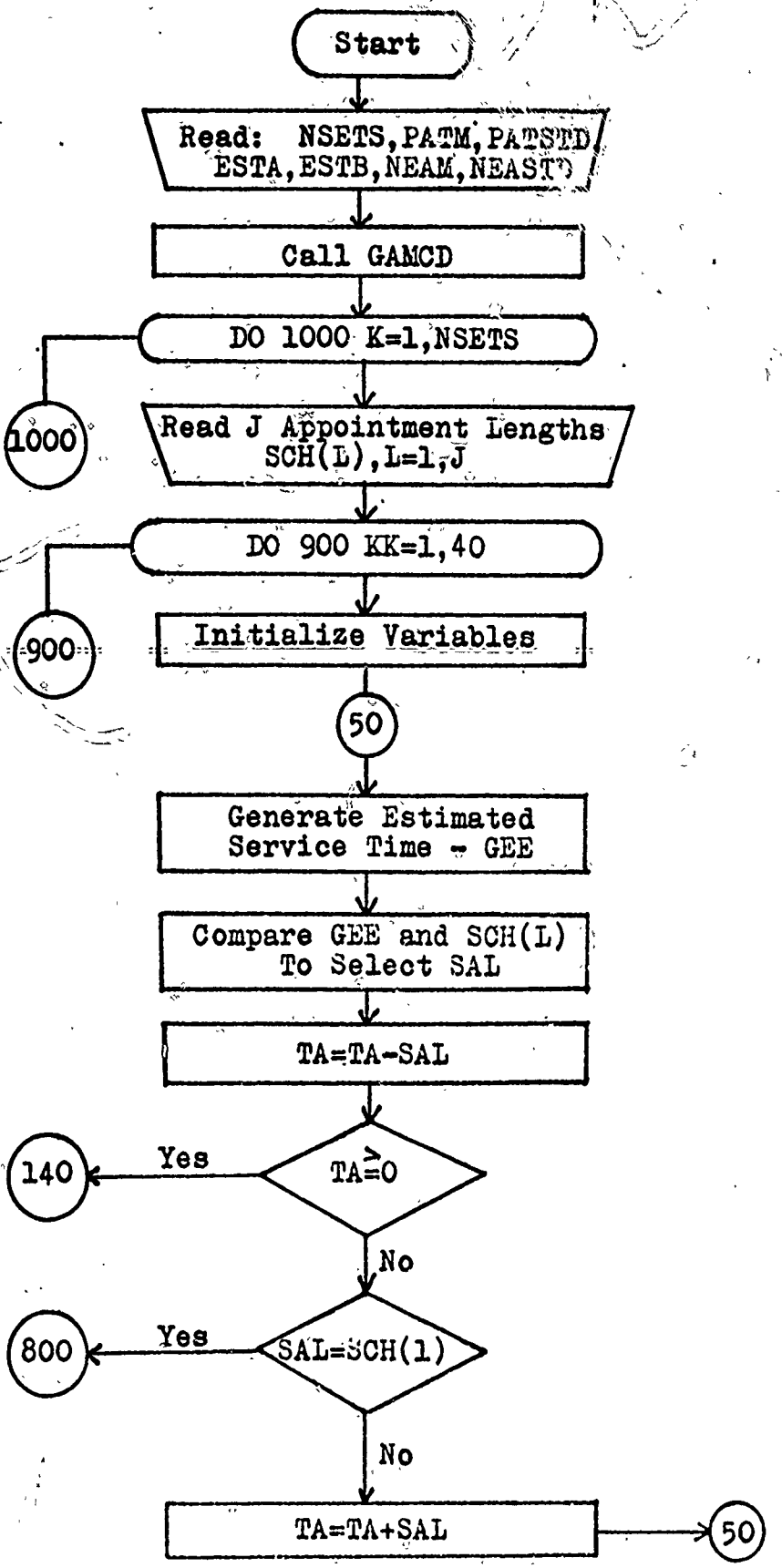
TA - Total time available for scheduling appointments.

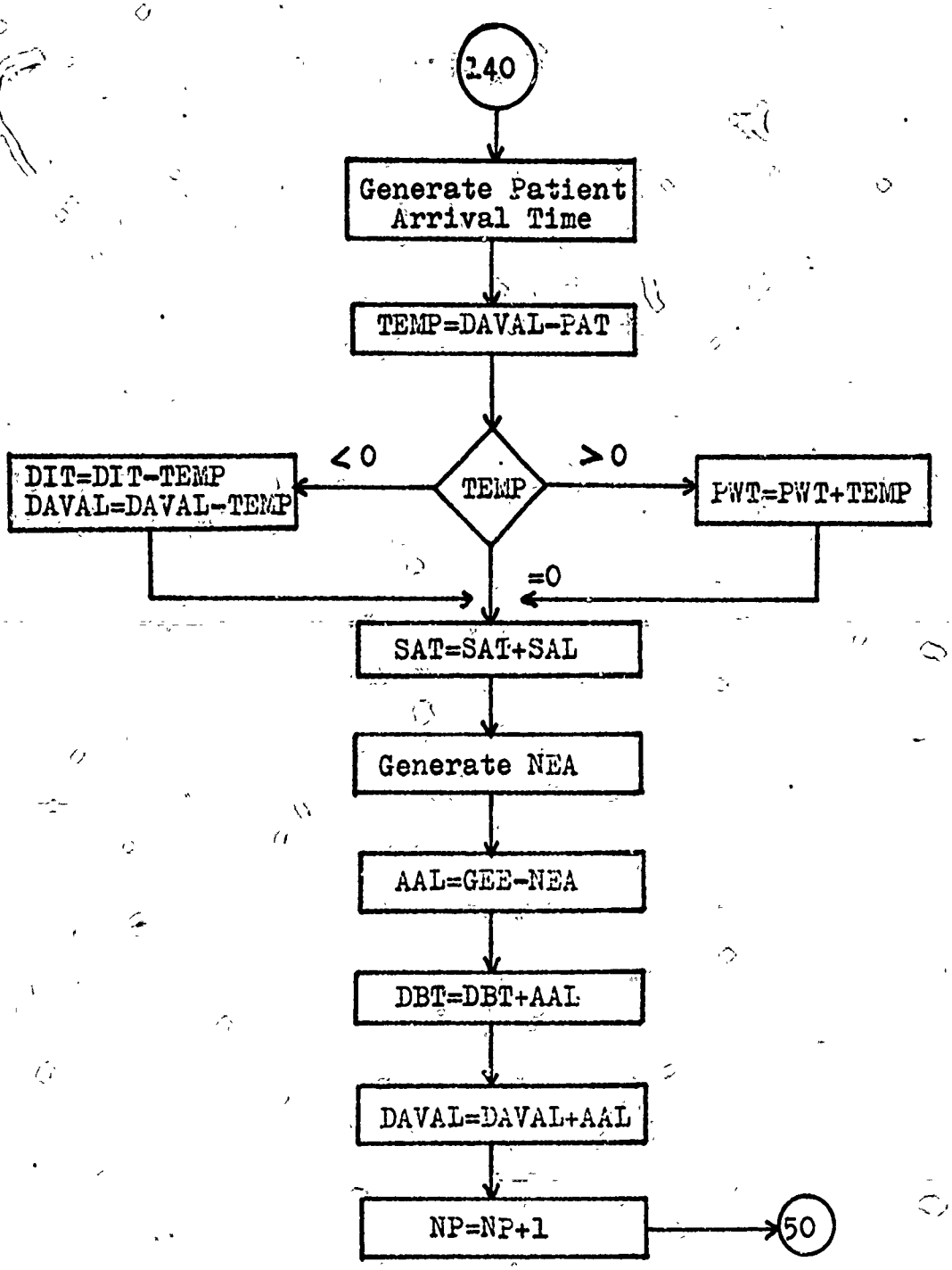
Explanation of Program Subroutines

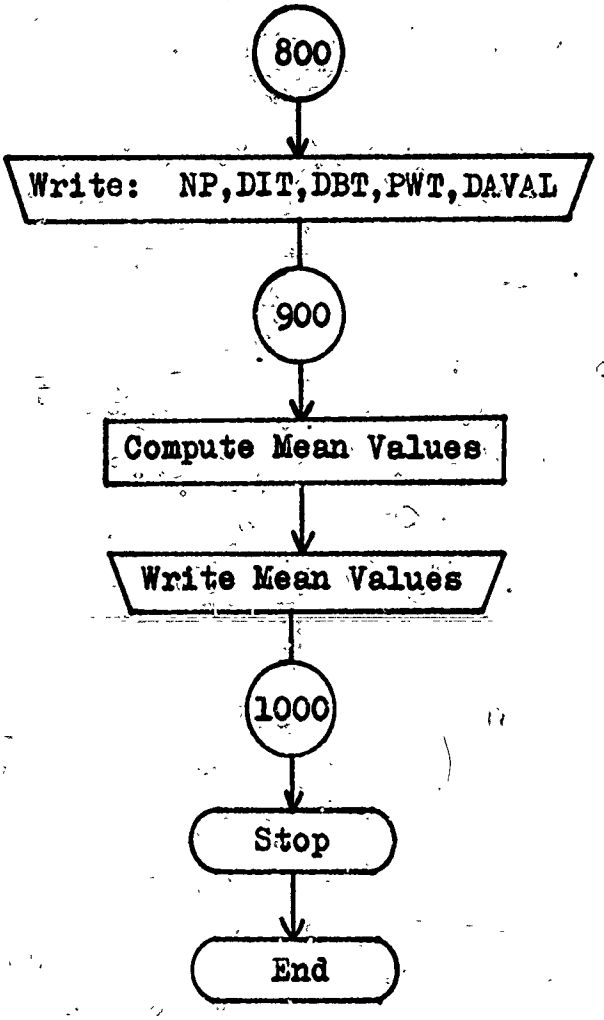
GAMCD - Computes a discrete cumulative distribution to approximate a specified gamma distribution. This discrete distribution is used to approximate random drawings from the gamma estimated service time distribution.

GAUSS - Performs a random draw from a normal distribution with a specified mean and standard deviation. This is an IBM 360 internal subroutine and was used for drawings from the normally distributed patient arrival times and the normally distributed estimated minus actual service times.

RANDU - This is an IBM 360 internal subroutine to generate random numbers.


Start
Read: NSETS,PATM,PATSTD
ESTA,ESTB,NEAM,NEASTD
Call GAMCD
DO 1000 K=1,NSETS
1000
Read J Appointment Lengths
SCH(L),L=1,J
DO 900 KK=1,40
900
Initialize Variables
50
Generate Estimated
Service Time - GEE
Compare GEE and SCH(L)
To Select SAL
TA=TA-SAL
140
Yes
TA≥0
No
800
Yes
SAL=SCH(1)
No
TA=TA+SAL
50


240
Generate Patient Arrival Time
TEMP=DAVAL-PAT
TEMP
<0
>0
=0
DIT=DIT-TEMP
DAVAL=DAVAL-TEMP
PWT=PWT+TEMP
SAT=SAT+SAL
Generate NEA
AAL=GEE-NEA
DBT=DBT+AAL
DAVAL=DAVAL+AAL
NP=NP+1
50


800
Write: NP,DIT,DBT,PWT,DAVAL
900
Compute Mean Values
Write Mean Values
1000
Stop
End

```
C DENTIST SCHEDULE SIMULATION
C AAL=ACTUAL APPOINTMENT LENGTH
C DBT=DENTIST BUSY TIME
C DIT=DENTIST IDLE TIME
C GEE=DENTIST ESTIMATED TIME (GAMMA DISTR.)
C NEA=DENTIST ESTIMATE MINUS ACTUAL TIME (NORMAL DISTR.)
C NP =NUMBER OF PATIENTS
C PWT=PATIENT WAITING TIME
C SAL=SCHEDULED APPT. LENGTH
C TA =TOTAL TIME AVAILABLE
C SAT=SCHEDULED APPT. TIME
C PAT=PATIENT ARRIVAL TIME
C DAVAL = DENTIST AVAILIBILITY TIME
      DIMENSION SCH(20),NS(4),G(200),CD(200)
      REAL NEAM,NEASTD,NEA,NPM
C
      READ(5,1) NSETS,PATM,PATSTD,ESTA,ESTB,NEAM,NEASTD
    1 FORMAT(I5,6F10.0)
      CALL GAMCD(G,CD,ESTA,ESTB,100,5.0,95.0)
      DO 1000 K=1,NSETS
      IX=38951
C J = NUMBER OF APPT. LENGTHS AVAILABLE
      READ(5,1) J, SINC
      READ(5,2) (SCH(L),L=1,J)
    2 FORMAT(10F5.0)
      WRITE(6,4) K,(SCH(L),L=1,J)
    4 FORMAT(1H1,10X,18HAPPOINTMENT SYSTEM, I2,5X,1H
     (,10F5.0,2H),////)
      WRITE(6,5)
    5 FORMAT(1HO,7X,2HNP,7X,3HDIT,7X,3HDBT,7X,3HPWT,
     5X,5HDAVAL///)
      AVV=0.
      NPM=0.
      DITM=0.
      DBTM=0.
      PWTM=0.
C
      DO 900 KK=1,40
      SAT=60.
      TA=360.
      DAVAL=65.
      DBT=0.
      PWT=0.
      NP=0
      DIT=0.
C GENERATE ESTIMATED SERVICE TIME - GEE
   50 CALL RANDU(IX,IY,V)
      IX=IY
      IF(V.GT.CD(1)) GO TO 60
      GEE=G(1)
      GO TO 90
   60 IF(V.LT.CD(100)) GO TO 70
      GEE=G(100)
```

```
      GO TO 90
   70 DO 80 L=2,100
      IF(.NOT.(V.GE.CD(L-1).AND.V.LT.CD(L))) GO TO 80
      GEE=G(L)
      GO TO 90
   80 CONTINUE
C SELECT SAL FROM AVAILABLE SCHEDULE TIMES
   90 SCH1=SCH(1) + SINC
      IF(GEE.GT.SCH1) GO TO 100
      SAL=SCH(1)
      GO TO 130
  100 IF(GEE.LT.SCH(J)) GO TO 110
      SAL=SCH(J)
      GO TO 130
  110 DO 120 L=2,J
      IF(.NOT.(GEE.GT.(SCH(L-1)+SINC).AND.GEE.LE.
      (SCH(L)+SINC))) GO TO 120
      SAL=SCH(L)
      GO TO 130
  120 CONTINUE
C
  130 TA=TA-SAL
      IF(TA.GE.0.) GO TO 140
      IF(SAL.LE.SCH(1)) GO TO 800
      TA=TA+SAL
      GO TO 50
C TAKE IN NEW PATIENT AS SOON AS FREE
C GENERATE PATIENT ARRIVAL TIME
  140 CALL GAUSS(IX,PATSTD,PATM,V)
      IF(V.LT.-20..OR.V.GT.45.) GO TO 140
      PAT=SAT-V
      AVV=AVV+V
      TEMP=DAVAL-PAT
      IF(TEMP)160,170,150
  150 PWT=PWT+TEMP
      GO TO 170
  160 DIT=DIT-TEMP
      DAVAL=DAVAL-TEMP
  170 SAT=SAT+SAL
C GENERATE NEA
      CALL GAUSS(IX,NEASTD,NEAM,NEA)
      AAL=GEE-NEA
      DBT=DBT+AAL
      DAVAL=DAVAL+AAL
      NP=NP+1
      GO TO 50
C
  800 WRITE(6,6) NP,DIT,DBT,PWT,DAVAL
    6 FORMAT(8X,I2,4F10.1)
      NPM=NPM+NP
      DITM=DITM+DIT
      DBTM=DBTM+DBT
      PWTM=PWTM+PWT
```

```
  900 CONTINUE
      AVV=AVV/NPM
      NPM=NPM/40.
      DITM=DITM/40.
      DBTM=DBTM/40.
      PWTM=PWTM/40.
      WRITE(6,8) NPM,DITM,DBTM,PWTM
    8 FORMAT(/1X,5HMEANS,F4.1,4F10.1)
      WRITE(6,7) AVV
    7 FORMAT(////,10X,27HMEAN PATIENT ARRIVAL TIME=,F5.1)
 1000 CONTINUE
      STOP
      END
```

```
      SUBROUTINE GAMCD(X,CD,ALPHA,BETA,N,BLIM,ULIM)
C GENERATES GAMMA CUMULATIVE DISTRIBUTION
      DIMENSION X(1),CD(1)
      XN=N
      DEM=GAMMA(ALPHA)*BETA**ALPHA
      DELTX=(ULIM-BLIM)/(XN-1.)
      X(1)=BLIM
      DO 50 J=2,N
   50 X(J)=X(J-1)+DELTX
C
      DO 70 I=1,N
      IF(I-1)65,65,66
   66 J=I-1
      IF(X(I).LE.X(J)) GO TO 70
   68 A=X(J)
      T=X(I)
      GO TO 69
   65 T=X(I)
      FTX=0.
   84 A=0.1*X(1)
   69 K=0
      L=0
      B=T
      EPS=.05/XN
      MIT=20
      TERM=0.
      DELTX=(B-A)/4.
      DEL2=DELTX+DELTX
      PSUM=0.
      Y=A
      TERM=Y**(ALPHA-1.)/EXP(Y/BETA)
      QSUM=TERM
      Y=B
      TERM=Y**(ALPHA-1.)/EXP(Y/BETA)
      QSUM=QSUM+TERM
      ESUM=0.
      Y=A
    1 Y=Y+DEL2
      TERM=Y**(ALPHA-1.)/EXP(Y/BETA)
      ESUM=ESUM+TERM
      IF(Y-B+DEL2+DELTX)1,2,2
    2 ODSUM=0.
      Y=A-DELTX
    3 Y=Y+DEL2
      TERM=Y**(ALPHA-1.)/EXP(Y/BETA)
      ODSUM=ODSUM+TERM
      IF(Y+DEL2-B)3,4,4
    4 SUM=(QSUM+ESUM+ESUM+4.*ODSUM)*DELTX/3.
      K=K+1
      IF(ABS((SUM-PSUM)/SUM)-EPS)6,5,5
```

```
    5 IF(K-MIT)8,9,9
    8 DEL2=DELTX
      DELTX=0.5*DELTX
      PSUM=SUM
C
      ESUM=ESUM+ODSUM
      GO TO 2
    9 MIT=MIT+10
      FPS=FPS+10.
      L=L+1
      IF(L-5)8,6,6
    6 FTX=FTX+SUM/DEM
      CD(I)=FTX
   70 CONTINUE
      RETURN
      END
```

APPENDIX F

MODIFIED COMPUTER PROGRAM FOR SIMULATION MODEL B

A revision to the computer program for simulation model B was necessary in order to simulate scheduling each patients initial appointment length based on the examining dentists' estimate of the service time required for each patients first appointment. The program arranges the appointment lengths to be used throughout the clinic session and prints out the specific schedule to be used. The modified program and two sample schedules are presented for the readers information. The schedules are for appointment system Y with both 32 patients and 40 patients. To aid in the appointment scheduling, the schedules are listed with the appointment lengths in order and also with the appointment times ordered.

A computer flow diagram and explanation of the variables used in the original model can be found in Outpatient Scheduling, A Simulation Approach (Ref 4: Appendix C).

```
C AT = ARRIVAL TIMES
C AM = MEAN OF NORMALLY DISTRIBUTED AT
C STDA = STANDARD DEV OF AT
C WT = WALK-IN TIMES
C EX = MEAN INTER ARRIVAL TIME OF WALK-IN PATIENTS
C DAT = DENTIST AVAILABILITY TIME
C NDA = NUMBER OF DENTISTS AVAILABLE
C TDA = TIME DENTISTS AVAILABLE
C ALPHA = SHAPE OF GAMMA DISTRIBUTION
C BETA = SCALE OF GAMMA DISTRIBUTION
      DIMENSION AT(150,2),WT(15),DAT(8),NDA(14),TDA(14)
     *,CDDA(7),G(200),CD(200),PWT(4000),DASH(20)
     *,B(10,10),A(100),C(100),D(100),E(100),F(100)
      COMMON AT
      DATA DASH/20*1H./
      DATA TDA/65.,95.,125.,155.,185.,215.,245.,275.,305.,
     *335.,365.,395.,425.,455./
      DATA CDDA/0.,.02,.12,.43,.74,.98,1.0/
C READ PARAMETERS OF DISTRIBUTIONS AND DATA
      KK=14
      READ(5,1) NSETS
      READ(5,2) AM,STDA,EX,ALPHA,BETA,AM1,STDD
    1 FORMAT(3I5)
    2 FORMAT(7F10.0)
C GENERATE GAMMA DISTR
      NN=100
      CALL GAMCD(G,CD,ALPHA,BETA,NN,15.,90.)
C READ APPOINTMENT TIMES
      DO 1000 JJ=1,NSETS
      SINC=5.
      READ(5,1) NSSETS,N,MMM
      XN=N
      DO 1000 JJJ=1,NSSETS
      IX=38951
      READ(5,3) (A(L),L=1,N)
    3 FORMAT(20F4.0)
C
      NPD=N/MMM
      K=1-MMM
      DO 11 J=1,MMM
      M=J
      DO 10 I=1,NPD
      K=K+MMM
      IF(K.GT.N) K=K-N
      B(I,J)=A(K)
      C(M)=A(K)
      F(M)=K
      M=M+MMM
```

```
   10 CONTINUE
      K=K-MMM+1-MMM
      IF(K.GE.MMM) GO TO 11
      K=N+K+1-2*MMM
   11 CONTINUE
      BEGIN=700
      MX=MMM+1
      DO 15 J=1,MMM
      AT(J,2)=C(J)
   15 AT(J,1)=0.
      M=1
      DO 16 J=MX,N
      AT(J,2)=C(J)
      AT(J,1)=AT(M,1)+C(M)
   16  M=M+1
      DO 17 J=1,N
      TEMP=AT(J,1)/60.0
   17 AT(J,1)=BEGIN+100.0*AINT(TEMP  )+AMOD(AT(J,1),60.0)
      CALL ORD2(1,N,2)
      WRITE(6,20) JJ,JJJ,N,MMM
   20 FORMAT(1H1,10X,8HSCHEDULE,I3,I4,5X,I3,9H PATIENTS,
     *5X,I3,9H DENTISTS,//)
      WRITE(6,21) (AT(J,2),AT(J,1),J=1,N)
   21 FORMAT(10X,5HAPPT.,5X,5HAPPT.,/,10X,6HLENGTH,4X,
     *4HTIME,//,(10X,F4.0,5X,F6.0))
      CALL ORD2(1,N,1)
      WRITE(6,20) JJ,JJJ,N,MMM
      WRITE(6,22) (AT(J,1),AT(J,2),DASH,J=1,N)
   22 FORMAT(10X,5HAPPT.,5X,5HAPPT.,10X,7HPATIENT,/,10X,
     *4HTIME,6X,6HLENGTH,//,(10X,F6.0,4X,F4.0,9X,20A1))
C
      NPW=0
      AVV=0.
      CSLM=0.
      CTM=0.
      CSL=0.
      AAPW=0.
      AADW=0.
      AAVD=0.
      DO 900 NJK=1,25
C
      DO 12 J=1,N
   12 AT(J,2)=F(J)
      DO 13 J=1,MMM
   13 AT(J,1)=60.0
      MX=MMM+1
      M=1
      DO 14 J=MX,N
```

```
      AT(J,1)=C(M)+AT(M,1)
   14 M=M+1
C
C GENERATE N ARRIVAL TIMES   NORMAL DISTR
   24 DO 30 J=1,N
   25 CALL GAUSS(IX,STDA,AM,V)
      IF(V.LT.-20..OR.V.GT.45.) GO TO 25
      AVV=AVV+V
      E(J)=0.
      CALL RANDU(IX,IY,YFL)
      IX=IY
      IF(YFL.GT.CD(1)) GO TO 26
      D(J)=G(1)
      GO TO 29
   26 IF(YFL.LT.CD(100)) GO TO 27
      D(J)=G(100)
      GO TO 29
   27 DO 28 L=2,100
      IF(.NOT.(YFL.GE.CD(L-1).AND.YFL.LT.CD(L))) GO TO 28
      D(J)=G(L)
      GO TO 29
   28 CONTINUE
   29 AT(J,1)=AT(J,1)-V
   30 CONTINUE
      AVV=AVV/XN
      INC=0.
      DO 40 J=1,N
   34 INC=INC+SINC
      DO 35 L=1,N
      IF(D(J).LE.(A(1)+INC)) GO TO 38
      IF(D(J).LE.(A(L)+SINC).AND.E(L).EQ.0.) GO TO 39
      IF((D(J)-A(L)+INC).LT.0.AND.A(L+1).GT.A(L)) GO TO 36
      IF(L.EQ.N.AND.(D(J)-A(L)+INC).GE.0.) GO TO 37
      IF(L.EQ.N.AND.(D(J)-A(L)+INC).LT.0.) GO TO 36
   35 CONTINUE
   36 IF(E(L).EQ.0.) GO TO 39
      IF((D(J)-A(L)-SINC).GT.0.AND.A(L-1).LT.A(L)) GO TO 34
      L=L-1
      IF(L.GT.0) GO TO 36
      GO TO 34
   37 IF(E(L).EQ.0.) GO TO 39
      L=L-1
      GO TO 37
   38 IF(E(L).EQ.0.) GO TO 39
      L=L+1
      GO TO 38
   39 E(L)=D(J)
      INC=0.
```

```
   40  CONTINUE
C GENERATE KK DEN AVAILABLE NBRS (EVERY 30 MIN)
      DO 50 J=1,KK
   50 NDA(J)=MMM
C ORDER ARRIVAL TIMES
      CALL ORD2(1,N,1)
      CALL ORDER(WT,15)
C INIALIZE DAT
      DO 60 L=1,8
   60 DAT(L)=65.
      M=NDA(1)
      NP=1
      NW=1
      NTDA=M
      AN=0.
      DN=0.
      APW=0.
      ADW=0.
      K=1
C COMPARE DENTIST AVAIL TIME TO PATIENT AT
      MM=20
   70 IF(DAT(1).LE.AT(NP,1)) GO TO 80
   71 NN=NP
   72 IF(NN.EQ.N) GO TO 80
      NN=NN+1
      IF(DAT(1).GE.AT(NN,1)) GO TO 72
      NZ=NN-NP
C REORDER ARRIVAL TIMES
   80 TIM=AT(NP,1)
      NZ1=AT(NP,2)
      SER=E(NZ1)
      CALL GAUSS(IX,STDD,AM1,V)
      SER=SER-V
          NZ=N-NP
      NP=NP+1
      CALL ORD2(NP,NZ,1)
C GENERATE SERVICE TIME
      CTM=CTM+SER
   95 CONTINUE
C CALCULATE WAITING OR IDLE TIME
  100 WAIT=TIM-DAT(1)
      IF(WAIT)120,125,110
  110 ADW=ADW+WAIT
      DAT(1)=DAT(1)+WAIT
      DN=DN+1.
      WAIT=0.
      GO TO 125
C RECORD PATIENT WAITING TIME
```

```
  120  APW=APW-WAIT
  125  AN=AN+1.
       NPW=NPW+1
       PWT(NPW)=-WAIT
C ADD SER TIME TO DOC AVAIL TIME
  130  DAT(1)=DAT(1)+SER
       CSL=DAT(1)-60.
       CALL ORDER(DAT,M)
       IF(NP.GT.N) GO TO 200
       IF(DAT(1).LE.TDA(K+1)) GO TO 70
       K=K+1
       IF(K.LT.KK)GO TO 135
       K=K-1
       GO TO 200
  135  J=M
       M=NDA(K)
       NTDA=NTDA+M
       IF(J-M)140,70,150
  140  L=J+1
       DO 145 I=L,M
  145  DAT(I)=TDA(K)
       GO TO 70
  150  L=J-M
       DO 155 I=1,M
  155  DAT(I)=DAT(I+L)
       GO TO 70
C COMPUTE AVG WAITING AND IDLE TIMES
  200  APW=APW/AN
       XNTDA=FLOAT(NTDA)/FLOAT(K)
       AVD=ADW/XNTDA
       IF(DN.EQ.0.) GO TO 210
       ADW=ADW/DN
       GO TO 220
  210  ADW=0.
       AVD=0.
  220  CONTINUE
       WRITE(6,6)JJ,JJJ,NJK
    6  FORMAT(1H1,10X,'APPOINTMENT SYSTEM',I3,I4,
      *' (RUN',I3,')',//)
       MM=AN
       M=NPW-MM+1
       CTM=CTM/XN
       NW=NW-1
       CALL WRIT(APW,ADW,AVD,PWT(M),MM,AVV,CTM,CSL,NW,XNTDA)
       AAPW=AAPW+APW
       AADW=AADW+ADW
       AAVD=AAVD+AVD
       CSLM=CSLM+CSL
```

```
  900  CONTINUE
       ANN=NJK
       AAPW=AAPW/ANN
       AADW=AADW/ANN
       AAVD=AAVD/ANN
       WRITE(6,7) JJ,JJJ,NJK
     7 FORMAT(1H1,10X,'APPOINTMENT SYSTEM',I3,I4,'(ALL',I3,
      *' RUNS COMBINED)',//)
       AVV=0.
       CTM=0.
       CSL=CSLM/25.0
       NW=0
       XNTDA=0
       CALL WRIT(AAPW,AADW,AAVD,PWT,NPW,AVV,CTM,CSL,NW,XNTDA)
 1000  CONTINUE
       STOP
       END
```

SCHEDULE Y 32 PATIENTS 4 DENTISTS

APPT. LENGTH	APPT. TIME
30.	700.
30.	700.
30.	730.
30.	800.
30.	845.
30.	830.
30.	915.
30.	945.
30.	1015.
30.	1015.
30.	1045.
30.	1115.
30.	1145.
30.	1215.
45.	700.
45.	700.
45.	745.
45.	730.
45.	830.
45.	815.
45.	900.
45.	900.
45.	945.
45.	1030.
45.	1045.
45.	1130.
45.	1145.
60.	745.
60.	915.
60.	945.
60.	1045.
60.	1115.

SCHEDULE Y 32 PATIENTS 4 DENTISTS

APPT. TIME	APPT. LENGTH	PATIENT
700.	30.	
700.	30.	
700.	45.	
700.	45.	
730.	30.	
730.	45.	
745.	45.	
745.	60.	
800.	30.	
815.	45.	
830.	30.	
830.	45.	
845.	30.	
900.	45.	
900.	45.	
915.	30.	
915.	60.	
945.	30.	
945.	45.	
945.	60.	
1015.	30.	
1015.	30.	
1030.	45.	
1045.	30.	
1045.	45.	
1045.	60.	
1115.	30.	
1115.	60.	
1130.	45.	
1145.	30.	
1145.	45.	
1215.	30.	

SCHEDULE Y 40 PATIENTS 5 DENTISTS

APPT. LENGTH	APPT. TIME
30.	700.
30.	700.
30.	730.
30.	800.
30.	800.
30.	845.
30.	830.
30.	830.
30.	915.
30.	900.
30.	945.
30.	1015.
30.	930.
30.	1015.
30.	1045.
30.	1115.
30.	1130.
30.	1145.
30.	1200.
45.	700.
45.	700.
45.	745.
45.	730.
45.	830.
45.	815.
45.	900.
45.	900.
45.	945.
45.	945.
45.	1030.
45.	1030.
45.	1045.
45.	1045.
45.	1130.
45.	1130.
60.	730.
60.	745.
60.	815.
60.	1230.
60.	1115.

SCHEDULE Y 40 PATIENTS 5 DENTISTS

APPT. TIME	APPT. LENGTH	PATIENT
700.	30.	
700.	30.	
700.	45.	
700.	45.	
700.	60.	
730.	30.	
730.	45.	
745.	45.	
745.	60.	
800.	30.	
800.	30.	
815.	45.	
830.	30.	
830.	30.	
830.	45.	
845.	30.	
900.	30.	
900.	45.	
900.	45.	
915.	30.	
915.	60.	
930.	30.	
945.	30.	
945.	45.	
945.	45.	
1000.	45.	
1015.	30.	
1015.	30.	
1030.	45.	
1030.	60.	
1045.	30.	
1045.	45.	
1045.	45.	
1115.	30.	
1115.	45.	
1130.	30.	
1130.	45.	
1130.	45.	
1145.	30.	
1[illegible].	[illegible].	

APPENDIX G

APPOINTMENT SYSTEMS (1-27) CUMULATED OUTPUT

APPOINTMENT SYSTEM 1 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	28.48 MIN
AVERAGE LENGTH OF IDLE TIME	=	7.21 MIN
AVERAGE DENTIST IDLE TIME	=	14.63 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	397.01
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	1.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	54	24.00	24.00
	10.	20	8.89	32.89
	15.	15	6.67	39.56
	20.	21	9.33	48.89
	25.	13	5.78	54.67
	30.	12	5.33	60.00
	35.	11	4.89	64.89
	40.	14	6.22	71.11
	45.	8	3.56	74.67
	50.	6	2.67	77.33
	55.	11	4.89	82.22
	60.	8	3.56	85.78
OVER	60.	32	14.22	100.00

APPOINTMENT SYSTEM 2 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	21.13 MIN
AVERAGE LENGTH OF IDLE TIME	=	10.39 MIN
AVERAGE DENTIST IDLE TIME	=	24.49 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	372.91
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	1.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	61	30.50	30.50
	10.	24	12.00	42.50
	15.	20	10.00	52.50
	20.	17	8.50	61.00
	25.	13	6.50	67.50
	30.	15	7.50	75.00
	35.	6	3.00	78.00
	40.	9	4.50	82.50
	45.	8	4.00	86.50
	50.	2	1.00	87.50
	55.	4	2.00	89.50
	60.	6	3.00	92.50
OVER	60.	15	7.50	100.00

APPOINTMENT SYSTEM 3 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	31.19 MIN
AVERAGE LENGTH OF IDLE TIME	=	4.31 MIN
AVERAGE DENTIST IDLE TIME	=	7.72 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	356.14
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	1.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ.	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	39	19.50	19.50
	10.	13	6.50	26.00
	15.	20	10.00	36.00
	20.	16	8.00	44.00
	25.	19	9.50	53.50
	30.	16	8.00	61.50
	35.	9	4.50	66.00
	40.	5	2.50	68.50
	45.	9	4.50	73.00
	50.	11	5.50	78.50
	55.	6	3.00	81.50
	60.	7	3.50	85.00
OVER	60.	30	15.00	100.00

APPOINTMENT SYSTEM 4 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	18.54 MIN
AVERAGE LENGTH OF IDLE TIME	=	6.72 MIN
AVERAGE DENTIST IDLE TIME	=	19.72 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	327.67
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	1.00

INDIVIDUAL WAITING TIMES

UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
5.	68	38.86	38.86
10.	10	5.71	44.57
15.	20	11.43	56.00
20.	10	5.71	61.71
25.	14	8.00	69.71
30.	14	8.00	77.71
35.	5	2.86	80.57
40.	5	2.86	83.43
45.	4	2.29	85.71
50.	9	5.14	90.86
55.	2	1.14	92.00
60.	3	1.71	93.71
OVER 60.	11	6.29	100.00

APPOINTMENT SYSTEM 5 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	13.75 MIN
AVERAGE LENGTH OF IDLE TIME	=	22.07 MIN
AVERAGE DENTIST IDLE TIME	=	55.79 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	363.73
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	1.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	83	47.43	47.43
	10.	9	5.14	52.57
	15.	21	12.00	64.57
	20.	12	6.86	71.43
	25.	13	7.43	78.86
	30.	9	5.14	84.00
	35.	5	2.86	86.86
	40.	6	3.43	90.29
	45.	3	1.71	92.00
	50.	7	4.00	96.00
	55.	2	1.14	97.14
	60.	0	0.0	97.14
OVER	60.	5	2.86	100.00

APPOINTMENT SYSTEM 6 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	12.33 MIN
AVERAGE LENGTH OF IDLE TIME	=	13.26 MIN
AVERAGE DENTIST IDLE TIME	=	41.20 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	349.15
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	1.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	84	48.00	48.00
	10.	21	12.00	60.00
	15.	15	8.57	68.57
	20.	10	5.71	74.29
	25.	8	4.57	78.86
	30.	11	6.29	85.14
	35.	7	4.00	89.14
	40.	5	2.86	92.00
	45.	4	2.29	94.29
	50.	2	1.14	95.43
	55.	4	2.29	97.71
	60.	1	0.57	98.29
OVER	60.	3	1.71	100.00

APPOINTMENT SYSTEM 7 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	7.27 MIN
AVERAGE LENGTH OF IDLE TIME	=	31.74 MIN
AVERAGE DENTIST IDLE TIME	=	105.45 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE-TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	355.61
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	1.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	95	63.33	63.33
	10.	11	7.33	70.67
	15.	6	4.00	74.67
	20.	8	5.33	80.00
	25.	17	11.33	91.33
	30.	6	4.00	95.33
	35.	5	3.33	98.67
	40.	0	0.0	98.67
	45.	2	1.33	100.00
	50.	0	0.0	100.00
	55.	0	0.0	100.00
	60.	0	0.0	100.00
OVER	60.	0	0.0	100.00

APPOINTMENT SYSTEM 8 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	7.43 MIN
AVERAGE LENGTH OF IDLE TIME	=	30.87 MIN
AVERAGE DENTIST IDLE TIME	=	96.61 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	346.77
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	1.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	93	62.00	62.00
	10.	14	9.33	71.33
	15.	7	4.67	76.00
	20.	6	4.00	80.00
	25.	17	11.33	91.33
	30	5	3.33	94.67
	35.	5	3.33	98.00
	40.	2	1.33	99.33
	45.	0	0.0	99.33
	50.	1	0.67	100.00
	55.	0	0.0	100.00
	60.	0	0.0	100.00
OVER	60.	0	0.0	100.00

APPOINTMENT SYSTEM 9 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	12.51 MIN
AVERAGE LENGTH OF IDLE TIME	=	7.19 MIN
AVERAGE DENTIST IDLE TIME	=	15.24 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	376.33
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	4.00

INDIVIDUAL WAITING TIMES

UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
5.	272	34.00	34.00
10.	112	14.00	48.00
15.	114	14.25	62.25
20.	113	14.13	76.38
25.	72	9.00	85.38
30.	54	6.75	92.13
35.	23	2.88	95.00
40.	15	1.88	96.88
45.	14	1.75	98.63
50.	8	1.00	99.63
55.	2	0.25	99.88
60.	1	0.13	100.00
OVER 60.	0	0.0	100.00

APPOINTMENT SYSTEM 10 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	24.17 MIN
AVERAGE LENGTH OF IDLE TIME	=	3.66 MIN
AVERAGE DENTIST IDLE TIME	=	2.97 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	363.41
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	4.00

INDIVIDUAL WAITING TIMES

UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
5.	96	12.00	12.00
10.	70	8.75	20.75
15.	92	11.50	32.25
20.	107	13.38	45.63
25.	105	13.13	58.75
30.	65	8.13	66.88
35.	76	9.50	76.38
40.	63	7.88	84.25
45.	28	3.50	87.75
50.	30	3.75	91.50
55.	22	2.75	94.25
60.	20	2.50	96.75
OVER 60.	26	3.25	100.00

APPOINTMENT SYSTEM 11 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	25.10 MIN
AVERAGE LENGTH OF IDLE TIME	=	3.41 MIN
AVERAGE DENTIST IDLE TIME	=	3.21 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	363.73
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	4.00

INDIVIDUAL WAITING TIMES

UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
5.	96	12.00	12.00
10.	78	9.75	21.75
15.	77	9.63	31.38
20.	118	14.75	46.13
25.	87	10.88	57.00
30.	75	9.38	66.38
35.	59	7.38	73.75
40.	51	6.38	80.13
45.	36	4.50	84.63
50.	39	4.88	89.50
55.	27	3.38	92.88
60.	19	2.38	95.25
OVER 60.	38	4.75	100.00

APPOINTMENT SYSTEM 12 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	22.02 MIN
AVERAGE LENGTH OF IDLE TIME	=	3.89 MIN
AVERAGE DENTIST IDLE TIME	=	4.09 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	364.78
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	4.00

INDIVIDUAL WAITING TIMES

UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
5.	123	15.38	15.38
10.	84	10.50	25.88
15.	83	10.38	36.25
20.	125	15.63	51.88
25.	89	11.13	63.00
30.	72	9.00	72.00
35.	53	6.63	78.63
40.	58	7.25	85.88
45.	34	4.25	90.13
50.	32	4.00	94.13
55.	20	2.50	96.63
60.	8	1.00	97.63
OVER 60.	19	2.38	100.00

APPOINTMENT SYSTEM 13 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	22.63 MIN
AVERAGE LENGTH OF IDLE TIME	=	4.82 MIN
AVERAGE DENTIST IDLE TIME	=	6.10 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	366.41
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	4.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	125	15.63	15.63
	10.	69	8.63	24.25
	15.	86	10.75	35.00
	20.	112	14.00	49.00
	25.	93	11.63	60.63
	30.	71	8.88	69.50
	35.	59	7.38	76.88
	40.	66	8.25	85.13
	45.	38	4.75	89.88
	50.	27	3.38	93.25
	55.	23	2.88	96.13
	60.	18	2.25	98.38
OVER	60.	13	1.63	100.00

APPOINTMENT SYSTEM 14 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	12.65 MIN
AVERAGE LENGTH OF IDLE TIME	=	8.74 MIN
AVERAGE DENTIST IDLE TIME	=	15.72 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	361.43
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	4.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	257	34.27	34.27
	10.	101	13.47	47.73
	15.	126	16.80	64.53
	20.	106	14.13	78.67
	25.	54	7.20	85.87
	30.	39	5.20	91.07
	35.	25	3.33	94.40
	40.	14	1.87	96.27
	45.	6	0.80	97.07
	50.	8	1.07	98.13
	55.	3	0.40	98.53
	60.	5	0.67	99.20
OVER	60.	6	0.80	100.00

APPOINTMENT SYSTEM 15 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	22.44 MIN
AVERAGE LENGTH OF IDLE TIME	=	4.67 MIN
AVERAGE DENTIST IDLE TIME	=	3.23 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	347.69
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	4.00

INDIVIDUAL WAITING TIMES

UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
5.	83	11.07	11.07
10.	81	10.80	21.87
15.	85	11.33	33.20
20.	129	17.20	50.40
25.	86	11.47	61.87
30.	87	11.60	73.47
35.	78	10.40	83.87
40.	39	5.20	89.07
45.	25	3.33	92.40
50.	22	2.93	95.33
55.	9	1.20	96.53
60.	6	0.80	97.33
OVER 60.	20	2.67	100.00

APPOINTMENT SYSTEM 16 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	12.93 MIN
AVERAGE LENGTH OF IDLE TIME	=	6.23 MIN
AVERAGE DENTIST IDLE TIME	=	13.45 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	332.02
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	4.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	249	35.57	35.57
	10.	90	12.86	48.43
	15.	89	12.71	61.14
	20.	88	12.57	73.71
	25.	59	8.43	82.14
	30.	53	7.57	89.71
	35.	33	4.71	94.43
	40.	16	2.29	96.71
	45.	11	1.57	98.29
	50.	6	0.86	99.14
	55.	4	0.57	99.71
	60.	2	0.29	100.00
OVER	60.	0	0.0	100.00

APPOINTMENT SYSTEM 17 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	7.47 MIN
AVERAGE LENGTH OF IDLE TIME	=	10.73 MIN
AVERAGE DENTIST IDLE TIME	=	34.91 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	353.20
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	4.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ.	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	390	55.71	55.71
	10.	82	11.71	67.43
	15.	77	11.00	78.43
	20.	62	8.86	87.29
	25.	43	6.14	93.43
	30.	24	3.43	96.86
	35.	13	1.86	98.71
	40.	5	0.71	99.43
	45.	2	0.29	99.71
	50.	2	0.29	100.00
	55.	0	0.0	100.00
	60.	0	0.0	100.00
OVER	60.	0	0.0	100.00

APPOINTMENT SYSTEM 18 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	6.67 MIN
AVERAGE LENGTH OF IDLE TIME	=	12.35 MIN
AVERAGE DENTIST IDLE TIME	=	42.23 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	362.60
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	4.00

INDIVIDUAL WAITING TIMES

UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
5.	415	59.29	59.29
10.	84	12.00	71.29
15.	69	9.86	81.14
20.	57	8.14	89.29
25.	38	5.43	94.71
30.	22	3.14	97.86
35.	7	1.00	98.86
40.	7	1.00	99.86
45.	0	0.0	99.86
50.	1	0.14	100.00
55.	0	0.0	100.00
60.	0	0.0	100.00
OVER 60.	0	0.0	100.00

APPOINTMENT SYSTEM 19 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	12.06 MIN
AVERAGE LENGTH OF IDLE TIME	=	7.70 MIN
AVERAGE DENTIST IDLE TIME	=	16.51 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	334.57
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	4.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	250	35.71	35.71
	10.	109	15.57	51.29
	15.	99	14.14	65.43
	20.	87	12.43	77.86
	25.	51	7.29	85.14
	30.	39	5.57	90.71
	35.	27	3.86	94.57
	40.	18	2.57	97.14
	45.	13	1.86	99.00
	50.	6	0.86	99.86
	55.	0	0.0	99.86
	60.	0	0.0	99.86
OVER	60.	1	0.14	100.00

APPOINTMENT SYSTEM 20 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	13.32 MIN
AVERAGE LENGTH OF IDLE TIME	=	7.99 MIN
AVERAGE DENTIST IDLE TIME	=	15.50 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	377.43
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	5.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	355	35.50	35.50
	10.	139	13.90	49.40
	15.	130	13.00	62.40
	20.	128	12.80	75.20
	25.	73	7.30	82.50
	30.	59	5.90	88.40
	35.	35	3.50	91.90
	40.	20	2.00	93.90
	45.	26	2.60	96.50
	50.	18	1.80	98.30
	55.	6	0.60	98.90
	60.	5	0.50	99.40
OVER	60.	6	0.60	100.00

APPOINTMENT SYSTEM 21 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	22.66 MIN
AVERAGE LENGTH OF IDLE TIME	=	4.07 MIN
AVERAGE DENTIST IDLE TIME	=	4.50 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	365.17
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	5.00

INDIVIDUAL WAITING TIMES

UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
5.	159	15.90	15.90
10.	110	11.00	26.90
15.	112	11.20	38.10
20.	138	13.80	51.90
25.	109	10.90	62.80
30.	101	10.10	72.90
35.	65	6.50	79.40
40.	54	5.40	84.80
45.	29	2.90	87.70
50.	25	2.50	90.20
55.	33	3.30	93.50
60.	14	1.40	94.90
OVER 60.	51	5.10	100.00

APPOINTMENT SYSTEM 22 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	10.06 MIN
AVERAGE LENGTH OF IDLE TIME	=	7.29 MIN
AVERAGE DENTIST IDLE TIME	=	15.01 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	331.44
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	5.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	357	40.80	40.80
	10.	132	15.09	55.89
	15.	138	15.77	71.66
	20.	102	11.66	83.31
	25.	69	7.89	91.20
	30.	41	4.69	95.89
	35.	20	2.29	98.17
	40.	8	0.91	99.09
	45.	7	0.80	99.89
	50.	1	0.11	100.00
	55.	0	0.0	100.00
	60.	0	0.0	100.00
OVER	60.	0	0.0	100.00

APPOINTMENT SYSTEM 23 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	5.97 MIN
AVERAGE LENGTH OF IDLE TIME	=	11.26 MIN
AVERAGE DENTIST IDLE TIME	=	38.75 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	353.86
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	5.00

INDIVIDUAL WAITING TIMES

UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
5.	533	60.91	60.91
10.	118	13.49	74.40
15.	89	10.17	84.57
20.	64	7.31	91.89
25.	42	4.80	96.69
30.	16	1.83	98.51
35.	7	0.80	99.31
40.	5	0.57	99.89
45.	1	0.11	100.00
50.	0	0.0	100.00
55.	0	0.0	100.00
60.	0	0.0	100.00
OVER 60.	0	0.0	100.00

APPOINTMENT SYSTEM 24 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	17.89 MIN
AVERAGE LENGTH OF IDLE TIME	=	6.81 MIN
AVERAGE DENTIST IDLE TIME	=	13.02 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	375.71
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	3.00

INDIVIDUAL WAITING TIMES

UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
5.	167	27.83	27.83
10.	59	9.83	37.67
15.	66	11.00	48.67
20.	66	11.00	59.67
25.	68	11.33	71.00
30.	38	6.33	77.33
35.	39	6.50	83.83
40.	34	5.67	89.50
45.	23	3.83	93.33
50.	20	3.33	96.67
55.	8	1.33	98.00
60.	7	1.17	99.17
OVER 60.	5	0.83	100.00

APPOINTMENT SYSTEM 25 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	25.40 MIN
AVERAGE LENGTH OF IDLE TIME	=	2.46 MIN
AVERAGE DENTIST IDLE TIME	=	2.75 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	365.71
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	3.00

INDIVIDUAL WAITING TIMES

UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
5.	77	12.83	12.83
10.	58	9.67	22.50
15.	63	10.50	33.00
20.	67	11.17	44.17
25.	79	13.17	57.33
30.	49	8.17	65.50
35.	46	7.67	73.17
40.	44	7.33	80.50
45.	35	5.83	86.33
50.	15	2.50	88.83
55.	15	2.50	91.33
60.	16	2.67	94.00
OVER 60.	36	6.00	100.00

APPOINTMENT SYSTEM 26 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	13.68 MIN
AVERAGE LENGTH OF IDLE TIME	=	7.44 MIN
AVERAGE DENTIST IDLE TIME	=	16.37 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	327.23
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE		3.00

INDIVIDUAL WAITING TIMES

	UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
	5.	191	36.38	36.38
	10.	69	13.14	49.52
	15.	66	12.57	62.10
	20.	61	11.62	73.71
	25.	51	9.71	83.43
	30.	28	5.33	88.76
	35.	22	4.19	92.95
	40.	11	2.10	95.05
	45.	5	0.95	96.00
	50.	6	1.14	97.14
	55.	1	0.19	97.33
	60.	3	0.57	97.90
OVER	60.	11	2.10	100.00

APPOINTMENT SYSTEM 27 (ALL 25 RUNS COMBINED)

AVERAGE PATIENT WAITING TIME	=	8.78 MIN
AVERAGE LENGTH OF IDLE TIME	=	13.08 MIN
AVERAGE DENTIST IDLE TIME	=	37.87 MIN
MEAN EARLY AT OF PATIENT	=	0.0
MEAN SERVICE TIME	=	0.0
LENGTH OF CLINICAL SESSION	=	347.40
NUMBER OF WALK-IN PATIENTS	=	0
NUMBER OF DENTISTS AVAILABLE	=	3.00

INDIVIDUAL WAITING TIMES

UPPER LIMIT	OBS. FREQ	PERCENT OF TOTAL	CUMULATIVE PERCENTAGE
5.	281	53.52	53.52
10.	71	13.52	67.05
15.	50	9.52	76.57
20.	45	8.57	85.14
25.	36	6.86	92.00
30.	15	2.86	94.86
35.	10	1.90	96.76
40.	2	0.38	97.14
45.	3	0.57	97.71
50.	2	0.38	98.10
55.	3	0.57	98.67
60.	2	0.38	99.05
OVER 60.	5	0.95	100.00

APPENDIX H

OUTPUT FOR APPOINTMENT SYSTEMS (A THROUGH E)

Explanation of Variables Used

NP - Total number of patients scheduled during each simulated clinic session.

DIT - Total dentist idle time for each simulated clinic session.

DBT - Total service time to complete the number of patients scheduled.

PWT - Total waiting time for all the patients scheduled during each simulated clinic session.

DAVAL - Dentist availability time. The sum of DIT and DBT for each simulated clinic session. An additional 65 minutes for the dentists' initial availability time is also included. A DAVAL of 420 minutes represents a clinic length of 360 minutes.

APPOINTMENT SYSTEM A (45, 90)

	NP	DIT	DBT	PWT	DAVAL
	7	25.3	373.5	99.9	463.7
	6	69.0	263.8	20.4	397.8
	7	70.0	292.3	40.3	427.3
	6	85.5	224.7	50.3	375.1
	8	71.0	253.0	23.9	389.0
	5	56.5	280.4	26.2	401.9
	7	0.0	399.2	422.3	464.2
	7	25.0	310.1	16.7	400.0
	5	43.1	284.0	44.5	392.1
	7	47.1	295.8	44.4	407.9
	7	19.7	331.6	71.3	416.3
	8	83.1	249.3	24.5	397.4
	6	85.5	253.7	54.6	404.1
	8	104.8	209.7	45.2	379.5
	7	38.3	299.5	19.4	402.8
	8	89.1	223.0	34.2	377.1
	7	1.5	363.4	89.9	429.9
	6	57.4	277.1	23.9	399.5
	6	73.4	239.7	8.8	378.2
	8	49.0	287.2	54.1	401.2
	6	69.7	262.6	9.8	397.3
	7	64.1	283.4	51.2	412.5
	7	28.7	313.7	46.3	407.4
	6	0.0	323.9	196.5	388.9
	7	90.5	245.5	13.3	401.0
	5	48.3	310.4	44.2	423.7
	5	43.2	328.7	8.8	436.9
	7	48.5	291.4	102.7	404.9
	6	48.7	259.7	43.6	373.4
	8	0.0	311.6	85.6	376.6
	8	66.9	255.6	19.3	387.6
	7	84.0	261.8	17.3	410.9
	8	25.3	328.3	88.1	418.6
	7	8.3	338.3	111.8	411.6
	7	73.2	248.5	65.9	386.7
	6	24.1	308.3	42.4	397.4
	7	77.8	273.4	23.8	416.2
	7	0.0	361.7	148.7	426.7
	7	19.2	322.9	77.0	407.1
	8	32.7	313.5	120.2	411.2
MEANS	6.8	48.7	291.4	63.3	

MEAN PATIENT ARRIVAL TIME = 9.8

APPOINTMENT SYSTEM B (30, 60, 90)

NP	DIT	DBT	PWT	DAVAL
6	35.1	296.9	38.0	397.0
8	1.8	345.1	152.8	411.9
9	54.0	306.2	118.4	425.2
10	27.7	316.2	118.7	408.8
7	39.3	313.4	78.0	417.7
7	8.7	342.8	79.3	416.5
7	69.8	251.4	23.0	386.2
9	0.0	370.4	352.4	435.4
7	0.0	369.8	188.1	434.8
9	64.2	289.3	39.8	418.5
7	39.00	324.1	102.0	428.0
8	21.4	330.3	83.00	416.7
6	46.0	286.2	20.2	397.2
7	21.2	324.7	57.0	410.9
9	0.0	357.3	172.1	422.3
9	4.7	350.1	241.7	419.8
8	0.0	386.3	321.2	451.3
8	31.4	366.5	251.1	462.9
9	9.5	356.1	81.4	430.6
9	25.6	348.0	124.0	438.5
8	14.3	349.9	112.3	429.2
8	21.5	324.5	93.8	411.0
8	13.9	338.9	74.6	417.8
6	0.0	358.9	164.3	423.9
10	0.0	377.4	285.9	442.4
8	40.8	314.8	78.00	420.6
7	5.9	369.4	127.1	440.3
9	18.1	339.4	114.0	422.4
9	90.7	269.1	31.3	414.9
8	0.0	360.9	143.4	425.9
7	67.5	294.9	12.2	427.4
9	0.0	379.4	235.7	444.4
9	11.2	358.8	88.1	435.1
7	10.8	355.9	42.8	431.7
10	0.6	338.4	91.0	404.0
8	40.0	321.7	83.6	426.7
7	37.2	321.3	43.4	423.5
9	3.7	336.4	165.3	405.1
8	48.9	290.8	43.1	404.7
7	25.5	339.4	144.5	429.9
MEANS 8.0	23.5	334.3	120.4	

MEAN PATIENT ARRIVAL TIME = 9.6

APPOINTMENT SYSTEM C (20, 40, 60, 80, 100)

NP	DIT	DBT	PWT	DAVAL
8	20.1	358.8	98.6	443.8
10	26.7	346.1	183.6	437.8
9	48.0	318.2	131.6	431.2
7	0.0	335.5	111.0	400.5
12	27.7	298.8	213.9	391.5
7	5.6	348.6	52.7	419.1
8	0.0	387.3	207.3	452.3
9	41.0	315.4	78.2	421.4
11	68.7	284.2	50.8	417.9
8	27.9	337.8	163.3	430.7
8	0.0	369.7	176.7	434.7
7	35.6	313.8	6.1	414.4
8	0.0	350.5	174.9	415.5
7	21.7	375.0	134.9	461.8
10	0.0	353.3	180.3	418.3
7	0.0	351.8	145.6	416.8
7	0.0	395.0	249.8	460.0
9	4.9	388.0	189.4	457.9
7	46.9	307.4	53.8	419.2
10	0.0	381.3	347.0	446.3
8	0.0	338.9	77.4	403.9
7	0.0	415.2	239.9	480.2
9	24.0	302.9	52.7	391.8
10	1.5	357.8	162.8	424.3
9	66.9	294.4	87.3	426.3
9	56.0	304.7	82.4	427.8
6	47.7	257.4	29.5	370.1
8	7.4	345.1	43.8	417.5
7	7.5	322.0	70.1	394.5
8	21.0	335.3	88.8	421.3
10	26.0	308.7	107.4	399.7
9	0.0	346.6	225.3	411.6
8	32.7	312.1	49.1	409.8
7	9.5	337.9	114.6	412.4
7	0.0	372.3	229.5	437.3
8	14.7	364.7	153.1	444.4
7	15.5	337.5	77.8	418.0
7	22.1	332.4	129.5	419.5
9	52.5	307.8	23.7	425.4
9	60.1	297.4	60.8	422.5
MEANS 8.3	21.0	337.7	126.4	

MEAN PATIENT ARRIVAL TIME = 9.3

APPOINTMENT SYSTEM D (30, 45, 60, 75, 90)

NP	DIT	DBT	PWT	DAVAL
7	15.1	339.5	53.6	419.6
9	5.6	381.0	234.4	451.6
8	25.9	297.7	82.6	388.6
8	1.9	353.1	191.5	420.0
8	35.1	311.9	78.9	411.9
8	35.1	310.3	121.9	410.4
8	26.7	337.2	42.2	428.9
8	0.0	362.9	191.1	427.9
8	11.1	310.9	88.5	387.0
9	17.3	382.3	205.7	464.6
7	25.3	360.4	138.4	450.7
9	68.8	286.2	81.1	420.1
10	29.7	327.5	63.0	422.2
10	12.9	339.2	90.8	417.0
9	8.7	375.7	301.4	449.4
8	5.1	311.4	93.2	381.6
9	7.5	339.5	153.0	412.0
10	0.0	389.2	339.6	454.2
7	0.0	353.8	126.3	418.8
8	4.0	389.9	219.1	458.8
9	64.4	276.2	63.5	405.6
7	48.4	296.1	39.6	409.5
8	11.9	335.0	107.8	411.9
7	0.0	373.6	222.4	438.6
8	0.0	365.7	218.2	430.7
9	12.5	289.7	146.7	367.1
10	52.0	303.1	80.3	420.1
9	7.2	317.1	158.8	389.2
7	12.5	321.2	86.7	398.7
10	21.0	344.8	125.9	430.8
9	0.0	382.3	194.1	447.2
8	0.0	389.2	209.9	454.2
9	0.5	357.6	170.0	423.1
9	2.7	347.5	97.3	415.2
7	31.9	332.2	68.1	429.1
8	17.1	306.2	66.9	388.3
7	2.9	328.0	86.8	395.9
7	4.8	365.9	92.3	435.7
7	10.0	336.1	83.8	411.1
9	15.4	339.8	148.8	420.2
MEANS 8.3	16.3	339.2	134.1	

MEAN PATIENT ARRIVAL TIME = 9.6

APPOINTMENT SYSTEM E (30, 40, 50, 60, 70, 80, 90)

NP	DIT	DBT	PWT	DAVAL
7	15.3	373.5	124.9	453.7
8	0.0	350.6	150.8	415.6
8	1.1	355.6	163.7	421.7
9	29.8	345.5	335.4	440.3
8	10.8	361.0	104.1	436.7
8	0.0	385.5	282.1	450.5
7	0.0	370.0	185.8	435.0
9	1.1	328.7	130.5	394.8
7	10.5	348.1	139.5	423.6
10	5.1	342.5	107.3	412.6
7	20.7	342.5	152.7	428.2
7	22.7	302.1	17.0	389.9
9	9.6	312.7	76.3	387.3
9	0.0	395.0	271.0	460.0
8	15.4	362.8	117.4	443.2
9	0.0	355.4	238.8	420.4
9	25.2	385.5	163.7	475.7
9	8.0	370.9	265.2	443.9
8	24.2	325.1	147.6	414.4
8	0.0	356.2	207.0	421.2
8	0.0	364.6	178.9	429.6
9	11.1	349.7	82.3	425.8
10	27.3	343.9	115.1	436.2
10	13.7	356.2	243.5	434.8
7	0.0	388.1	203.1	453.1
9	22.4	321.6	107.2	409.1
8	0.0	416.2	344.0	481.2
6	27.7	310.1	36.9	402.7
8	15.3	339.4	123.0	419.7
9	40.5	289.0	46.8	394.5
8	11.4	335.3	129.2	411.7
11	6.0	350.3	156.2	421.3
9	16.0	376.3	237.0	457.3
6	5.6	342.7	51.8	413.4
7	0.0	340.6	134.9	405.6
10	40.8	319.7	103.3	425.4
7	0.0	374.9	167.4	439.9
8	6.7	355.1	170.0	426.8
8	3.6	389.0	335.3	457.6
9	2.5	339.7	183.5	407.2
MEANS 8.3	11.2	351.8	164.5	

MEAN PATIENT ARRIVAL TIME = 9.8

VITA

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