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7/25/68

A SYSTEMS APPROACH IN THE PLANNING OF A HOSPITAL OUTPATIENT CLINIC

A THESIS

Presented to

The Faculty of the Graduate Division

by

Andrew Thomas Sumner

In Partial Fulfillment

of the Requirements for the Degree

Master of Science in Industrial Engineering

Georgia Institute of Technology

June, 1970

A SYSTEMS APPROACH IN THE PLANNING
OF A HOSPITAL OUTPATIENT CLINIC

Approved:

Chairman ______________________

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Date approved by Chairman 6-2-70

ACKNOWLEDGEMENTS

Credit for direction of this thesis must be shared equally between James B. Mathews and Richard K. C. Hsieh. Professor Mathews, Assistant Director of the Program in Hospital Medical Systems (PHMS), Medical College of Georgia, provided initial guidance and continually reviewed drafts of the thesis. Dr. Hsieh, Chief of Health Services Research, U. S. Public Health Service, and Lecturer of Operations Research at the Johns Hopkins University, School of Hygiene and Public Health, reviewed the final drafts of the thesis and continually encouraged the early completion of the thesis.

Sincerest appreciation is also extended to Harold E. Smalley and John R. Freeman. Dr. Smalley, Director of the Health Systems Research Center at the Georgia Institute of Technology, served as thesis advisor and patiently waited for two years for the results of this research. His professional approach to health problems and continual inspiration encouraged the author to undertake this research and continue professionally in the health field. Dr. Freeman, Director, Health Systems Research Division, J. Hillis Miller Health Center, University of Florida, formerly with the PHMS at Georgia Tech, initially encouraged the author to enter the PHMS and suggested the problem area undertaken in this thesis.

My deepest gratitude is also extended to the two other members of my thesis advisory committee. Dr. William W. Hines, Associate Director for Graduate Programs, School of Industrial and Systems Engineering at Georgia Tech, reviewed approaches to the study and suggested improvements in the manuscript. Walter W. Diggs, Administrator, Eugene Talmadge Memorial Hospital, provided general guidance and assessed the practicality of the study approaches.

Among the numerous people whose suggestions contributed to the research are Marvin A. Griffin, Director, Department of Industrial Engineering, University of Alabama; Joseph A. Harrison, Assistant Professor of Mathematics, Morehouse College; Max G. Holland, Assistant Professor of Management, Georgia State University; and William G. Sullivan, Senior Systems Engineer, Medical College of Georgia.

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ABSTRACT

The health facilities planning problem has been studied in the past by architects, medical consultants, and hospital administrators.The results of these studies have primarily been the development of suggested planning ratios (for example, square feet per bed, examining rooms per physician) and qualitative information related to the determination of space requirements. These ratios have limited predictive merit because they are usually based upon average square feet allocated to departments of a number of existing hospitals. In addition, the ratios have no direct relationship to the facility requirements of an individual hospital. For example, the simple application of the ratios does not take into account variations among hospitals in factors such as demand, methods of processing demand, or numbers of personnel.

The intent of this study is to illustrate that another methodology, which utilizes the systems approach, computer simulation, regression analysis, and optimization techniques, can add a valuable dimension to the long-range health facilities planning process. The specific objective of this investigation is to develop a methodology for predicting the number of examining rooms needed in an outpatient clinic. The general methodology presented herein consists of the development of a computer simulation model of an outpatient clinic, a sensitivity analysis of the model to changes in component values, the development of regression equations which relate outpatient

clinic performance to the number of examining rooms, and the formulation of a mathematical expression which predicts the required number of examining rooms as a function of the measures of effectiveness of the clinic.

With minor modification, the methodology presented herein can be used to predict the required number of examining rooms in most outpatient clinics. The methodology is especially suited for long-range facilities planning problems, but portions of it may be used for short-range planning. The general approach of this study can be used to predict the required values of other components (e.g., the number of physicians, the number of medical students, and the appointment schedule) of an outpatient clinic.

CHAPTER I

INTRODUCTION

Health and medical care have received increased attention in the United States in recent years. Although the quality of medical care has been emphasized through the ages, only recently has the delivery of health services been a topic of concern to health professionals. Evidence of the increased national attention to health matters may be shown by the fact that the ratio of health expenditures to the Gross National Product (GNP) rose from 3.6 per cent in 1929 to 5.9 per cent in 1963.[1] It has been estimated that the total expenditure for health in 1965 was $38.4 billion and the dollar expenditure for health increased 44 per cent from 1961 to 1965.[2] These costs may not appear alarming to the casual reader, but to the health economist they indicate that the health expenditure may soon reach 10 per cent of the GNP.

Hospital care accounts for most of the expenditure for health. Even when fees for medical services rendered in hospitals were not included in the data, hospital expenditures in 1964 constituted 40

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[1] Klarman, Herbert E., The Economics of Health, Columbia University Press, New York, 1965, p. 9.

[2] Somers, Herman M. and Anne R. Somers, "A Program for Research in Health Economics," Public Health Service Publication No. 947-7, January 1967, p. 11.

per cent of the total health expenditure. From 1946 to 1964 hospital expenses rose from $1.96 billion to $12.03 billion an increase of 513 per cent.[3] During this same period, hospital charges (excluding fees for medical services) increased 234 per cent while the cost of living index increased only 59 per cent. The number of employees in hospitals also increased rapidly from 1950 to 1964. The average number of personnel per patient increased from 1.8 to 2.4, respectively.[4]

Traditionally the major source of hospital capital funds was philanthropy. However, since new Federal laws have been enacted, the Federal Government has increased its hospital expenditures and now has become the major source of hospital capital funds. The Hill-Burton hospital construction program, the Health Professions Education Assistance Act, and the NIH research facilities program have largely been responsible for the Federal expenditures for health facilities construction. In 1965 the Federal Government financed 35 per cent of all health facilities construction expenditures.[5]

Realizing that duplication and fragmentation of hospital facilities in a region could result from the large amount of Federal money being supplied, two Public Health Acts have been enacted recently to insure effective planning of hospital facilities. The first of these, "Comprehensive Health Planning and Public Health

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[3]Smalley, Harold E. and John R. Freeman, Hospital Industrial Engineering, Reinhold Publishing Corporation, New York, 1966, p.2.

[4] Somers, *op. cit.*, p. 14.

[5]*Ibid.*, p. 12

Services Amendments of 1966," Public Law 89-749,[6] provided $7.5 million for the period from July 1, 1966 to June 30, 1968 to establish a "Comprehensive Health Planning Agency " in each state. In addition, the Act allocates $12.5 million for comprehensive regional, metropolitan area, or local area health planning and $4 million for training studies, and demonstrations of effective comprehensive health planning. The second act, Public Law 90-174,[7] "Partnership for Health Amendments of 1967," provided capital funds for replacement, modernization, and expansion of health care facilities. Also, the Act extended Public Law 89-749 until 1970 and provided more funds for its enactment.

Federal grants for hospital construction have largely been responsible for the 17 per cent growth in the number of hospitals from the 1946 level of 6,125 to the 1967 level of 7,160. Construction costs, in terms of 1957-1959 dollars, have risen from $315 million in 1946 to $1.63 billion in 1965.[8] Although most of this increase can be attributed to the increased rate of new hospital construction and more expensive fixed medical equipment, some of this cost has been a result of duplication in hospital facilities and inefficient use of hospital space.[9]

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[6]"Comprehensive Health Planning and Public Health Services Amendments of 1966," Public Law 89-749, 89th Congress, .3008, November 3, 1966, 11 pp.

[7]"Partnership for Health Amendments of 1967," Public Law 90-174, 90th Congress, H.R. 6418, December 5, 1967, 10 pp.

[8]Health, Education, and Welfare Trends, U.S. Government Printing Office, 1965 edition, p. 35.

[9]Somers, op. cit., p. 18.

One of the areas of most recent interest in hospital planning is the relationship between hospital construction costs and annual operating expenses. Since the average ratio of capital construction costs to annual operating expenses is approximately 2 to 1, the tendency in the past to reduce hospital construction costs may very well have resulted in high operating expenses and, consequently, high long-range costs. Although very few projects have been initiated to determine the relationship between capital costs and operating costs, a very exhaustive study[10] on this subject is currently being undertaken by the Federal Health Programs Service of the U.S. Public Health Service. In this project systems and industrial engineering techniques are being utilized to plan efficient operating methods prior to recommending the modernization of existing facilities or the provision of new space for each of the 10 USPHS Hospitals.

In most architectural and hospital journals, hospital construction costs have been compared over time and among institutions on a "per bed basis." This measure of cost is becoming less and less meaningful because of the increasing proportion of hospital space devoted to non-bed purposes (for example, outpatient services, education, and research). In most of the recently constructed teaching hospitals, inpatient space occupies less than one-third of the total space.

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[10] "Systems and Industrial Engineering Studies and Services in the Planning and Programming of PHS General Hospital Facilities," Contract NOQ. PH 110-68-39, Edgar N. Duncan, Project Director, Associate Director, Federal Health Programs Service, Health Services and Mental Health Administration, U.S. Public Health Service, 79 pp.

In the past hospital outpatient services were provided to people who could not afford the services of a physician.[11] As the population began to increase more rapidly than the supply of physicians, the outpatient departments of hospitals presented an alternative to obtaining medical care from general practitioners. In 1920 the Rockefeller Foundation promoted the concept of proprietary outpatient clinics by awarding the Harvard Medical School a $.6 million grant to establish a proprietary outpatient clinic which would charge patients for services rendered.[12] Since the majority of the patients seen in the Harvard outpatient clinics were indigent, the clinic could not produce sufficient revenue, and the charges for clinic services were eliminated shortly thereafter. The proprietary clinic concept was abandoned until 1933 when the Blue Cross Association developed the concept of prepaid health insurance. The prepaid health insurance concept was readily accepted by the population, and the demand for hospital services increased rapidly. From 1955 to 1967 the number of outpatient visits in hospitals rose from 73.5 million to 148.2 million, respectively.[13] This growth of 102 per cent was substantially greater than the 39 per cent increase in inpatient admissions for the same period. These figures substantiate the contention that providing

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[11]"Reminiscences and Prospectives in Ambulatory Services," an article in "The Expanding Role of Ambulatory Services in Hospitals and Health Departments," The New York Academy of Medicine, January 1965, Vol. 41, No. 1, p. 135.

[12]*Ibid.*, p. 134.

[13]Sources: "Guide Issue," *Hospitals*, August 1, 1955, Vol. 29, No. 15, Part 2; "Guide Issue," *Hospitals*, August 1, 1968, Vol. 42, No. 15, Part 2.

outpatient services is becoming an increasingly important function of hospitals.

Objectives

The specific objective of this investigation is to develop a methodology for predicting the number of outpatient examining rooms needed in an outpatient clinic. The overall purpose of this study is to provide a quantitative basis for determining long-range space requirements for an outpatient clinic. The general methodology presented herein consists of the development of a computer simulation model of the clinic, a sensitivity analysis of the model to changes in component values, the development of regression equations which predict outpatient clinic performance as a function of the number of examining rooms, and the formulation of a mathematical expression which predicts the required number of examining rooms as a function of the measures of effectiveness of the clinic.

Nature of the Problem

The health facilities planning problem is one of the most complex problems facing planners. The task of the planner is to provide adequate and attractive space for the operation of hospital functions. Since hospital construction is expensive and time consuming, newly constructed hospital space is expected to provide adequate accommodations for several years in the future. Therefore, it is necessary for the planner to identify future hospital functions and to predict their space requirements. To make these long-range predictions hospital planners must operate under conditions of assumed certainty, risk, or uncertainty. Most predictions must be made under conditions of uncertainty due to the difficulties and inaccuracies in anticipating changes in demand for and the methods of delivery of hospital services.

A diagram depicting the long-range health facilities planning process is shown in Figure 1. The focus of attention in this thesis is on the first two steps (the functional program and the architectural program) which appear on the left portion of Figure 1. The functional program has only recently been elevated to a major and comprehensive phase of the planning process. The functional program describes the objectives and the research, teaching and service functions of the hospital. This program concludes with a preliminary list of needed types of space for each major department. For example, 40 examining rooms and 20 residents' offices might be included as types of space required in an outpatient department. The architectural program describes site preparation requirements, proposed hospital budget, construction cost estimates, and the space requirements for each functional area of the hospital.

Traditionally, space requirements for hospitals have often been determined by multiplying ratios of square feet per bed by the planned number of beds. This method of determining space requirements is still used by many hospital planners, especially in those departments where a functional program is difficult to develop. Although this "multiplicative" method of determining space requirements is simple to apply and requires little planning time, the ratios may have no direct relationship to individual hospital operations. The

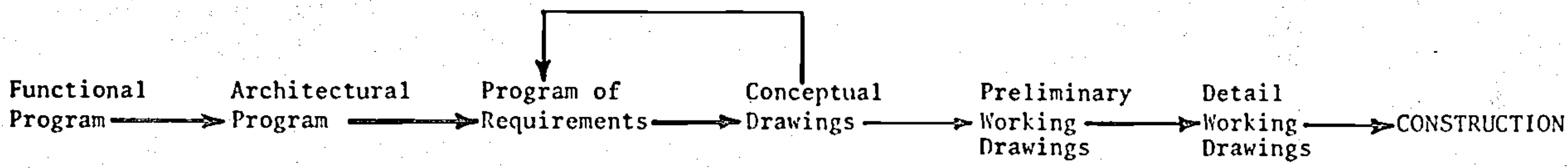

Figure 1. Health Facilities Planning Process

use of these ratios tends to standarize departmental space requirements among hospitals and the ratios are not sensitive to variations in such factors as demand, methods of processing demand, or numbers of personnel. In addition, these ratios have limited predictive merit since they are usually based upon the average square feet allocated to the various departments of a number of existing hospitals.

The specific objective of this thesis is to develop a methodology for predicting the number of examining rooms needed in an outpatient clinic. In long-range planning, the prediction of examining room requirements has not previously been considered as a systems problem. Expert judgment and historic ratios (for example, physicians per examining room, examining rooms per bed) have often been used. In this thesis the prediction of examining room requirements was conceptualized as a systems problem. Examining rooms were viewed as one of the resources consumed by patients as they travelled through an outpatient clinic "system." It seemed reasonable that a high number of examining rooms would be advantageous (for example, low patient waiting time and short clinic duration); while a low number of examining rooms would also be advantageous (for example, low construction costs and high room utilization). In this framework the methodology is intended to predict the number of examining rooms which would result in optimal outpatient clinic performance.

Scope and Limitations

The present study was concerned with only a portion of the functional and architectural programs for an outpatient clinic. Other components of the functional and architectural programs (for example, the number of offices for residents, interns and nurses, restrooms, and conference rooms) were not investigated. Also, no attempt was made to calculate the space requirement for examining rooms.

A specific outpatient clinic, the Orthopedic Clinic at Eugene Talmadge Memorial Hospital (ETMH) in Augusta, Georgia, was chosen to illustrate the methodology presented herein. The operation of the ETMH Orthopedic Clinic is representative of other outpatient clinics at ETMH, as well as other teaching hospitals. Therefore, by incorporating the appropriate source data, the methodology can be applied to the planning of most types of outpatient clinics for teaching hospitals.

Since most voluntary hospitals do not utilize medical students in the examination of outpatients, the computer simulation programs developed in this study would have to be modified to describe the flow of patients through the voluntary hospital outpatient clinics. In general, the methodology described in this study should be helpful in the planning of space requirements for any hospital department. It should be most beneficial to those departments which process large workloads and expect future changes in the departmental planning variables.

In Chapter II a literature survey of hospital and outpatient clinic planning is presented. Concepts of the systems approach and simulation which led to the development of the methodology are described in Chapter III. Chapter IV includes a description of a graphical model of an outpatient clinic, the development of a computer simulation program of the model, and a sensitivity analysis of the model to changes in values of system components. In Chapter V simulation is utilized to provide data for developing regression equations and an expression which predicts the number of examining rooms needed in an outpatient clinic.

CHAPTER II

LITERATURE SURVEY

Until the close of World War II little interest developed in hospital planning. Prior to that time, the planning and design of a hospital was a relatively unorganized undertaking.[1] Since communication among hospitals was limited in the post war era, news of a bad hospital design seldom was transmitted; and if it was, the complaints were likely regarded as operational problems. Apparently, no methodologies for the planning process or guides for determining space requirements in hospitals were published.

Interest in better delivery of health care probably developed as a result of the medical care rendered by the Armed Forces Medical Corps in World War II. When military veterans sought medical care in the civilian health care system, they were disturbed by the inaccessability of good medical care and demanded government intervention. As a result of the demand for better health services, the National Hospital Program of the U. S. Public Health Service was established in 1946. One component of the National Hospital Program, the Division of Hospital Facilities, was responsible for instituting improvements in hospital design. The Division financed studies in

[1]Cunningham, Robert M., Jr., "Design and Construction of General Hospitals," The Modern Hospital, March 1947, p. 3.

hospital planning, and results of the studies appeared in the literature in 1946 and 1947.[2] In these studies hospital planning criteria were developed to assist hospital planners in determining space requirements for hospitals. Also, a specific square feet per bed value was recommended for each hospital department. These values were based upon expert judgment, and no attempt was made to quantitatively relate demand (or workload) to space requirements. It should be noted that these values tended to standardize the square feet per department among hospitals with the same number of beds. For example, two hospitals with the same number of beds and a difference of 50,000 annual laboratory tests would be allocated the same number of square feet in the laboratory. The constant square feet per bed figure also did not reflect the relationship between the method of processing demand and space requirements in each department. For example, if a hospital has a laboratory with automated equipment, it will probably have different space requirements from a hospital without automated equipment. However, since the workload and the method of processing demand in each department among institutions was probably similar in many hospitals in 1946, the square feet per bed value probably was a good approximation to actual space requirements. These studies were especially helpful to architects who were inexperienced in hospital planning and design, and the overall effect was an improvement of the planning process and hospital design.

With the advent of digital computers and systems analysis

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[2]"The Functional Basis of Hospital Planning," The Modern Hospital, March 1947, p. 6.

techniques in the 1950's, further interest developed in researching the complex problems involved in hospital planning. In 1959 a study was initiated by Souder[3] which attempted to apply the "systems approach" to hospital planning. The objectives of the study were the development of a methodology for planning hospital facilities and the development of criteria for locating hospital departments relative to each other. Souder collected data on traffic patterns of hospital personnel and material in two general hospitals. He also developed a computer program which enabled an architect to sketch hospital floor plans by using a light pen and a cathode ray tube. Alternative hospital designs were evaluated by calculating travel time for alternative methods of processing demand in hospital departments. Based upon data collected from the two hospitsls, he made some generalizations about hospital interdepartmental traffic. Until Souder reported his findings, little work had appeared in the literature concerning interdepartmental traffic in terms of planning variables such as demand and methods of processing demand.

In 1963 Souder[4] reported an extension of his earlier work on interdepartmental traffic. Detailed information was gathered on the size of departments from three general hospitals in an attempt to develop criteria for determining departmental space requirements in hospitals. This study included a list of hospital departments and a

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[3]Souder, James J., et al., Planning for Hospitals: A Systems Approach Using Computer-Aided Techniques, American Hospital Association, Chicago, 1964, 167 pp.

[4]Souder, James J., "Estimating Space Needs and Costs in General Hospital Construction," American Hospital Association, Chicago, 1963, 32 pp.

recommended square feet per bed value for each department. Since Souder's results were directly related to the existing three study hospitals, use of the criteria for predicting space requirements should be questioned. Once again, no attempt was made to relate demand or the method of processing demand to space requirements. Nevertheless, Souder's work was the first major revision of the criteria published by the Division of Hospital Facilities in 1946.

One of the most comprehensive documents concerning the hospital planning process was written by Wheeler[5] in 1964. Wheeler identified the major steps in the planning process and described the programming and design phases of hospital facilities planning. Planning criteria and methodologies were developed for each major hospital department. He stated that the functional program for the outpatient department involves estimating the future demand of clinics and preparing a weekly schedule for all clinics. Wheeler recommended that the utilization of examining rooms, the use of consulting-examining rooms, and the increasing growth of outpatient clinics be considered when determining the number of outpatient examining rooms to be built. For most departments Wheeler related workload and demand to space requirements. This book was one of the first to document a methodology of the complete planning process.

A report[6] published in 1964 by the U. S. Public Health Service

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[5]Wheeler, E. Todd, Hospital Design and Function, McGraw-Hill Book Co., New York, 1964, 296 pp.

[6]"Medical Education Facilities: Planning Considerations and Architectural Guide," U. S. Public Health Service Publication No. 1180-A-16, 1964, pp. 113-122.

listed recommended space requirements for medical education facilities. Space requirements for hospital departments were developed for hypothetical 500 and 700 bed teaching hospitals. The recommended space requirements were the result of a survey of several medical schools. Although the report acknowledged the existence of relationships among space requirements, demand, and method of processing demand, the recommendations were assessments of historical data and experience, not quantitative calculations.

A manual[7] of the hospital planning process was published in 1966 by the American Hospital Association. This document described the functions of each member of the hospital planning committee. Checklists of recommended types of space were developed for each hospital department, but formulas for determining space requirements were not proposed. In general, this manual lacks planning criteria and quantitative methodologies for determining space requirements.

One of the most exhaustive studies concerning outpatient department planning appeared in the literature in 1967.[8] Relationships among space requirements, demand, and method of processing demand were identified. For example, it was stated that if separate dressing rooms were provided, the required number of examining rooms would be reduced.[9] Also, the number of examining rooms needed for an outpatient department was calculated by estimating the expected number

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[7] "Manual of Hospital Planning Procedures," American Hospital Association, Chicago, 1966, 72 pp.

[8] "Hospital Planning Note 6: Organization and Design of Outpatient Departments," Her Majesty's Stationery Office, Edinburg, 1967, 85 pp.

[9] Ibid., p. 3

of new and return patients in each clinic, the average patient examining time per clinic specialty, doctor waiting time, the effect of trends in population on the outpatient department, and the number of hours the outpatient department would operate each day. Although the authors stated that gross estimates of the planning factors would suffice, no attempt was made to explain the possible effects of the gross estimates on the operation of the future outpatient department. This study identified the effect of time on the estimates when it was stated, "As the services given to patients and organization of these services develop with time, the number of patients making a reasonable load may change."[10]

In a health facilities planning study[11] completed in 1968 at the University of Iowa, "systems analysis" was used to determine space requirements in a proposed outpatient clinic. Workloads, utilization rates, clinic schedules, and patient flow were used to ascertain space requirements. This study described a unique attempt to involve people representing many professions in hospital planning. A few planning factors were identified in the study, but the relative importance of each planning factor was not determined.

Perhaps the current state of the art of hospital planning can best be described by a paper presented in January 1968 by Herman Smith.[12] Although Smith identified the need for a more scientific

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[10] Ibid., p. 20.

[11] Clasen, Glen E., et al., "Perspective for Planning the University of Iowa Hospitals and Clinics," 1968, 424 pp.

[12] Smith, Herman, "Theory of Hospital Functional Planning," Proceedings of the Hospital Trustees and Administrators Institute on Hospital Planning, Atlanta, 1968, pp. 79-114.

approach to planning, his proposed methodology of "functional planning" is not described. The examples cited by Smith in explaining "functional planning" appear to be based primarily upon experience and subjective factors. For example, Smith makes the following two statements:

1. For the new 300 bed hospital where outpatient service will have to be developed on an educational basis, 10 square feet per bed for a combined emergency and outpatient department or 3,000 square feet should be sufficient.[13]

2. If no sundries are to be sold in the pharmacy, three square feet per bed or 900 square feet should be provided for the pharmacy.[14]

Studies regarding short-run planning for outpatient departments have appeared in the literature in recent years. Many of the studies[15, 16, 17] were primarily concerned with reducing patient waiting time. Although empirical evidence from existing outpatient departments was used in these studies, a quantitative basis for the suggested improvements was not presented.

An interesting approach to reducing patient waiting time was presented by Dreibelbis[18] in 1968. A private medical practice was

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[13] Ibid., p. 93.

[14] Ibid., p. 97.

[15] Hinds, Richard J., "Appointment Survey Pinpoints Causes of Clinic Delays," Hospital Topics, Vol. 40, December 1962, pp. 42-45.

[16] Durbin, Richard L., "Developing an Outpatient Department," Hospital Topics, Vol. 4, November 1965, pp. 67-70.

[17] Frakes, Roy A., "Study of Outpatient Department Results In More Efficient Room Usage," Hospitals, Vol. 40, No. 22, Nov. 16, 1966, pp. 79-81.

[18] Dreibelbis, Robert E., "How Long Do You Keep Patients Waiting?", Medical Economics, June 24, 1968, pp. 61-66.

described in which the average patient waiting time was five minutes. He credited this short waiting time to well-trained personnel and a well-designed appointment system. Apparently the design for patient flow was based upon experimentation and the experience of the author. Although the relatively low average patient waiting time is a creditable result, the advisability of his particular method of processing patients (examining one patient before completing another examination) has been questioned by many physicians, and in one case[19] it was specifically not recommended. Dreibelbis was apparently the first physician to assign appointments to patients based on their specific expected examination time.

A comprehensive guide to the analysis of outpatient department operations was published by the United Hospital Fund[20] in 1967. This report describes components of outpatient departments and identifies significant problem areas. The authors stressed the importance of a well-designed appointment system. Also, they recommended that long-range values of components be considered when planning for short-run improvements.

Many of the recent attempts to improve the operation of outpatient clinics have involved the application of operations research techniques. One of the earliest of these studies was reported by

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[19]"Hospital Planning Note 6," Op. Cit., p. 45.

[20]"Systems Analysis and Design of Outpatient Department Appointment and Information Systems," United Hospital Fund of New York, New York, 1967, 95 pp.

Gabrielson[21] in 1959. This study involved a thorough analysis of the operation of an outpatient department at the Johns Hopkins Hospital. After a proposed system of operation was developed, detailed descriptions of the existing and proposed systems were completed. Manual Monte Carlo simulations of each system were conducted to determine if the proposed system would result in improved outpatient clinic performance. A mathematical model was developed which indicated that parallel patient flow would result in lower average patient waiting than serial patient flow if patients arrived in random fashion.[22] This study made no attempt to relate short-run operational improvements to long-range facilities planning. However, the study illustrates the advantages of using simulation in system analysis.

Goldman and Bassin[23] completed a study in 1963 which described information flow, patient flow, and resource requirements in an outpatient department. A simplified model of the outpatient department was developed, and a manual simulation of the model was performed to determine staffing requirements. This model of the clinic was developed in an attempt to schedule the use of examining rooms for specific medical departments.

In 1964 three brief studies of appointment systems were reported in Operational Research Quarterly. In the first of these,

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[21]Gabrielson, Ira W., et al., "Analysis of Congestion in an Outpatient Clinic," The Johns Hopkins Hospital, Baltimore, Md., 1959, 48 pp.

[22]*Ibid.*, p. 45.

[23]Goldman, Jay and Phillip Bassin, "Outpatient Department Study," The Jewish Hospital of St. Louis, St. Louis, August, 1963, 24 pp.

Jackson[24] attempted to design an improved patient appointment system with reduced patient waiting time. For one month he collected examination times of a physician in private medical practice. A graphical model of the medical practice was developed. The effect of alternative appointment schedules on patient waiting times was then predicted by computer simulation. Jackson stated that the actual clinic operation could be approximated by a negative exponential service time distribution and interarrival distribution. Based upon the results of the computer simulation, the author concluded "... if the ratio between average consulting time and the patient interarrival time is between .85 and .95, neither the patient nor the physician will experience long waiting times."[25] Jackson should be credited with relating a theoretical model to an actual clinic operation and documenting the use of computer simulation in the design of an appointment system.

In the second study, Welch[26] analyzed data previously collected in a 1952 study conducted by the Department of Health in Scotland. He showed that very few patients arrived late for appointments, but physicians were late for appointments most of the time. An analysis of the data also suggested that physician lateness accounted for only

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[24]Jackson, R. P., "Design of an Appointment System," Operational Research Quarterly, Sept. 1964, Vol. 15, pp. 219-224.

[25]*Ibid*., p. 222.

[26]Welch, J. D., "Appointment Systems in Hospital Outpatient Departments," Operational Research Quarterly, Sept. 1964, Vol. 15, pp. 224-232.

20 per cent of the patient waiting time. The remaining portion of patient waiting time was found to be caused by the difference in arrival rate and service rate. Welch made several recommendations to improve the operation of outpatient departments, but he did not recommend criteria for determining space requirements. He made one of the first attempts to quantify the effects of patient appointment interval, patient punctuality, and physician punctuality on the performance of an outpatient department. Welch was also one of the first to document the relationship between an appointment system and space requirements when he stated that the size of the waiting room could be reduced with a good appointment system.

In the third study, Fry[27] described the implementation of an appointment system for a physician in general practice. The study focused on operational details of a private medical practice. However, the author emphasized the importance of a good appointment system in reducing patient waiting time, and he was one of the first to suggest using scheduled gaps in an appointment system to allow for walk-in patients.

Fetter and Thompson[28] published the results of a research project concerning the outpatient department in 1966. The authors identified seven components which have an effect on the performance

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[27]Fry, John, "Appointments in General Practice," Operational Research Quarterly, Sept. 1964, Vol. 15, pp. 233-237.

[28]Fetter, Robert B. and John D. Thompson, "Patients' Waiting Time and Doctors' Idle Time in the Outpatient Setting," Health Services Research, Vol. 1, No. 1, Summer 1966, pp. 66-90.

of an outpatient clinic. A computer program for simulating an outpatient clinic was developed so that the effect of many of the variables could be tested. The program generated a schedule of appointments in which the load factor (the per cent of scheduled appointments filled by appointive patients), appointment interval, and office hours had been predetermined. Four experiments were conducted using the computer program, and the results of the experiments were analyzed. In the first experiment it was found that patient waiting time increased and physician waiting time decreased when the patient load factor was increased. The purpose of the second experiment was to determine the effect of patient punctuality on patient waiting time. Patient waiting time was significantly reduced when the patients were assumed to arrive on time. The effect of physician arrival time on patient waiting time and physician waiting time was investigated in the third experiment. Patient waiting time was found to be more sensitive to physician arrival time than was physician waiting time. In the fourth experiment the effects of appointment interval, physician punctuality and load factor on physician productivity were investigated in a series of simulations. The Fetter and Thompson study was very comprehensive and illustrated the use of computer simulation in determining the effects of many factors on the operation of an outpatient clinic. However, no attempt was made to use computer simulation for long-range facilities planning.

A study reported by Williams[29] in 1967 was similar in scope to

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29Williams, William J., et al., "Simulation Modeling of a Teaching Hospital Outpatient Clinic," Hospitals, Vol. 41, No. 21, Nov. 1,1967, pp. 71-75, 128.

the Fetter and Thompson study. The Williams' study focused on both short-run and long-range objectives. A flow diagram of outpatient flow was constructed, and a manual simulation of the outpatient department was performed by using physician examining times and flow diagram. The simulation was verified by comparing the simulated results with data on the existing system. The authors used the simulation to design an improved appointment system and to predict personnel requirements. This study appears to be the first in which simulation was used both for short-run and long-range planning.

Lane and Freeman[30], in an unpublished paper, reported the use of computer simulation in the planning of a private medical practice in 1967. The objective of this investigation was to assist two physicians in determining their examining room requirements for a proposed building. A special purpose simulation language, GPSS III, was used to develop a computer simulation program of the clinic. The authors simulated 20 days of medical practice and 5 varying numbers of rooms for each day to provide quantitative information for determining the desired number of examining rooms. The criteria for choosing a specific number of examining rooms included the expected completion time for physicians (clinic duration), the average patient waiting time, and the percentage of time the rooms were occupied. The results of the computer simulations were presented in tabular form so that the physicians could easily view the results of alternative numbers

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[30] Lane, Walter W. and John R. Freeman, (Unpublished Paper), University of Florida, June 1967, 12 pp.

of examining rooms.

The results of the literature survey show a general lack of a quantitative basis for predicting space requirements in long-range facilities planning, and, specifically, in outpatient department planning. Although a few authors have discussed changing trends in the health field, no attempt to incorporate significant long-range planning factors into a quantitative facilities planning methodology has been reported. The study described in the following chapters attempts to provide quantitative information regarding the effects of selected long-range planning factors on outpatient department planning. The results of this investigation should add a valuable dimension to the process of planning a hospital outpatient department.

CHAPTER III

DEVELOPMENT OF THE METHODOLOGY

The objective of this investigation was to develop a methodology for predicting the number of outpatient examining rooms needed in an outpatient clinic. The prediction of examining room requirements was considered to be a long-range planning problem. Usually long-range planning is concerned with the way system components may interact with each other and with their environment to shape the future, rather than with just predictions based on statistical analyses of past data. While the number of examining rooms is the ultimate prediction sought, the nature of the long-range facilities planning problem seems to require that the planning methodology include an investigation of the interacting effects of changes in other systems components as well. Thus, the methodology presented herein focuses on predicting the effects of changes in component values on outpatient clinic performance instead of emphasizing statistical analyses of past data. Examining rooms were viewed as one of the resources consumed by patients as they travelled through an outpatient clinic "system". Using the systems framework of the problem, it seemed reasonable that the required number of examining rooms could be determined by evaluating the effects of different numbers of examining rooms on the outpatient clinic performance.

In this chapter the concepts which influenced the development of the methodology will be presented as the general methodology is described. A detailed explanation of the methodology is contained in Chapters IV and V. The methodology used in this study was intended to reflect the systems approach, using computer simulation and regression analysis as the primary techniques.

Systems Approach

The term "system" is used in many contexts. Webster's has defined the term "system" as a "combination of parts in a whole or an orderly arrangement according to some common law."[1] With this definition of "system", it is easily understandable why the term is used so frequently. Philosophically, the term "system" can be used to describe anything since each object or collection of objects are part of the (whole) universe. When the term "system" is used to describe any useful endeavor, it usually means "a relatively large number of components related in a relatively complex manner for the accomplishment of some function or objective."[2] Thus, a radio, a chemical process, and a department store may all be considered systems.

The "systems approach" is a concept which has been utilized to design, implement, or improve systems. Hall[3] has defined the "systems approach" as encompassing the following steps:

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[1]Webster's New School and Office Dictionary, The World Publishing Co., New York, 1962, p. 895.

[2]Mathews, James B., "Systems Planning For Hospitals: An Objective Approach," Unpublished Paper, presented to Tri-State Hospital Council, Chicago, Illinois, April 1968, p. 2.

[3]Hall, Arthur D., A Methodology For Systems Engineering, D. Van Nostrand Co., Inc., Princeton, New Jersey, 1962, p. 90.

1. Defining the problem.
2. Selecting the objectives.
3. Synthesizing systems.
4. Analyzing the systems.
5. Selecting the best alternative.
6. Planning for action.

In the present study, particular attention has been devoted to step 3--synthesizing systems. In this step, it is necessary to identify a manageable number of significant components. Then a model of the system, either graphical or mathematical, is constructed to relate these components in a logical manner. It should be noted that judgement and experience are commonly used to identify the significant components which are included in the model. Also, since significant components of a system can be evaluated only in terms of the eventual use of a model or the objectives of the endeavor, it is necessary to consider the objectives when constructing a model of the system.

The first two steps of the methodology presented herein were derived directly from step 3 of the systems approach. The other steps in the methodology were based upon steps 4 and 5 of the systems approach--analyzing the systems, and selecting the best alternative. In the following section the general methodology will be described.

Methodology

The general methodology used in the present study evolved from the systems approach. First, a graphical model of a future outpatient clinic was developed. Second, system components of the model were identified. Third, a sensitivity analysis which employed computer simulation was utilized to provide information for predicting single values of the components. Fourth, the outpatient clinic performance was simulated for alternative numbers of examining rooms. Fifth, regression analysis was utilized to develop a mathematical expression which predicts the required number of examining rooms as a function of the measures of effectiveness of the clinic.

Due to the long-range planning focus of this study, it was especially difficult to choose single values of the components--step 3 of the general methodology. It was realized that many of the values of components would be established in the future by policies and decisions of appropriate hospital personnel, for example, the number of physicians, the number of students, the number of outpatients, the appointment schedule, and the number of examining rooms. Other component characteristics,termed component values interchangeably in this thesis, such as the patient arrival distribution, the physician examining time distribution, and the student examining time distribution, would probably depend upon environmental factors and not upon overt decisions of hospital personnel. Whether or not the component values could be controlled in the future by hospital personnel, it was virtually impossible to identify each future event which would influence the values of components, and to predict the nature of its effect at the initial state. Moreover, even if a detailed functional program were developed for some planning horizon by statistical analyses of past data, no guarantee existed that the program would be implemented as planned. For example, if it were predicted that four physicians would examine patients in an outpatient clinic, the actual number of physicians might deviate from the predicted number because of difficulties in receiving budget approval.

Due to the aforementioned problems involved in predicting single values of components, a sensitivity analysis approach was employed in this study. This approach emphasizes analyses of the effects of a range of future components values on outpatient clinic performance. By analyzing the sensitivity of clinic performance to variations in the values of components, the planner can better determine how to allocate his time and resources in attempting to predict, improve, or choose the future component values. He can also obtain a better understanding of the effects of uncertainty on his estimates and can assess the degree of precision and accuracy required. For example, as applied in this study, the planner's time could be devoted to predicting single values of the components which exhibited the larger effects. If the measures of effectiveness of outpatient clinic performance increase or decrease monotonically over the range of values for each component, the maximum overall change in response is equal to the difference between the response values at the endpoints of the range. Since the four measures of effectiveness (clinic duration, examining room utilization, average patient waiting time, and average physician waiting time) used in the present study were assumed to be monotonic functions of each of the components, "boundary values" (the endpoints of the range) were used in place of the complete range for each component. For example, since a demand ranging from 20 to 50 patients was expected for each future clinic session, two levels, 20 and 50 patients, were used as boundary values.

Methodologies of two previous studies were helpful in developing an experimental design to compare the effects of the components (and boundary values) on the outpatient clinic performance. In 1967, Colley[4] reported a study which, like the present study, focused on the effects of changes in system components in a long-range planning problem. Colley investigated the effectiveness of alternative medical support systems in the immediate post-war period. The experimental design utilized in the study consisted of five factors at two levels each (boundary values). A computer program was written to simulate each of the 32 (2^5) possible outcomes in a complete block factorial experiment. The effect of each alternative support system was computed by averaging the simulation results for each of the two levels of a factor and then subtracting. The resulting differences were then arranged in descending order to indicate the relative importance of each support system. An indication of possible two-factor interactions was calculated by totaling appropriate combinations of high and low levels and then plotting the results. Two-factor interaction was identified by inspection of the plotted results. It is interesting to note that each block in the experimental design was only replicated once, and no statistical tests were used to ascertain the significance of the alternative support systems. The authors contended that they desired to <u>rank</u> the significance of the support systems, and statistical tests would not provide the desired result.

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[4]Colley, John L., et. al., "A Simulation Model of a Saturated Medical System," Journal of Industrial Engineering, Proceedings 18, 1967, pp. 138-155.

Goldman and Knappenberger[5], in a paper presented at the 19th Annual Institute Conference of AIIE in 1968, investigated alternative values of components in a facilities planning problem. In their study a computer simulation program was used to evaluate the effects of three scheduling policies, two expediting policies, and three sizes of operating room suites on the performance of an operating room. The number of days waited by patients for elective surgery, operating room utilization, and the amount of overtime of surgical staff required were chosen as the three measures of effectiveness in the study. A model of an operating room was developed, and a computer program of the model was written in FORTRAN IV. An 18 block (3 X 3 X 2) complete factorial experiment with two replications was designed to test the effects of scheduling policies, expediting policies, and sizes of operating room suites. A computer program was developed for each block in the experiment, and 36 computer simulations were conducted. An analysis of variance for each of the three measures of effectiveness was conducted for the complete factorial experiment.

Both of the above studies employed complete block factorial designs to predict the effect of changes in systems. In the present methodology, since no a priori information was available regarding the higher order interactions, a 640 complete block factorial experiment was designed to compare the effects of components on the out-patient clinic performance. Since measures of effectiveness (clinic

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[5]Goldman, Jay and H. Allan Knappenberger, "Simulation of Operating Room Scheduling," Journal of Industrial Engineering, Proceedings 19, 1968, (preprint), 12 pp.

duration, examining room utilization, average patient waiting time, and average physician waiting time) were chosen to represent outpatient clinic performance, four separate 640 block experimental designs had to be developed. In order to conduct these four experiments, a procedure which predicted the responses for each of the combinations of boundary values was needed. Due to its capability to simulate future systems and process large experimental designs, computer simulation was chosen.

Through the development of a computer simulation model of a realistic system, one can gain valuable insight into the nature of the variables of a system and their complex interactions. By manipulating the computer simulation model, it is possible to describe the effects of changes in selected variables on the behavior of the system. In the methodology presented herein, a computer simulation program of the outpatient clinic was developed. Then simulation runs were conducted for each of the 640 blocks in the factorial experiment. The simulation results were evaluated by analysis of variance (ANOVA) and an analysis of mean differences in the measures of effectiveness for the boundary values.

The purpose of using an ANOVA in the present study was to determine if the components or their interactions, as represented by their boundary values, were statistically influencing the outpatient clinic performance. If a component did not affect the performance, any value of the component within the range of the boundary values could be chosen as the predicted single value without consuming additional planning time. If a component did affect performance, the single value would have to be chosen with care.

The purpose of using the analysis of mean differences, the second method of analysis employed in this study, was to rank the components which statistically influenced the outpatient clinic performance. The magnitudes of responses in each measure of effectiveness for each component were combined into an overall ranking of the relative importance of the components. This ranking enables planning time to be allocated to predicting single values of the components in accordance with their relative importance.

After planning time was devoted to predicting single values of the components, the computer simulation program developed previously was modified to accept alternate numbers of examining rooms and single values of the other six systems components. Regression equations for each measure of effectiveness were developed from the simulation results. By assigning weights to each measure of effectiveness and combining equations, a single expression was developed which predicts the outpatient clinic performance as a function of the number of examining rooms. By setting the first derivative of this equation equal to zero and solving for the number of examining rooms, a mathematical expression was obtained which predicts the number of examining rooms which will maximize the clinic performance as a function of the measures of effectiveness of the clinic.

Data Collection

The data used in the experiment were collected at Eugene Talmadge Memorial Hospital in Augusta, Georgia. The Eugene Talmadge

Memorial Hospital (ETMH), clinical teaching unit of the Medical College of Georgia (MCG), is a 400 bed referral hospital which provided services for 9,000 inpatient admissions and 50,000 outpatient visits in 1967. General inpatient services and extensive outpatient services are offered to residents of the State of Georgia who have been referred to ETMH by state health agencies or private practitioners. The data used in the methodology were collected in studies related to the Systems Planning Project, a cooperative facilities planning effort of the Georgia Institute of Technology and the Medical College of Georgia. The Systems Planning Project (SPP), part of the overall systems engineering effort of the Program in Hospital and Medical Systems, was concerned with developing functional and architectural programs for a proposed 1000 bed hospital at the MCG. The interest of the author in health facilities planning and outpatient department planning was stimulated by his employment on the SPP.

The Orthopedic outpatient clinic at ETMH was used to illustrate the methodology of this study. The Division of Orthopedic Surgery, including the Orthopedic outpatient clinic, is an organizational unit of the Department of Surgery at the Medical College of Georgia. In 1967 the Orthopedic Surgery Division provided services for 3,000 outpatients. The Orthopedic clinic is representative of most of the outpatient clinics at ETMH.

A detailed explanation of the methodology and data collection is presented in the following two chapters. For ease of presentation, the methodology has been divided into two phases. The first phase of the methodology is presented in Chapter IV, while the second phase of the methodology is presented in Chapter V. The following summary of the methodology, which appears in list form, may be used as a guide to Chapters IV and V.

<u>First Phase of the Methodology (Chapter IV)</u>

1. Develop a graphical model of an outpatient clinic.
2. Identify system components of the model.
3. Select several system components and their boundary values for investigation.
4. Develop an experimental design to test the sensitivity of the selected components.
5. Develop a computer simulation program for the sensitivity analysis.
6. Process the simulation program on a computer.
7. Identify the statistically significant system components.
8. Analyze the mean differences in the measures of effectiveness for the boundary values of the system components.

<u>Second Phase of the Methodology (Chapter V)</u>

9. Predict single values of the system components.
10. Modify the original computer simulation program to accept alternative numbers of examining rooms.
11. Process the simulation program on a computer.
12. Develop regression equations for each of the four measures of effectiveness.
13. Construct a single mathematical expression to predict the required number of examining rooms.

CHAPTER IV

FIRST PHASE OF THE METHODOLOGY

The first phase of the methodology consisted of the development of a graphical model of an outpatient clinic, identification of system components, selection of boundary values of system components, development of an experimental design to test the sensitivity of the components, development of a computer simulation program, and analysis of the sensitivity of the clinic performance to changes in component values.

Development of a Graphical Model

A study of the outpatient services at ETMH conducted by Holland[1] and this author provided the general framework and a graphical model of the ETMH outpatient flow. This model is shown in Figure 2. New patients enter the hospital and proceed to the admissions office, credit office, and the outpatient admitting office. After having height, weight, and temperature recorded, the patient receives a physical examination. If further diagnostic tests are required, the patient is either sent directly to the proper area or given a return appointment. The patient flow through the admissions office,

[1] Holland, Max G., "The Patient Input System at Eugene Talmadge Memorial Hospital," (Unpublished Report), Program in Hospital and Medical Systems, Atlanta, Georgia, February, 1968, 95 pp.

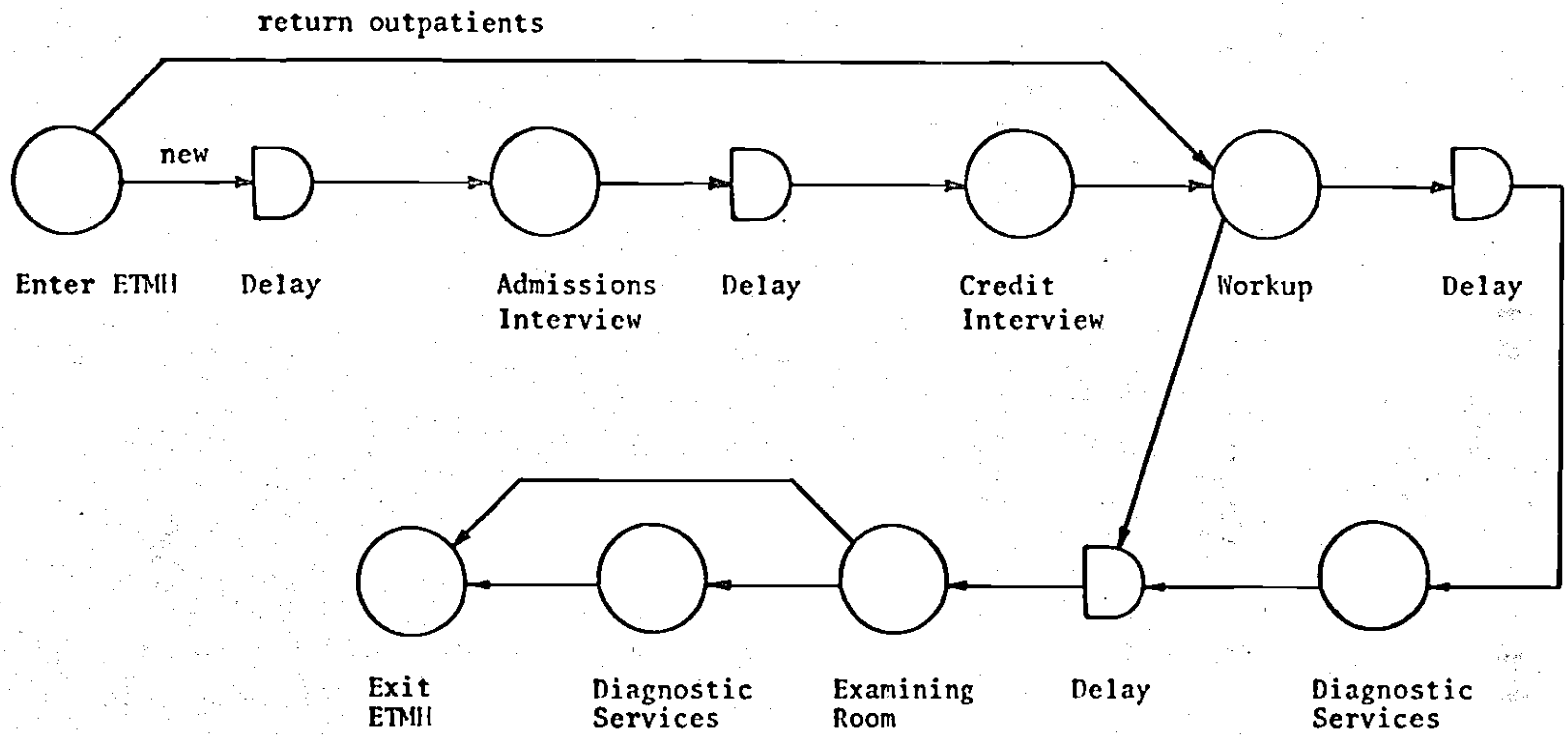

Figure 2. ETMH Outpatient Flow

credit office, and outlying areas as described in Figure 2 was not considered in the present study. In addition, Figure 2 was modified to describe the existing Orthopedic outpatient flow. Figure 3 illustrates the existing Orthopedic outpatient flow used in the present study. It should be noted that this outpatient flow was typical of most existing outpatient clinics at ETMH. According to the methodology of this study, a model of the future outpatient clinic must be conceived. For the sake of simplicity, the future outpatient flow was assumed to be identical to the existing outpatient flow. Therefore, Figure 3 also depicts the future Orthopedic outpatient flow.

Identification of System Components

Once a graphical model was constructed, the next step of the methodology was to identify system components. The identification of system components is needed prior to the manipulation of any model. A "system component", in the terminology of this study, is a factor which affects the output variables of a model of a system. One feature of this study was the attempt to identify a comprehensive list of system components. The following system components of the Orthopedic outpatient clinic model were identified:

1. Outpatient clinic demand (total number of patients).
2. Patient appointment schedule.
3. Patient arrival distribution
4. Number of admitting clerks.
5. Service time distribution of admitting clerks.
6. Capacity (number of patients) of the workup room.
7. Number of nurses.

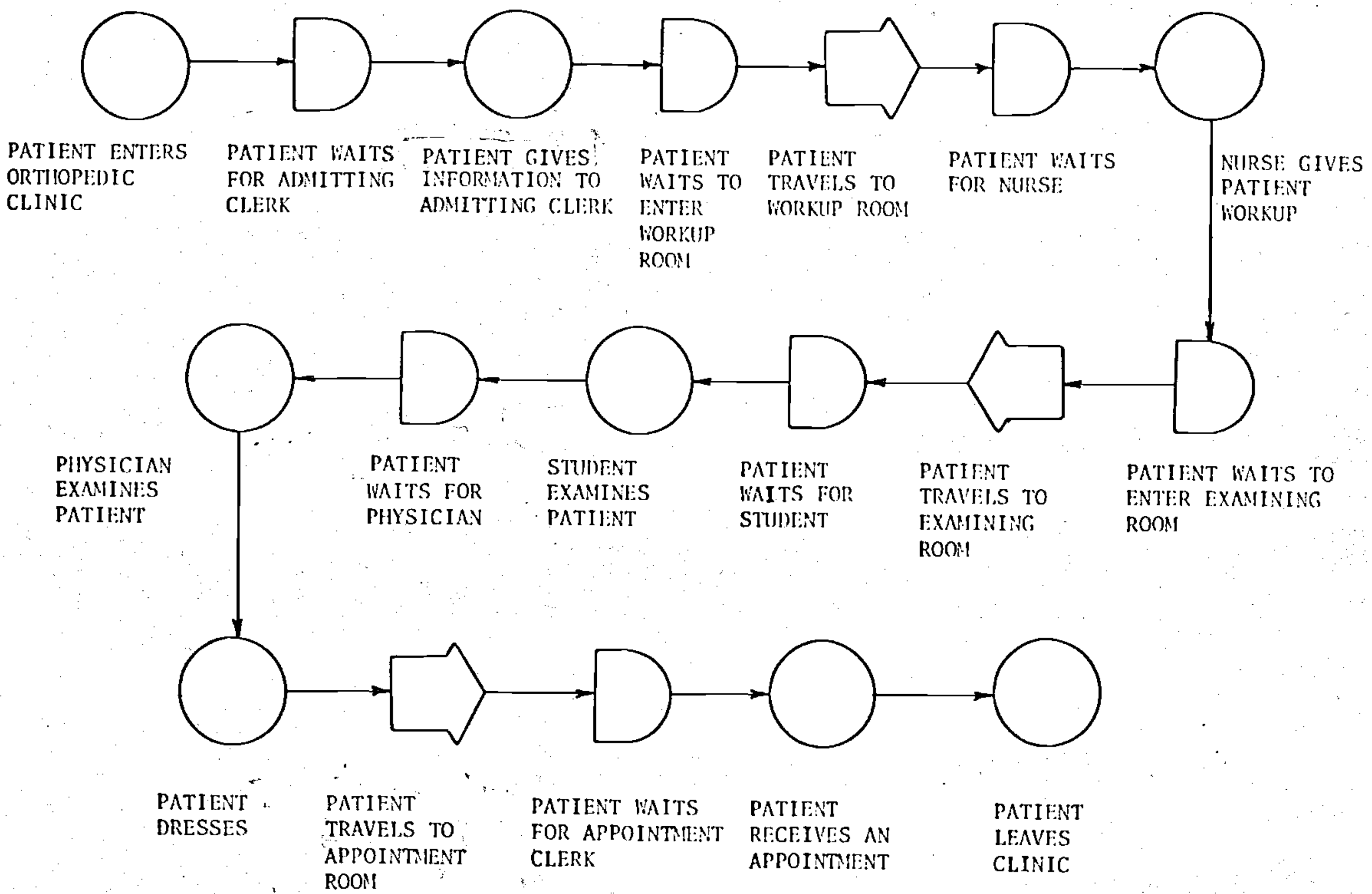

Figure 3. Orthopedic Outpatient Flow

8. Service time distribution of nurses.
9. Number of examining rooms.
10. Number of medical students.
11. Service time distribution of students.
12. Number of physicians.
13. Physician arrival time.
14. Physician examining time (service time distribution of physicians).
15. Number of appointment clerks.
16. Service time distribution of appointment clerks.

Selection of Components

The third step in the methodology was the selection of components for the sensitivity analysis. A literature survey was conducted to provide partial information for identifying the more important system components. In 1952, Welch and Bailey[2] stated that patient unpunctuality, physician arrival time, physician examining time, patient appointment interval, patient no-show rate, and the duration of physicians' rest time influenced the relationship between physicians' waiting time and patients' waiting time. Fetter and Thompson[3] reported that seven components - appointment interval,

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[2]Welch, J. S. and N. T. J. Bailey, "Appointment Systems in Hospital Outpatient Departments," Lancet, Vol. 1, 1952, p. 1107.

[3]Fetter, Robert B. and John D. Thompson, "Patients' Waiting Time and Doctors' Idle Time in the Outpatient Setting," Health Services Research, Vol. 1, No. 1, Summer 1966, pp. 77.

physician examining time, patient arrival distribution, number of no-shows, number of walk-ins, physician arrival time, and interruptions - influence the patient waiting time and physician waiting time relationships.

An article by Williams[4] suggests that the appointment interval, the number of physicians, the outpatient demand for each half-day session, and the number of clinic meeting days influence patient waiting time, physician waiting time, and the required number of examining rooms. Lane and Freeman[5] identified the effect of nurse workup time, physician examining time, room clearing time, and physician waiting time on the required number of examining rooms. The measures of effectiveness used in the study were clinic duration, examining room utilization, and patient waiting time.

A report published by the United Hospital Fund of New York[6] stated that outpatient demand, changes in patient population, physician arrival time, and amount of space affect outpatient clinic performance. In a methodology for determining outpatient department space requirements, Wheeler[7] reported that outpatient demand, physician examining time, and the ratio of consulting rooms to examination rooms influence

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[4] Williams, William J., et al., "Simulation Modeling of a Teaching Hospital Outpatient Clinic," Hospitals, Vol. 41, No. 21, Nov. 1, 1967, p. 128.

[5] Lane, Walter W. and John R. Freeman, (Unpublished Paper), University of Florida, June 1967, p. 2.

[6] "Systems Analysis and Design of Outpatient Department Appointment and Information Systems," United Hospital Fund of New York, New York, 1967, p. 5.

[7] Wheeler, E. Todd, Hospital Design and Function, McGraw-Hill Book Company, New York, 1964, pp. 229-236.

outpatient department space requirements.

According to the methodology of the present study (see Chapter III), the components which were expected to have the larger effects on the Orthopedic outpatient clinic performance were chosen for the sensitivity analysis. The selected system components were:

1. Outpatient clinic demand.
2. Patient arrival distribution.
3. Physician examining time distribution.
4. Number of physicians.
5. Number of medical students.
6. Physician arrival time.
7. Number of examining rooms.

The review of the above references and observations of the author provided the measures of effectiveness used in this study. The measures of effectiveness selected were as follows:

1. Clinic duration.
2. Examining rooms utilization.
3. Average patient waiting time.
4. Average physician waiting time.

Boundary Values of Selected Components

The fourth step in the methodology was the selection of data for the sensitivity analysis. For each of the seven components, boundary values were used in lieu of the complete range of possible values for 1972 (see Chapter III). Table 1 shows the boundary values for each component. The basis for choosing the specific values shown in Table 1

Table 1. Boundary Values for Selected Components

Component	Boundary Values
Demand	(1) 20 Patients per day (2) 50 Patients per day
Patient arrival distribution	(1) All patients at start of clinic (t=0) (2) Exponential interarrival (mean=1 min) (3) Exponential interarrival (mean=5 min) (4) Constant interarrival (1 min) (5) Constant interarrival (5 min)
Physician examining time	(1) Uniform distribution U[21,29];mean=25 (2) Uniform distribution U[30,40];mean=35 (3) Exponential distribution (mean=25) (4) Exponential distribution (mean=35)
Number of physicians	(1) Three (2) Six
Number of students	(1) Three (2) Six
Physician arrival time	(1) Zero min. after scheduled time (t=15) (2) 75 min. after scheduled time (t=90)
Number of examining rooms	(1) Eight (2) Fourteen

are presented in this section.

The boundary values for the first component, the outpatient clinic demand, were calculated by dividing the weekly demand by the number of clinic sessions per week. The Chief of the Orthopedic Division estimated that a weekly demand of 100 patients would exist in 1972. He also preferred that two clinic sessions per week be utilized to serve this demand. Generally, physicians preferred a minimum number of clinic sessions to be held each week. However, the assignment of equal numbers of patients to clinic sessions on each day of the week has been shown to minimize examining room requirements.[8] Therefore, the possibility of processing an equal number of patients for five days per week was also considered. The values chosen to represent demand were 20 and 50 patients per clinic session. These values represent five and two clinic sessions per week, respectively.

Boundary values for the patient arrival distribution, the second component, were determined by identifying the appointment schedules and arrival distributions that could be in existence in 1972. Five levels of boundary values (three classifications of patient arrival distributions, and two different means of interarrival times) were chosen for investigation. The first boundary value (or level) chosen corresponded to the existing "block" appointment schedule which is prevalent in many hospitals today. In this appointment schedule, all patients are scheduled to arrive at the start of a clinic session.

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[8]Sumner, Andrew T., "An Analysis of June, 1968, Examining Room Requirements at Eugene Talmadge Memorial Hospital," (Unpublished Report), Program in Hospital and Medical Systems, Augusta, Georgia, April, 1968, 59 pp.

The minimization of physicians' waiting time, and the reduction in patient and personnel scheduling problems, are probably responsible for the popularity of the "block" appointment schedule.

A study by Jackson[9] which was cited in Chapter II reported that the patient interarrival distribution could be approximated by a negative exponential distribution. Therefore, exponential interarrival distributions were considered in the second and third levels of the patient arrival distribution. In the second level, a mean interarrival time of one minute was used. This mean represents the case in which the patients are scheduled to arrive at 1 minute intervals. Jackson recommended that the mean interarrival time should be approximately equal to the mean throughput time of physicians. The mean throughput time of five minutes for the present study was calculated by dividing the mean physician examining time (30 minutes) by the maximum number of physicians (6) in the clinic. Accordingly, a mean interarrival time of five minutes was chosen for the third level of the patient arrival distribution.

Constant interarrival times were chosen for the fourth and fifth levels of the patient arrival distribution. In using this distribution, it was assumed that patients arrived exactly at the appointed time. Mean interarrival times of one and five minutes, identical to the exponential interarrival case, were utilized for the constant interarrival case.

Uniform and exponential distributions at two mean values each

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[9]Jackson, R. P., "Design of an Appointment System," Operational Research Quarterly, September 1964, Vol. 15, p. 222.

were chosen as boundary values for physician examining time, the third component. In the first two levels uniform distributions with means of 25 (range:21-29) and 35 (range:30-40) minutes were used. The existing mean of the physician examining time for Orthopedic patients was approximately 35 minutes. The mean of 25 minutes represented the author's estimate of the minimum mean that would be attainable in 1972. The uniform distribution was chosen for its simplicity and its ease of use in generating a stochastic process in the simulation program. In the third and fourth levels, exponential distributions were used for physician examining time. The same mean examining times, 25 and 35 minutes, were used so that the effects of the uniform and exponential examining time distributions could be compared. As mentioned in Chapter II, Jackson has also shown that physician examining time can be approximated by a negative exponental distribution.

The Chief of the Orthopedic Division estimated that four physicians would be assigned to the outpatient clinic in 1972. In order to provide data (extreme values) for the sensitivity analysis, three and six physicians were chosen as the boundary values for the number of physicians, the fourth component.

The future number of medical students assigned to the Orthopedic outpatient was expected to increase from the existing three medical students. The Chief of the Orthopedic Division estimated that five students would examine outpatients in 1972. The lower boundary value chosen for the number of students, the fifth component, was three. The higher boundary value, six, represented the author's estimate of the maximum number of students that could be in the

Orthopedic clinic in 1972.

The boundary values chosen for the physician arrival time, the sixth component, were zero and 75 minutes after the scheduled arrival of physicians in the clinic. The nurse supervisor of the Orthopedic clinic provided this range of arrival times. The lower boundary value of zero minutes late actually represented the arrival of a physician 15 minutes after the starting time of the clinic. Since preliminary processing of patients consumed approximately 15 minutes, physicians were scheduled to arrive at least 15 minutes after the start of the clinic.

The selection of boundary values for the last component, the number of examining rooms, was dependent on various combinations of values of the previously mentioned six components. The lower boundary value of eight rooms was calculated by multiplying the expected number of physicians in 1972, four, by the traditional ratio of two examining rooms per physician. The higher boundary value for examining rooms was based upon the multiplication of the higher boundary value for physicians (six) by two (the traditional ratio). However, since the ETMH Hospital Administrator preferred as many examining rooms as economically feasible, a higher boundary value of fourteen examining rooms was chosen for investigation.

Experimental Design

The next step in the methodology was the development of an experimental design to test the sensitivity of the selected components. A complete block factorial experiment was used to represent various combinations of boundary values for the sensitivity analysis. Since no prior assumptions were made concerning the components or interactions, the total number of blocks in the experiment equalled 640 (2 X 5 X 4 X 2 X 2 X 2 X 2).[10] Even though only one replication of each block was performed, these 640 blocks represented over 2 years of simulated experience of the clinic operation. It should also be noted that a demand of at least 20 patients was represented in each block of the experimental design. For this number of patients variations in the measures of effectiveness due to random error was expected to be minimal. In order to insure that the proper boundary values were utilized in each block, it was necessary to develop a coding matrix. The coding matrix, shown partially in Table 2, was based on a heuristic method of identifying each of the 640 permutations of boundary values. In Table 2, an "x" represents the inclusion of a boundary value in a block. By utilizing the coding matrix, it was also possible to relate properly block levels and the associated computer run discussed in the following section.

Development of a Computer Simulation Program

Due to its capability to simulate future systems and process large experimental designs, computer simulation was chosen to predict the clinic performance for each of the 640 permutations of boundary values. Since many simulation languages existed, it was necessary to select one language for use. The GPSS/360 special purpose simulation language was chosen for the following reasons:

[10]Refer to Table 1 for specific blocks and levels.

Table 2. Coding Matrix for Experimental Design

Components and Boundary Values	Experimental Design Block Number 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1. Demand																	
20 pat/day	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
50 pat/day																	
2. Pat. Arrival Distr.																	
block	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
exponential u=1																	
exponential u=5																	
constant u=1																	
constant u=5																	
3. Phy. Examining Time																	
uniform U[21,29]	x	x	x	x	x	x	x	x									
uniform U[30,40]									x	x	x	x	x	x	x	x	
exponential u=25																	x
exponential u=35																	
4. No. of Physicians																	
3 physicians	x	x	x	x					x	x	x	x					x
6 physicians					x	x	x	x					x	x	x	x	
5. No. of Med. Students																	
3 students	x	x			x	x			x	x			x	x			x
6 students			x	x			x	x			x	x			x	x	
6. Phy. Arrival Time																	
zero min. late	x		x		x		x		x		x		x		x		x
75 min. late		x		x		x		x		x		x		x		x	
7. No. of Exam. Rooms																	
8 examining rooms	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
14 examining rooms																	

1. GPSS/360 requires little programming time.
2. GPSS/360 has an extensive error-checking technique.
3. GPSS/360 is designed for discrete-flow systems like outpatient clinics.
4. GPSS/360 could be processed at the MCG Computer Center.

A review of the general characteristics of GPSS/360 is included in Appendix A.

Since GPSS/360 is a discrete-flow simulation language, it was relatively simple to develop a general computer program of the clinic. Figure 4 graphically depicts the relationship between the graphical model of the Orthopedic outpatient clinic and the GPSS/360 Program. In the left and center columns of Figure 4, the Orthopedic outpatient flow (previously exhibited in Figure 3) is depicted. In the right column the GPSS/360 blocks required to simulate the outpatient flow are shown. Patients were entered into the GPSS/360 simulation model by using a GENERATE block. Entry into a waiting line was represented by using a QUEUE block, and a departure from a waiting line was represented by a DEPART block. Service times were programmed by using ADVANCE blocks. Facilities (resources which hold one transaction at a time) were depicted by SEIZE and RELEASE blocks. Similarly, ENTER and LEAVE blocks were used with storages (resources used by more than one transaction at a time). The removal of transaction from the model was accomplished by using a TERMINATE block. Appendix B shows the simulation program used for blocks 609-621 of the coding matrix.

Analysis of Results

Operation of the simulation program on an IBM 360 Model

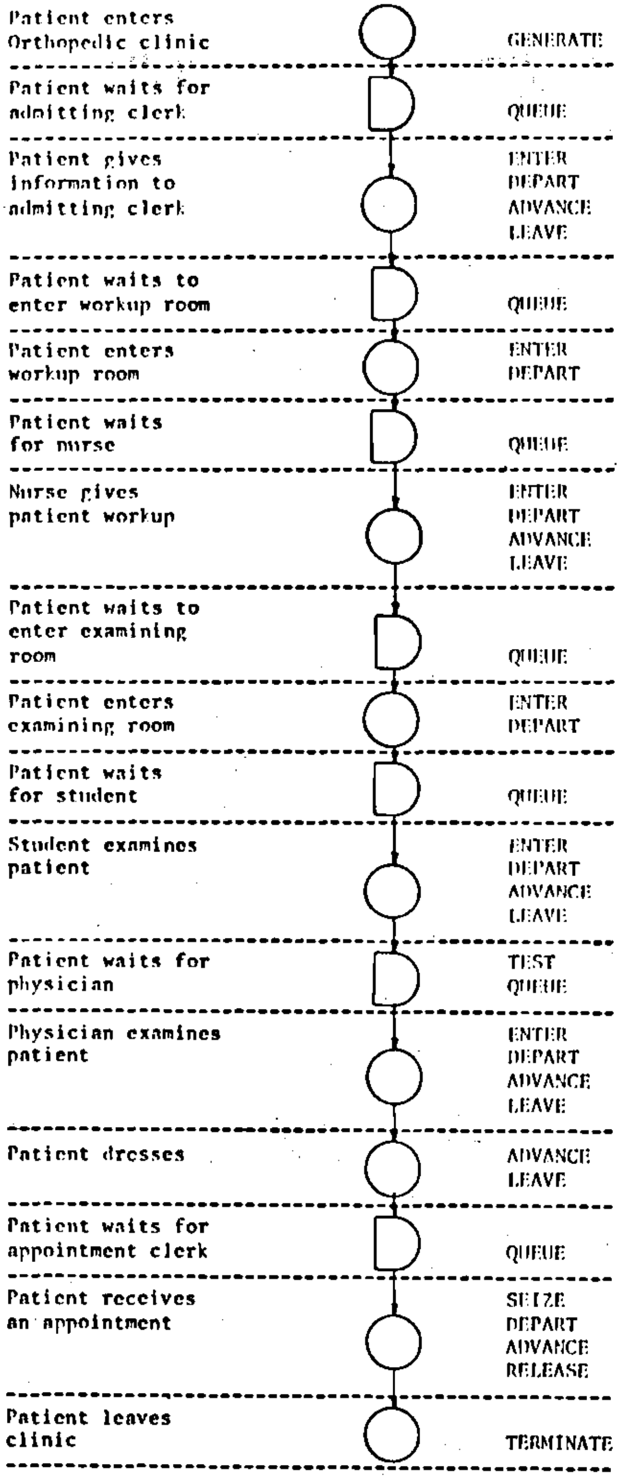

Figure 4. Outpatient Flow and GPSS/360 Program

40 65K computer consumed approximately 20 seconds for 20 patients and 40 seconds for 50 patients. Since the Medical College of Georgia Computer Center made time available in 40 minute batches, each job contained simulation programs for 64 blocks of the coding matrix. By duplicating and modifying programs, several 64-block jobs were processed concurrently.

An Analysis of Variance (ANOVA) and an analysis of mean differences in the measures of effectiveness of the boundary values were used to evaluate the simulation results. The purpose of ANOVA is to supply criteria for determining whether a component is influencing results.[11] The purpose of using ANOVA in the present study was to determine if the components or their interactions, as represented by their boundary values, were statistically influencing clinic performance. In order to apply ANOVA to this study it was necessary to make the following assumptions:

1. The effects of factors (components) were additive.
2. The residual errors were independent of the sources of variation (components and interactions).
3. The residual errors had a common variance, and were randomly and normally distributed.

Since each block in the experiment was simulated only one time, the highest order interaction was used as residual error in the F tests.

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[11]Wilson, E. Bright, An Introduction to Scientific Research, McGraw-Hill Book Company, Inc., 1966, p. 203.

[12]Duncan, Acheson J., Quality Control and Industrial Statistics, Richard D. Irwin, Inc., Homewood, Illinois, 1963, p. 584.

This method has been described by Rickmers and Todd[13], Hicks[14], and Duncan[15]. The results of the ANOVA and F ratios for each measure of effectiveness appear in Appendix C. The sources of variation were tested at confidence levels of .05 and .01.

All the components except the patient arrival distribution were found to be statistically significant at the .01 confidence level for each measure of effectiveness. The patient arrival distribution was found to have a statistically significant effect on examining room utilization and average patient waiting time, but not on clinic duration and average physician waiting time. A summary of the significance of the components and their interactions for each measure of effectiveness is shown in Table 3. On the left column the sources of variation are identified. The confidence level at which a source of variation was found to be statistically significant appears under the proper measure of effectiveness.

If weights are assigned to each measure of effectiveness, a decision-maker can ascertain which components have a significant effect on the outpatient clinic performance. For ease of presentation, it was assumed that a source of variation was significant if it were

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[13]Richmers, Albert D. and Hollis N. Todd, Statistics: An Introduction, McGraw-Hill Book Company, Inc., 1967, pp. 325-327.

[14]Hicks, Charles R., Fundamental Concepts in the Design of Experiments, Holt, Rinehart and Winston, Inc., New York, 1965, p. 91.

[15]Duncan, Acheson J. , Quality Control and Industrial Statistics, Richard D. Irwin, Inc., Homewood, Illinois, 1963, pp. 510-577.

Table 3. Statistical Significance of Components

CLIN	ROOM	AV PAT	AV PHY	SIGNIFICANT
V.01	.01	.01	.01	YES
S.01	.01	.01	.01	YES
P.01	.01	.01	.01	YES
T.01	.01	.01	.01	YES
A	.01	.01		YES
D.01	.01	.01	.01	YES
R.01	.01	.01	.01	YES
VS.05	.01	.01		YES
VP.05		.01	.01	YES
VT		.05	.05	YES
VA.05		.01		YES
VD	.01	.05		YES
VR	.01	.01	.01	YES
SP.01		.01	.01	YES
ST.01	.01	.01	.01	YES
SA	.01			YES
SD.01		.01	.01	YES
SR.01		.01	.01	YES
PT.01	.01	.01	.05	YES
PA				NØ
PD.01		.01	.01	YES
PR.01		.01	.01	YES
TA.05		.01		YES
TD.01	.01	.01	.01	YES
TR		.01		YES
AD	.01	.01		YES
AR	.01	.01		YES
DR.01	.01	.01	.01	YES
VSP		.05		YES
VST	.01	.01	.01	YES
VSA		.05		YES
VSD			.05	YES
VSR.05				YES
VPT				NØ
VPA				NØ
VPD				NØ
VPR				NØ
VTA				NØ
VTD				NØ
VTR				NØ
VAD	.05			YES
VAR				NØ
VDR				NØ
SPT				NØ
SPA			.05	YES
SPD.01	.01	.01	.01	YES
SPR.01		.01	.01	YES
STA.05	.01			YES
STD.01			.01	YES
STR.05				YES
SAD				NØ
SAR	.05			YES
SDR.01		.01	.01	YES
PTA			.01	YES
PTD.01	.01	.01	.01	YES
PTR.01		.01		YES
PAD				NØ
PAR		.05		YES
PDR			.01	YES
TAD		.05		YES
TAR		.05		YES
TDR				NØ
ADR				NØ

YES- Significant For At Least One Level
NO- Not Significant For Any Level

v = physician arrival time
s = number of medical students
p = number of physicians
t = physician examining time
p = patient arrival distribution
d = outpatient clinic demand
r = number of examining rooms

significant for at least one measure of effectiveness. In the right column of Table 3, a significant factor is indicated by a "yes" response. "No" responses indicate no significance for any measure of effectiveness. All the systems components and many of their interactions were found to be statistically significant.

An analysis of mean differences of boundary values was also utilized to evaluate the simulation results. The purpose of applying this technique in the present study was to rank the components which statistically influenced the outpatient clinic performance. Figures 5,6,7, and 8 graphically depict the changes in each measure of effectiveness for the boundary value means. Outpatient clinic demand appeared to be the most important component influencing clinic duration (see Figure 5). Demand also had the largest effect on examining room utilization (Figure 6). However, the number of examining rooms also had a large effect. Although the difference in boundary values for demand produced the largest affect on patient waiting time (Figure 7), the patient arrival distribution also appeared to be an important factor. The number of physicians was the most important component influencing the physician waiting time (Figure 8). The number of students and demand also produced a large change in the physician waiting time.

The mean for each boundary value and a ranking of the mean differences for each component are exhibited in Table 4. The mean differences in the measures of effectiveness for each component appear on the same line and to the right of the component name. For example, the mean difference in clinic duration for demand, 287.5 minutes,

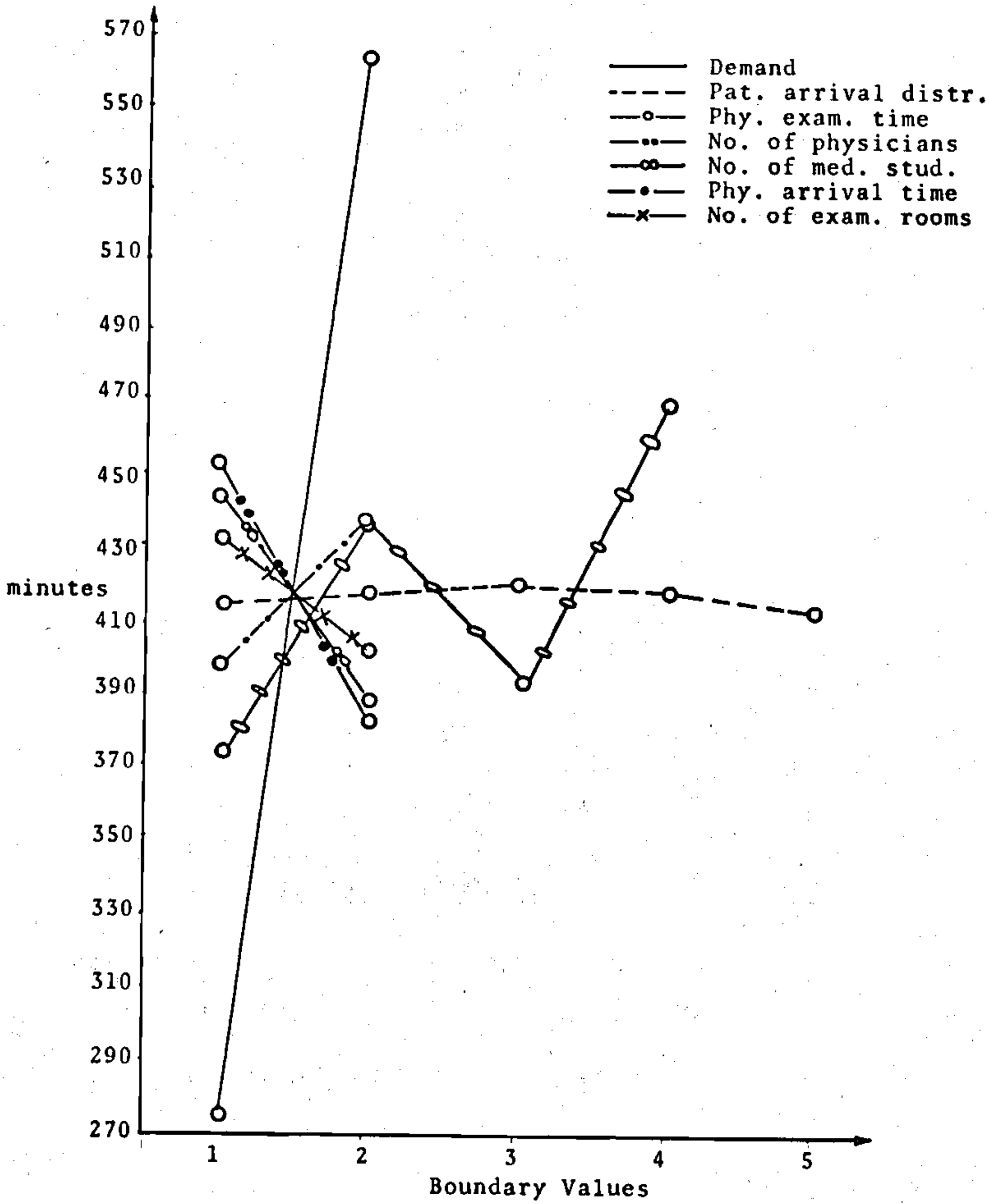

Figure 5. Clinic Duration

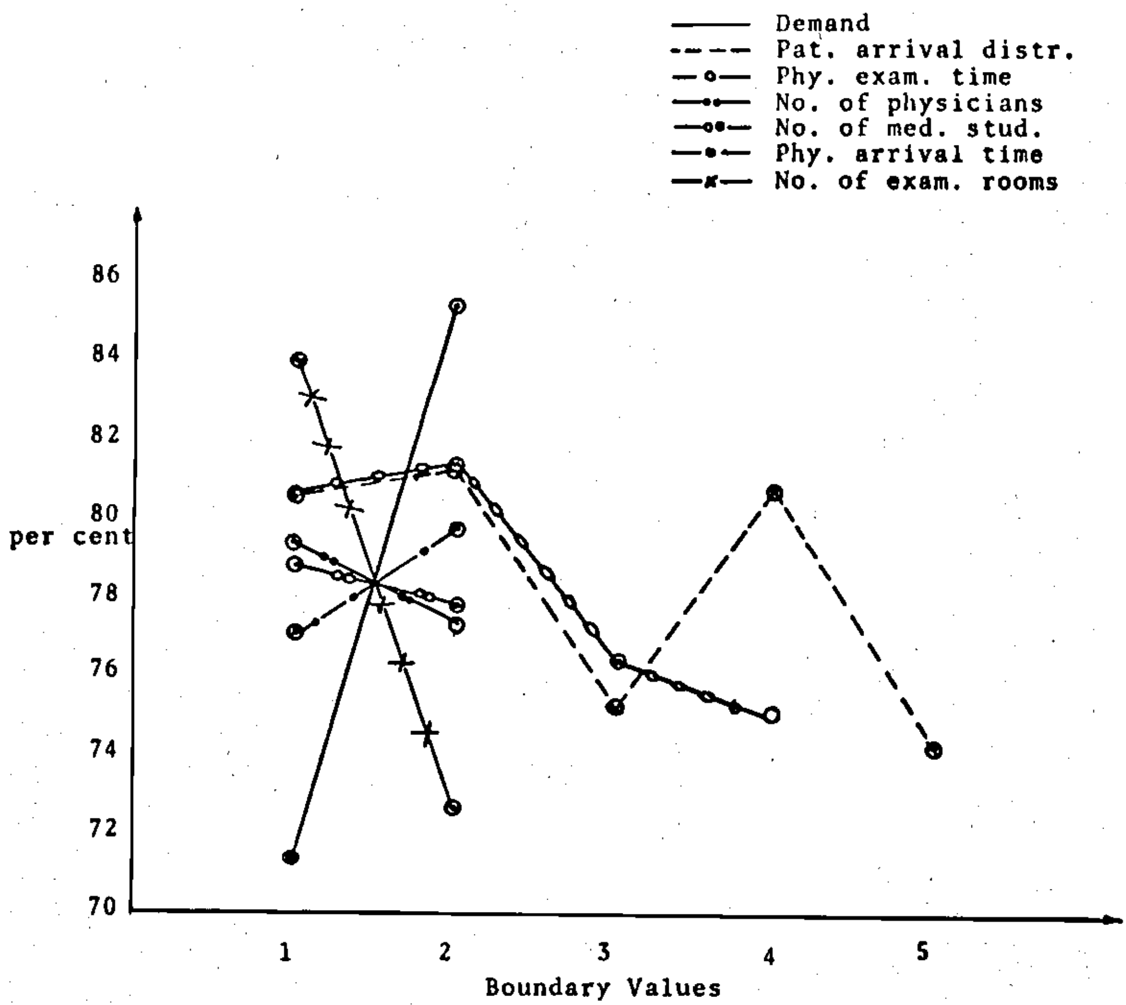

Figure 6. Examining Room Utilization

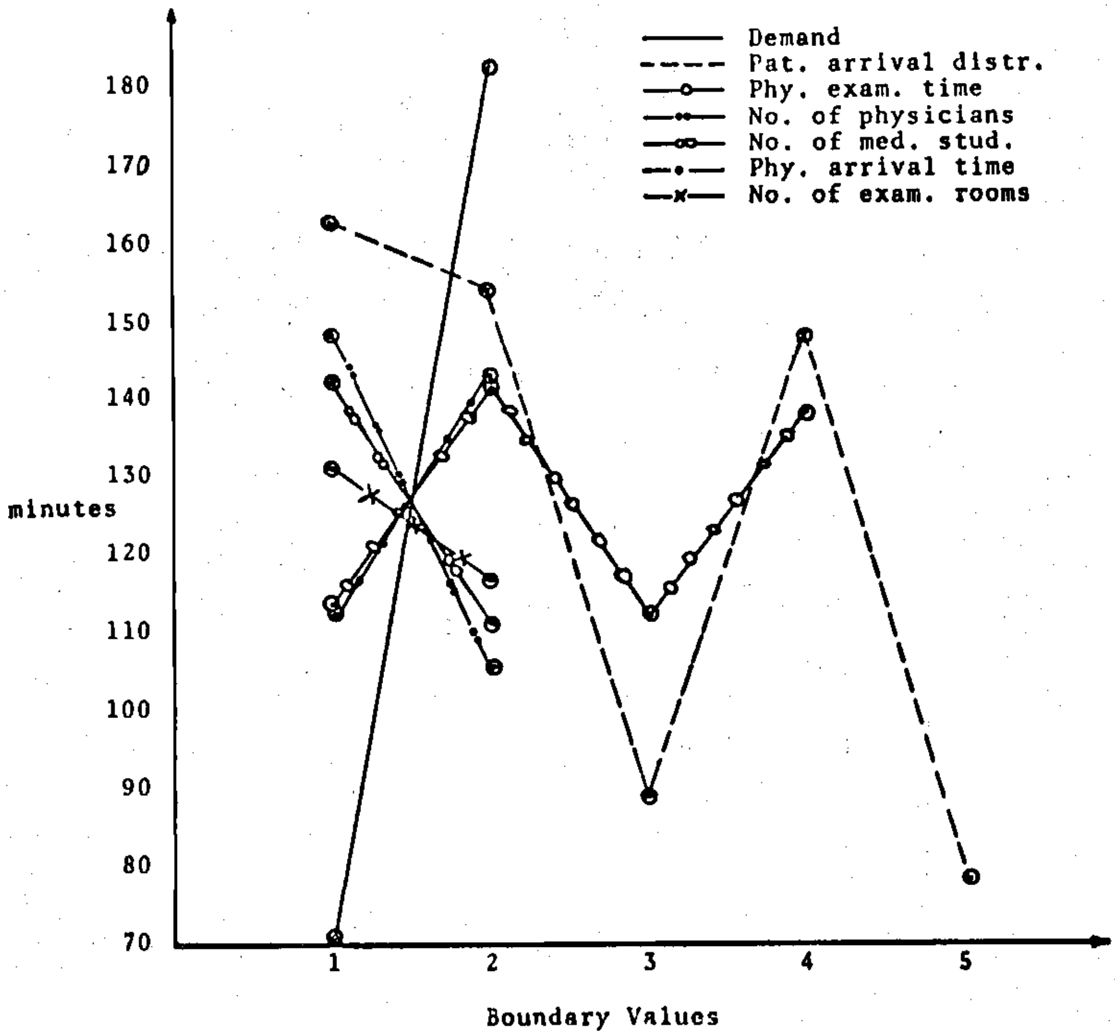

Figure 7. Average Patient Waiting Time

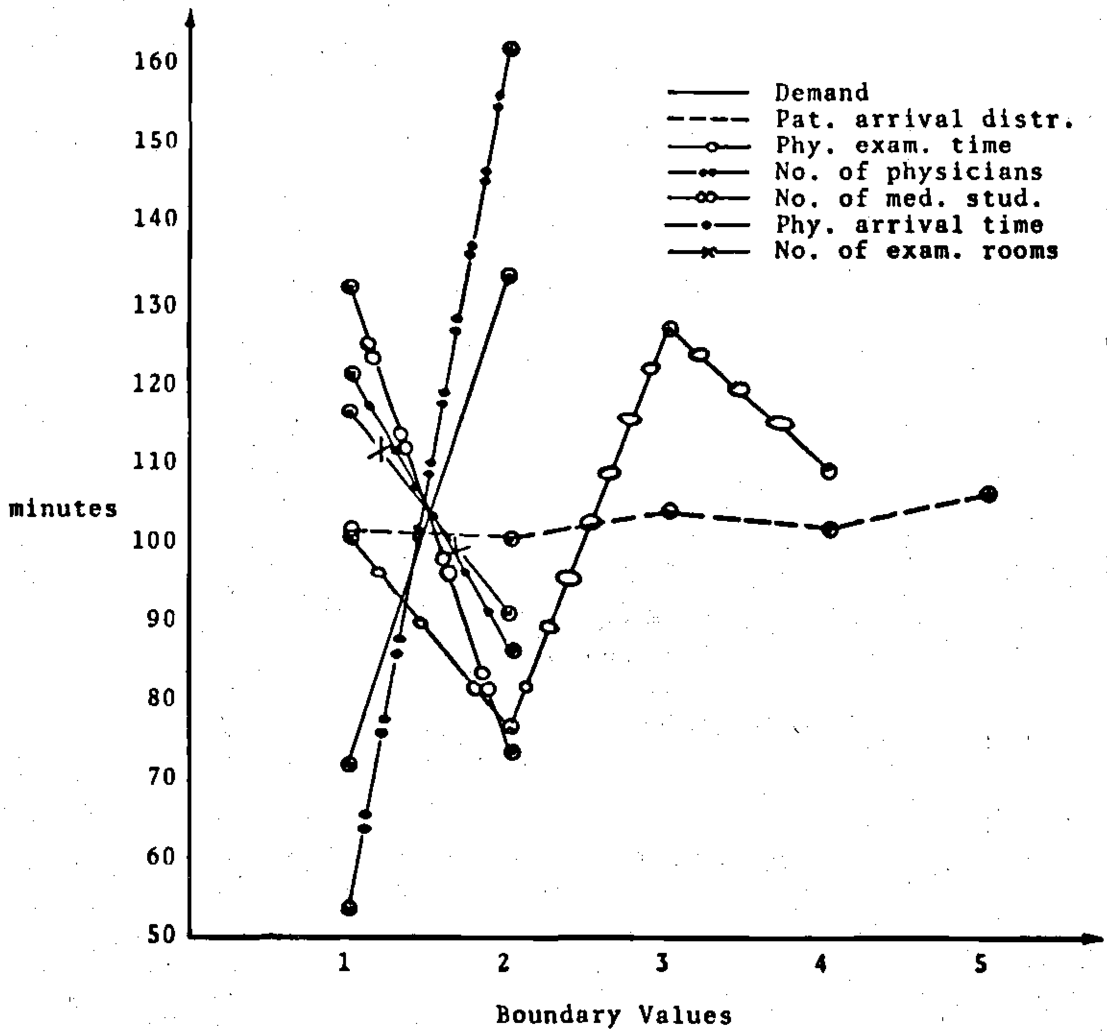

Figure 8. Average Physician Waiting Time

Table 4. Rank of Components

Components and Boundary Values	Clinic Duration (min.)	Exam. Room Utili-zation (%)	Avg. Patient Waiting Time (min.)	Avg. Physician Waiting Time (min.)	Overall Ranking
Demand	287.5 (1)	14.0 (1)	111.9 (1)	61.0 (2)	1
20 pat/day	273.6	71.4	70.6	72.9	
50 pat/day	560.6	85.4	182.5	133.9	
No. of Physicians	72.4 (3)	2.1 (6)	42.2 (3)	98.2 (2)	2
3 physicians	453.0	79.4	147.7	54.3	
6 physicians	380.6	77.3	105.5	152.5	
Phy. Exam. Time	95.5 (2)	5.9 (4)	29.1 (5)	50.4 (4)	3
uniform U:21,29:	372.5	80.6	114.4	100.8	
uniform U:30,40:	436.2	81.2	141.6	76.6	
exponential u-25	390.6	76.3	112.5	127.0	
exponential u-35	468.0	75.3	137.9	109.3	
No. of Students	59.8 (4)	1.1 (7)	32.1 (4)	58.2 (3)	4
3 students	446.7	78.9	142.6	132.5	
6 students	386.9	77.8	110.5	74.3	
Pat. Arrival Dist.	7.0 (7)	6.8 (3)	89.7 (2)	4.4 (7)	5
block	416.7	80.6	162.5	102.3	
exponential u-1	417.3	81.1	154.7	101.9	
exponential u-5	419.3	75.2	89.8	104.0	
constant u-1	418.6	80.7	148.1	102.6	
constant u-5	412.3	74.3	77.8	106.3	
Phy. Arrival Time	36.5 (5)	2.7 (5)	27.4 (6)	35.1 (5)	6
zero min. late	398.6	77.0	112.9	121.0	
75 min. late	435.1	79.7	140.3	85.9	
No. of Exam. Rooms	32.8 (6)	11.3 (2)	19.4 (7)	26.3 (6)	7
8 exam. rooms	432.8	84.0	136.3	116.6	
14 exam. rooms	400.8	72.7	116.9	90.3	

appears in the first row and second column of Table 4. In Table 4 the numbers in parentheses represent the ranking of the mean differences for each measure of effectiveness. It was assumed for simplicity that the ranking of components for each measure of effectiveness could be added to result in an overall ranking of the components. The overall ranking of the system components is shown in the right column of Table 4.

CHAPTER V

SECOND PHASE OF THE METHODOLOGY

In the second phase of the methodology computer simulation was used again, but for a different purpose. The simulation program previously developed was modified to accept single values of the components and nine alternative numbers of examining rooms. Regressive equations for each of the four measures of effectiveness were then developed from the results of this second simulation experiment. Finally, these four regression equations were combined into a single expression which predicts the number of examining rooms required in an outpatient clinic.

Prediction of Single Values of Components

The next step in the methodology was the prediction of single values of the system components. Planning time was devoted to predicting single values of the components in accordance with their relative importance as determined in the previous chapter. These values and nine alternative numbers of examining rooms were used as input to a simulation program.

For the first component, demand, further investigation revealed that 120 patients per week would probably be examined in three clinic sessions, or 40 patients per clinic session. Since the nurse supervisor of the Orthopedic clinic observed that 10 per cent of the scheduled patients did not arrive on the day of their appointment, a no-show rate of 10 per cent was used in the simulation program. Holland[1] reported that 96 per cent of the patients who were examined had appointments. Therefore, due to this low percentage, no walk-in patients were accounted for in the simulation program. Based upon the 10 per cent no-show rate and the 40 patients per clinic session, a demand of 45 patients per clinic session was scheduled in the simulation program.

The Hospital Administrator desired a modified block appointment schedule for the Orthopedic outpatient clinic. Therefore, a particular appointment schedule in which blocks of nine patients were scheduled at 9:00, 10:00 a.m., 11:00 a.m., 1:00 p.m., and 2:00 p.m. was used in the simulation program. Realizing that the punctual arrival (precisely at the appointment time) of patients considered in the previous chapter was an unrealistic assumption, the five scheduled blocks of patients were modified by an arrival distribution. This frequency distribution, shown in Table 5, was developed from Holland's[2] reported distribution of patient punctuality.

A mean of 30 minutes for the physician examining time, approximately equal to the mean which was observed by Holland[3], was used as input to the simulation program. A negative exponential distribution, which has been reported by Jackson (see Chapter II), was used to modify the mean examining time.

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[1]Holland, op. cit., p. 14.

[2]Ibid., pp. 61-62.

[3]Ibid., p. 89.

Table 5. Patient Arrival Distribution

	Time Interval (min.)	Relative Frequency Distribution	Cumulative Frequency Distribution
	60-50	.34	.34
	50-40	.09	.43
	40-30	.07	.50
Before	30-20	.06	.56
	20-10	.04	.60
	10-0	.02	.62
Appt. time			
	0-10	.04	.66
	10-20	.11	.77
	20-30	.04	.81
After	30-40	.04	.85
	40-50	.03	.88
	50-60	.12	1.00

The values used for the number of physicians and number of medical students, four and five, respectively, were exactly the same as estimated in the previous chapter. It was further assumed that physicians would arrive 25 minutes after their scheduled arrival.

Analysis of Results

The simulation program developed in the previous chapter was modified to accept the values of the components. In order to provide information for determining the required number of examining rooms for the Orthopedic clinic, the simulation program was manipulated at levels of 4, 5, 6, 7, 8, 9, 10, 11, and 12 examining rooms. Since the no-show function for demand could possibly result in a variable demand for each clinic session, each level of examining rooms was replicated five times to accomodate the random fluctations in the measures of effectiveness. The modified simulation program appears in Appendix D.

The results of the computer simulation are shown in Table 6. The five replications of each level have been averaged to facilitate the presentation of results. Table 6 shows that clinic duration rapidly decreased as the number of examining rooms increased. On the other hand, the idle time of examining rooms increased remarkably with the increase in examining rooms. After an initial decrease, the average patient waiting time leveled off at 8 examining rooms. The average physician waiting time decreased as the number of examining rooms increased.

Table 6. Simulation Results

Number of Examining Rooms	Clinic Duration (min.)	Idle Exam. Room Time (min.)	Avg. Patient Waiting Time (min.)	Avg. Physician Waiting Time (min.)
	843	148	187	374
4	725	116	167	348
	824	296	188	391
	677	56	137	338
	713	144	155	360
	u = 756	u = 152	u = 166.8	u = 363.2
	583	175	88	241
	675	235	128	251
5	689	415	107	285
	625	155	113	219
	563	140	83	212
	u = 627	u = 224	u = 103.8	u = 241.6
	554	330	66	139
	579	384	48	175
6	561	372	65	140
	563	270	76	146
	523	348	50	154
	u = 556	u = 341	u = 61	u = 150.8
	493	896	12	129
	512	539	50	111
7	605	763	54	131
	527	665	47	106
	515	469	45	91
	u = 530	u = 665	u = 41.6	u = 113.6
	451	1152	14	169
	586	1216	13	110
8	497	592	33	64
	455	944	12	126
	500	920	16	106
	u = 497.8	u = 965	u = 17.6	u = 115
	641	1908	43	164
	440	792	16	57
9	508	1278	17	116
	505	1368	24	81
	482	1044	12	75
	u = 515.2	u = 1278	u = 22.4	u = 98.6
	475	2000	9	134
	547	2790	1	164
10	470	1500	9	73
	504	1060	32	24
	528	1530	31	72
	u = 504.8	u = 1776	u = 16.4	u = 93.4
	478	2365	12	109
	456	2002	5	85
11	482	2123	19	138
	520	1947	25	107
	432	1045	29	26
	u = 473.6	u = 1896	u = 18	u = 93
	461	2880	3	113
	460	1044	40	22
12	498	2628	9	102
	456	2076	22	85
	482	2604	11	97
	u = 471.4	u = 2246	u = 17	u = 83.8

Regression Equations

Least square regression analysis was used to fit one linear and five non-linear functions to the simulated data. The six functions that were applied to the data are exhibited in Table 7. For each measure of effectiveness, the one function which exhibited the highest correlation coefficient was selected as its regression equation. The regression equations chosen for each measure of effectiveness are also shown in Table 7.

A graph of these equations is shown in Figure 9. As can be viewed in Figure 9, clinic duration, average patient waiting time, and average physician waiting time will decrease as the number of examining rooms is increased. However, examining room idle time increases markedly as the number of examining rooms increase. Although these equations provide valuable information for relating each measure of effectiveness with the number of examining rooms, examining room requirements can not easily be determined by analyzing the equations individually. For example, if minimization of average physician waiting time is chosen as the only decision criterion, an infinite number of examining rooms would be required since a mathematical minimum does not exist for the regression equation represented by Y_4.

The decision process for determining examining room requirements seems to indicate that tradeoffs would be made among the four measures of effectiveness. Since the unit of measurement of the four dependent variables is identical, the tradeoffs can be expressed in identical units, or weights, which represent the "worth" of the measures of effectiveness. If weights are assigned to each measure of

Table 7. Regression Equations

Functions Tested	Number
$Y = A + BX$	(1)
$Y = Ae^{BX}$	(2)
$Y = AX^{B}$	(3)
$Y = A + (B/X)$	(4)
$Y = 1/(A + BX)$	(5)
$Y = X/(A + BX)$	(6)

Where: X = Independent Variable
Y = Dependent Variable
A,B = Constants

Measures of Effectiveness	Regression Equations	Correlation Coefficients
Clinic Duration	Best fit to equation (4)	
	$Y_1 = 323.9 + 1587.9/X$	.86
Examining Room Idle Time	Best fit to equation (3)	
	$Y_2 = 3.04(X^{2.7})$	.94
Average Patient Waiting Time	Best fit to equation (4)	
	$Y_3 = -76.4 + 907.2/X$	.93
Average Physician Waiting Time	Best fit to equation (4)	
	$Y_4 = -76.0 + 1603.0/X$	.90

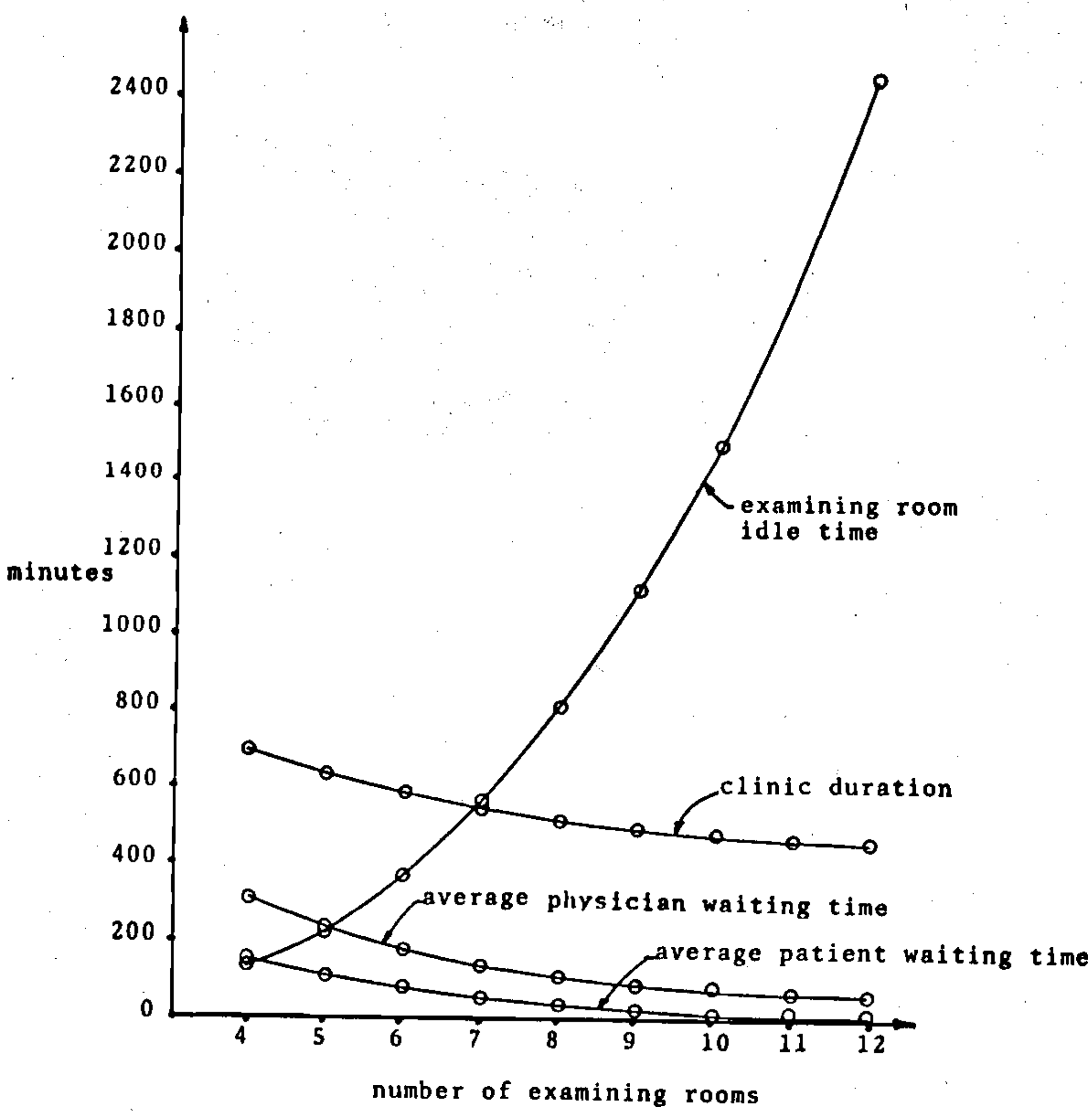

Figure 9. Regression Equations for Measures of Effectiveness

effectiveness, the four regression equations can be combined into a single equation. Accordingly, a, b, c, and d were used in this study to represent the weights assigned to clinic duration, examining room idle time, average patient waiting time, and average physician waiting time, respectively. These weights could realistically represent dollars per minute or some other measure of worth. The weighted sum of the four equations results in a single equation, called Z, which appears as follows:

$$\begin{aligned} Z &= aY_1 + bY_2 + cY_3 + dY_4 \\ &= 323.9a - 76.4c - 76.0d + b(3.04)\ X^{2.7} \\ &\quad + (1/X)\ (1587.9a + 907.2c + 1603.0d) \end{aligned}$$

where:
$a, b, c, d > 0$

The number of examining rooms which would result in a minimum value of Z was determined by setting the first derivative of Z equal to zero and solving for X. The resulting equation appears as follows:[4]

$$X = (\ (193.0a + 110.2c + 195.3d)\ (1/b)\ )^{.27}$$

The required number of examining rooms can be determined from the above equation by selecting appropriate values for a, b, c, and d.

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[4]The necessary and sufficient conditions for minimization are satisfied for the following reasons:

1. The above equation indicates that there is only one value of X which has zero slope for any $a, b, c, d > 0$.
2. The second derivative, d^2z/dx, shows that the point of zero slope is positive (therefore a minimum) for any $a, b, c, d > 0$. Visualize,

$$d^2z/dx = 14.0bx^{.7} + (2/x^3)\ (1587.9a + 907.2c + 1603.0d)$$

For example, if a, b, c, and d are assumed to be equal, the required number of examining rooms is six. It was not the intent of this study to ascertain the proper weights of the four measures of effectiveness, but rather to develop a methodology which can be used to predict the required number of examining rooms as a function of the measures of effectiveness.

CHAPTER VI

RESULTS AND CONCLUSIONS

Summary

The specific objective of this study was to develop a methodology for predicting the number of outpatient examining rooms needed in an outpatient clinic within the context of long-range facilities planning. Examining rooms were viewed as one of the resources consumed by patients as they travelled through an outpatient clinic "system". Using the systems framework of the problem, it seemed reasonable that the required number of examining rooms could be determined by evaluating the effects of different numbers of examining rooms on the outpatient clinic performance.

The general methodology of the study evolved from the systems approach. The first two steps of the methodology, the development of a graphical model of the outpatient clinic and the identification of system components, were direct applications of the systems approach. However, due to the long-range planning focus of this study, it was especially difficult to predict single values of the system components--step 3 of the general methodology. At the initial state, it was virtually impossible to identify each future event which could affect the values of the components or to predict the nature of its effect. Consequently, in this study the possible future values of each component were conceptualized as a range.

The sensitivity of clinic performance to variations in the component values was then investigated so that planning time could be devoted to predicting single values of the components which exhibited the larger effects. In this sensitivity analysis approach, the third step of the methodology, boundary values were used in lieu of the complete range for each component. Next, a 640 complete block factorial experiment was designed to compare the effects of components on the outpatient clinic performance. A computer simulation program was developed, and simulation runs were conducted for each of the 640 blocks in the experimental design. The simulation results were evaluated by analysis of variance and an analysis of mean differences in the measures of effectiveness. The magnitudes of change in each measure of effectiveness for each component were combined into an overall ranking of the relative importance of the components. Planning time was then devoted to predicting single values of the components in accordance with their relative importance.

Once single values of each component were chosen, the fourth step of the general methodology, the development and manipulation of a computer simulation program, was accomplished. The computer simulation program previously developed was modified to accept single values of the components, and simulation runs were conducted for alternative numbers of examining rooms. Regression equations for each measure of effectiveness were developed from the simulation results. A single equation was developed by assigning weights to each measure of effectiveness and combining the individual regression equations. By setting the first derivative of this expression equal to zero and solving for the number of examining rooms, a mathematical expression was obtained which predicts the number of examining rooms which will maximize the clinic performance as a function of the weights assigned to the measures of effectiveness. This was the fifth and final step of the general methodology.

Conclusions

The intent of this thesis is to illustrate that a methodology, which uses the systems approach, can add a valuable dimension to the long-range health facilities planning process. A methodology has been developed herein which should ultimately provide a more quantitative basis for the health facilities planning process.

One weakness in the traditional planning process, which uses ratios for determining space requirements, is its failure to relate individual hospital operations to space requirements. The methodology of this study, as described in Chapter IV, enables values of planning factors (for example, demand, number of physicians, number of students) to be used in determining space requirements. Since the ratios used in the traditional planning process have been based on square feet of existing hospitals, the traditional planning process is limited in predictive capability--a second weakness. The computer simulation program, regression equations, and optimization techniques used in the methodology of this study are not dependent on existing conditions, and they can be used to predict space requirements for any future values of components chosen by the planner.

The sensitivity analysis approach employed in the methodology also contributes to a more realistic approach to this type of problem. It can be used to determine optimum combinations of component values (e.g., the optimum combination of physicians, medical students, and nurses in an outpatient clinic). The sensitivity analysis also can be used to select a single value of a component. For example, a desired value for physician arrival time can be selected from several alternative values. Another possible use of the sensitivity analysis is to obtain a better understanding of the effects of uncertainty on estimates and to assess the degree of precision and accuracy required. For example, as described in the methodology presented herein, the sensitivity analysis can be used to identify the components which exhibited the larger effects on clinic duration so that planning time can be devoted to predicting single values of these components.

One reoccurring problem in health facilities planning is the lack of an objective criterion to judge alternative systems designs. The methodology presented herein contributes to the solution of this problem in two ways. First, rather than attempting to select a single measure of effectiveness, four measures of effectiveness were chosen. Second, the expression which predicts examining room requirements in this study was expressed as a function of weights assigned to each measure of effectiveness. Therefore, the planner can determine examining room requirements for individual hospitals by substituting appropriate weights for each measure of effectiveness.

Recommendations

Based upon experienced gained in this investigation, it is felt that one of the most important problems facing hospital planners is the development of a comprehensive, especially quantitative, planning methodology. The systems approach, computer simulation, regression analysis, and other industrial engineering and operations research techniques (e.g., engineering economy, simulation, statistical decision theory, plant layout, materials handling, and work measurement) can be beneficial in the development of such a methodology.

Several areas for further research were identified during the course of this study. It is recommended that further investigation be directed toward these problem areas. A partial list of these areas follows:

1. Investigate the functional relationship between patient appointment schedules and patient arrival distributions.
2. Identify the effects of managerial controls on the patient arrival distribution and patient no-show rate.
3. Investigate the effects of several planning horizons on the planning process.
4. Develop a methodology to predict the future demand and methods of processing the demand for each hospital department.
5. Develop a methodology for assigning examining rooms to all hospital medical departments.
6. Develop a simulation model for the planning of all outpatient clinics in a hospital.
7. Investigate the effect of more precise and up-to-date estimates of components used on the outpatient clinic clinic space requirements.

APPENDICES

APPENDIX A

Description of GPSS/360

The General Purpose Simulation System/360 (GPSS/360) is a special purpose simulation language developed by IBM. GPSS/360 is an expanded and refined version of the original General Purpose Systems Simulator (GPSS) developed by Gordon[1] in 1961. GPSS II, GPSS III, and GPSS/360, refined versions of the original GPSS, were designed for application on specific IBM computers. Only slight differences exist among GPSS II, GPSS III, and GPSS/360; however, the present discussion is limited to a description of GPSS/360.

GPSS is a flowchart-oriented language which utilizes "blocks" to describe a graphical model of a system. The block types can be categorized into three components which can be used to describe any discrete flow system. The three components are:

1. Dynamic component
2. Resource component
3. Logical component

The dynamic component of a system includes those items which are acted upon or processed through the system. These items, called "transactions" in GPSS/360 terminology, are created and destroyed as required during the simulation runs. Examples of transactions are automobiles, ships, and outpatients. Characteristics of

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[1]Gordon, Geoffrey, "A General Purpose System Simulator", IBM Systems Journal, Sept. 1962, pp. 1-20.

transactions may be specified by using "parameter" assignments. For example, parameters may represent the temperature of a hospital patient, the color of a toy train, or the freight tonnage of a ship.

The resource component of a system is composed of the resources of a system that are used by transactions. Resources may include such items as chairs, personnel, electricity, machinery and booths. A "facility" in GPSS/360 terminology is a resource that can only be used by one transaction at a time. An example of a facility is a gasoline pump in a filling station. A resource that can be utilized by more than one transaction simultaneously is defined as a "storage" in GPSS/360 terminology. A waiting room in a hospital is an example of a storage.

Decisions which alter the flow of transactions through a system may be designated as the logical components of a system. Although most decisions in simulation models are related to the status (empty or full) of a resource, some decisions may be based on characteristics of transactions or other elements within a system. For example, if a long waiting line develops at one particular cash register in a grocery store, new arrivals would probably attempt to enter a shorter line.

When a <u>computer simulation program</u> of a graphical model is developed, a more explicit description of the characteristics of a system can be made. The system components can be described by the following five categories:

1. Dynamic component - The creation and termination of transactions including the assignment of parameters and priority.
2. Resource component - The utilization of resources by

transactions.

3. Logical component - The decisions which alter the flow of transactions.

4. Computational component - Arithmetic variables, Boolean variables, and functions.

5. Statistical component - The storage of simulation statistics for future use.

The components of a graphical model are represented in GPSS/360 by 54 one-word subroutines which are called "blocks." The identifying name of each block corresponds to a general description of the flow of transactions through the model. Moreover, a graphical model of a system can be easily converted to a GPSS/360 computer program through the use of blocks. A list of the 54 blocks as related to the components of a graphical model is shown in Table 1. It should be noted that the GPSS/360 blocks may be used to represent more than one of the components of a simulation model. The blocks can be translated into a form acceptable to an IBM 360 computer through the use of Block Definition Cards. The information on a Block Definition Card consists of a location field (columns 1 - 6), an operation field (columns 8 - 18), and the operand field (columns 19 - 72). The location field, operation field, and the operand field of a Block Definition Card are shown in Figure 1. An identifying number for each block can appear in the location field of the Block Definition Cards. However, since the GPSS/360 Assembly Program automatically numbers the cards sequentially, the programmer usually leaves the location fields blank. Since it is sometimes necessary for a programmer to refer to a specific block in the program, relative addressing of block locations

Table 1. GPSS/360 Blocks

System Characteristics	Block Types
1. Dynamic	ADVANCE, ASSIGN, GENERATE, INDEX, SPLIT, TERMINATE, START, CLEAR, RESET
2. Resource	ENTER, LEAVE, RELEASE, RETURN, SEIZE, STORAGE
3. Logical	ALTER, ASSEMBLE, EXAMINE, GATE, GATHER, JOIN, LINK, LOGIC, LOOP, MATCH, PREEMPT, REMOVE, SCAN, PRIORITY, TEST, TRANSFER, UNLINK, BUFFER
4. Computational	VARIABLE, BVARIABLE, FUNCTION, HELP
5. Statistical	COUNT, DEPART, MARK, PRINT, QUEUE, SAVEVALUE, SELECT, TABULATE, WRITE, TABLE, QTABLE, MSAVEVALUE, INITIAL, UNTRACE, TRACE
6. Others	CHANGE, EXECUTE

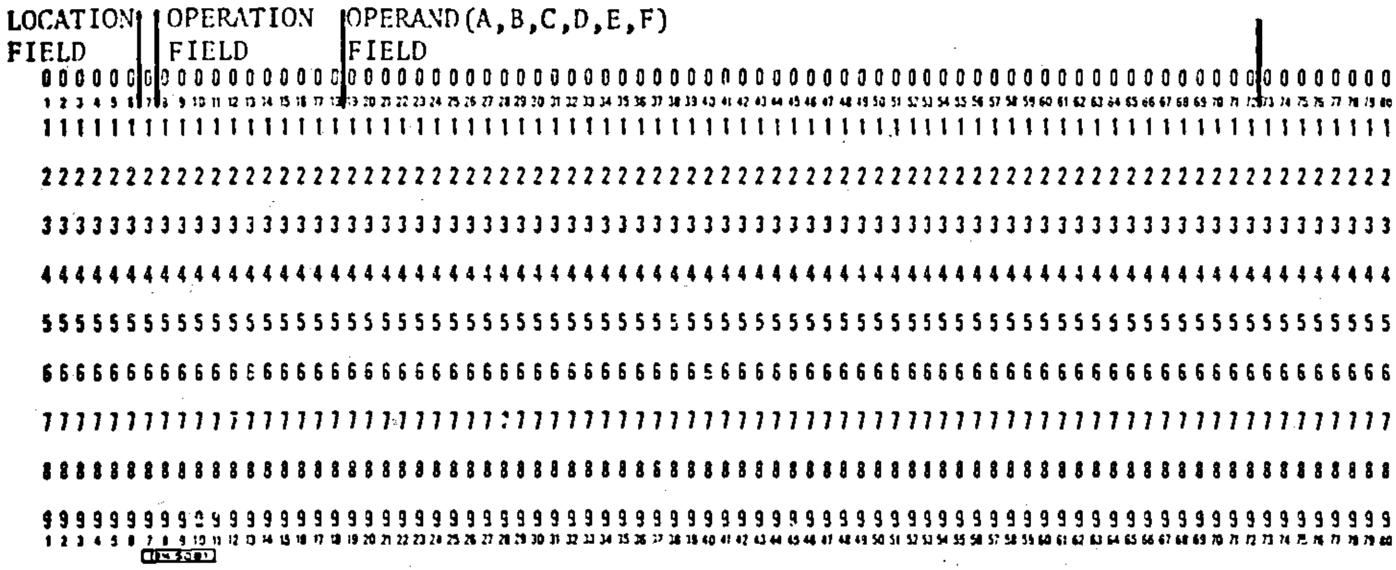

Figure 1. GPSS/360 Block Definition Card

is permitted. In GPSS/360 relative addressing, a symbol composed of three to five alphameric characters, the first three of which must be letters, is used to identify specific Block Definition Cards.

The identifying name of the block is entered in the operation field. The function of each different type of block is explained in detail in the GPSS/360 User's Manual.[2] The identifying names of control cards are also entered in the operation field. The information which is entered in the operand field is directly related to the identifying name location in the operation field. Generally, the values of the block parameters are entered in the operand field. The GPSS/360 User's Manual contains a list of operands for each type of block.

The GPSS/360 Assembly Program performs clerical operations and edits the Block Definition Cards to ensure that all required information for each block has been included. The Assembly Program Input Format accepts variables separated by commas in the operand field. An absence of a variable is represented by a comma. When a blank character is encountered in a field, no further characters in the field are edited by the Assembly Program. Therefore, comments concerning specific blocks can be entered after the first blank character in the operand field. Comments can also be entered by placing an asterisk in column 1 of the Block Definition Card and entering the desired comments in any of the remaining columns. The comments appear in the computer output of a simulation model, but they are not interpreted in the

[2] General Purpose Simulation System/360 User's Manual, IBM Manual H 20-0326-0, 1967, 244 pp.

operation of the program.

In addition to the Block Definition Cards, program control cards and system control cards are required in the operation of a GPSS/360 simulation program. A brief description of the ten model control cards follows:

1. SIMULATE: Must be present for a simulation run to be executed. Otherwise, the job will cease after the assembly phase.
2. START: Indicates that all program input cards have been received. Oftentimes, the START card is used to control the number of transactions entering a model.
3. CLEAR: Causes all transactions and statistics to be cleared from storage.
4. RESET: Clears most of the accumulated statistics, but allows transactions to remain in the model.
5. JOB: Used between different simulation models to execute the models as part of one project.
6. END: Specifies the end of a simulation program.
7. JOBTAPE: Enters external transactions into a simulation model.
8. REWIND: Rewinds the jobtape to the loading point.
9. LIST/UNLIST: Permits the printing and deletion, respectively, of blocks in the printout.
10. READ/SAVE: Allows statistics to be accumulated on the READ/SAVE tape and listed at a later date.

The development of GPSS/360 System Control Cards, which are unique for each computer installation, is described in the GPSS/360 Operator's Manual[3].

GPSS/360 can be used on any IBM 360 computer that has at least 64K words of storage. However, the capacity of specific types of blocks increases as the core size of the computer increases[4]. Table 2 shows the relationship of core size and blocks.

---

[3] General Purpose Simulation System/360 OS Operator's Manual, IBM Manual H 20-0311-1, 1967, 37 pp.

[4] GPSS/360 User's Manual, p. 19.

Table 2. System Capability of GPSS/360

Description	Basic Core Allocation Per Item (Bytes)	64K	128K	256K & up
Transactions	16*	200	600	1200
Blocks	12	120	500	1000
Facilities	28	35	150	300
Storages	40	35	150	300
Queues	32	70	150	300
Logic Switches	6	200	400	1000
Tables	48	15	30	100
Function	32	20	50	200
Variable	48	20	50	200
Savevalue (full word)	4	100	400	1000
Savevalue (half word)	2	50	200	500
User Chains	24	20	40	100
Groups	4	5	10	25
Boolean Variable	32	5	10	25
Matrix Savevalues (full)	24	5	10	25
Matrix Savevalues (half)	24	5	10	25

* Add 20 bytes of GPSS/360 common for every active transaction plus additional bytes for parameters.

APPENDIX B

Outpatient Clinic Simulation Program

```
BLOCK
NUMBER  *LOC   OPERATION  A,B,C,D,E,F,G              COMMENTS
               SIMULATE

        *                             ORTHOPEDICS OUTPATIENT CLINIC
        *                             MEDICAL COLLEGE OF GEORGIA
        *                                  ANDREW T. SUMNER

           1 FUNCTION    RN1,C24       EXPONENTIAL DISTR
        0      0     .1     .104  .2    .222  .3    .355  .4    .509  .5    .69
        .6     .915  .7     1.2   .75   1.38  .8    1.6   .84   1.83  .88   2.12
        .9     2.3   .92    2.52  .94   2.81  .95   2.99  .96   3.2   .97   3.5
        .98    3.9   .99    4.6   .995  5.3   .998  6.2   .999  7     .9997 8
         1     VARIABLE  K15-C1
         2     VARIABLE  QT1+QT2+QT3+QT4+QT5+QT6+QT7
         3     VARIABLE  C1-(SR6*C1)/K1000-K90
         4     VARIABLE  C1-(SR6*C1)/K1000-K15
1        BEGIN GENERATE  5,,,50        5 MIN ARRIVAL
2              QUEUE     1
3              ENTER     1             ENTER ADMITTING OFFICE
4              DEPART    1
5              ADVANCE   1,1           DISTR OF CLERK TIME
6              LEAVE     1             LEAVE ADMITTING OFFICE
7              QUEUE     2
8              ENTER     2             ENTER WORKUP ROOM
9              DEPART    2
10             QUEUE     3
11             ENTER     3             NURSE WORKUP
12             DEPART    3
13             ADVANCE   2,1           DISTR OF NURSE WORKUP TIME
14             LEAVE     3
15             LEAVE     2             LEAVE WORKUP ROOM
16             QUEUE     4
17             ENTER     4             ENTER EXAM ROOM
18             DEPART    4
19             QUEUE     5
20             ENTER     5             STUDENT EXAM
21             DEPART    5
22             ADVANCE   30,5          DISTR OF STUD EXAM TIME
23             LEAVE     5
24             TEST GE   V1,K0,RES
25             ADVANCE   V1
26       RES   QUEUE     6
27             ENTER     6             RESIDENT EXAM
28             DEPART    6
29       EXAM  ADVANCE   25,4          DISTR OF RES EXAM TIME
30             LEAVE     6
31             ADVANCE   5,1           DISTR OF DRESSING TIME
32             LEAVE     4             LEAVE EXAM ROOM
33             QUEUE     7
34             SEIZE     7             ENTER APPT ROOM
35             DEPART    7
36             ADVANCE   1,1           DISTR OF APPT TIME
37             RELEASE   7             LEAVE APPT ROOM
38             TABULATE  8
39             SAVEVALUE 2,V2
40             SAVEVALUE 3,V3
```

```
41            SAVEVALUE   4,V4
42            TERMINATE   1
        1     STORAGE     2
        2     STORAGE     10
        3     STORAGE     2
        4     STORAGE     14
        5     STORAGE     3
        6     STORAGE     3
        8     TABLE       M1,40,10,2
              START       50
              CLEAR
        1     VARIABLE    K90-C1
              START       50
              CLEAR
        1     VARIABLE    K15-C1
        5     STORAGE     6
              START       50
              CLEAR
        1     VARIABLE    K90-C1
              START       50
              CLEAR
        1     VARIABLE    K15-C1
        5     STORAGE     3
        6     STORAGE     6
              START       50
              CLEAR
        1     VARIABLE    K90-C1
              START       50
              CLEAR
        1     VARIABLE    K15-C1
        5     STORAGE     6
              START       50
              CLEAR
        1     VARIABLE    K90-C1
              START       50
              CLEAR
        1     VARIABLE    K15-C1
        5     STORAGE     3
        6     STORAGE     3
29      EXAM  ADVANCE     35,5        DISTR OF RES EXAM TIME
MULTIPLE DEFINITION OF SYMBOL IN ABOVE CARD
              START       50
              CLEAR
        1     VARIABLE    K90-C1
              START       50
              CLEAR
        1     VARIABLE    K15-C1
        5     STORAGE     6
              START       50
              CLEAR
        1     VARIABLE    K90-C1
              START       50
              CLEAR
        1     VARIABLE    K15-C1
        5     STORAGE     3
        6     STORAGE     6
              START       50
```

```
               CLEAR
         1     VARIABLE    K90-C1
               START       50
               CLEAR
         1     VARIABLE    K15-C1
         5     STORAGE     6
               START       50
               CLEAR
         1     VARIABLE    K90-C1
               START       50
               CLEAR
         1     VARIABLE    K15-C1
         5     STORAGE     3
         6     STORAGE     3
29       EXAM  ADVANCE     25,FN1       DISTR OF RES EXAM TIME
MULTIPLE DEFINITION OF SYMBOL IN ABOVE CARD
               START       50
               CLEAR
         1     VARIABLE    K90-C1
               START       50
               CLEAR
         1     VARIABLE    K15-C1
         5     STORAGE     6
               START       50
               CLEAR
         1     VARIABLE    K90-C1
               START       50
               CLEAR
         1     VARIABLE    K15-C1
         5     STORAGE     3
         6     STORAGE     6
               START       50
               CLEAR
         1     VARIABLE    K90-C1
               START       50
               CLEAR
         1     VARIABLE    K15-C1
         5     STORAGE     6
               START       50
               CLEAR
         1     VARIABLE    K90-C1
               START       50
               CLEAR
         1     VARIABLE    K15-C1
         5     STORAGE     3
         6     STORAGE     3
29       EXAM  ADVANCE     35,FN1       DISTR OF RES EXAM TIME
MULTIPLE DEFINITION OF SYMBOL IN ABOVE CARD
               START       50
               CLEAR
         1     VARIABLE    K90-C1
               START       50
               CLEAR
         1     VARIABLE    K15-C1
         5     STORAGE     6
               START       50
               CLEAR
```

```
1       VARIABLE    K90-C1
        START       50
        CLEAR
1       VARIABLE    K15-C1
5       STORAGE     3
6       STORAGE     6
        START       50
        CLEAR
1       VARIABLE    K90-C1
        START       50
        CLEAR
1       VARIABLE    K15-C1
5       STORAGE     6
        START       50
        CLEAR
1       VARIABLE    K90-C1
        START       50
        END
```

ANOVA For Clinic Duration

V	1	191062.	191062.	163.06	**
S	1	578643.	575643.	493.839	**
P	1	838102.	838102.	715.274	**
T	3	904632.	301544.	257.351	**
A	4	3856.16	964.04	.822754	
D	1	13223270	13223270	11285.3	**
R	1	164288.	164288.	140.211	**
VS	1	7466.55	7466.55	6.37228	*
VP	1	6058.55	6088.55	5.19624	*
VT	3	3066.08	1022.03	.872243	
VA	4	12771.6	3192.91	2.72497	*
VD	1	1299.6	1299.6	1.10914	
VR	1	2755.6	2755.6	2.35175	
SP	1	211412.	211412.	180.428	**
ST	3	36765.	12255.	10.459	**
SA	4	2567.72	641.93	.547851	
SD	1	169455.	169455.	144.621	**
SR	1	25527.8	25527.8	21.7865	**
PT	3	166373.	55457.6	47.3299	**
PA	4	993.56	248.39	.211987	
PD	1	210467.	210467.	179.622	**
PR	1	19691.4	19691.4	16.8055	**
TA	12	30429.1	2535.76	2.16413	*
TD	3	74050.4	24683.5	21.066	**
TR	3	5431	1810.33	1.54502	
AD	4	2335.32	583.83	.498266	
AR	4	4828.75	1207.19	1.03027	
DR	1	26214.4	26214.4	22.3725	**
VSP	1	3376.41	3376.41	2.88158	
VST	3	6484.8	2161.6	1.84481	
VSA	4	7206.09	1801.52	1.5375	
VSD	1	2640.63	2640.63	2.25363	
VSR	1	7075.6	7075.6	6.03863	*
VPT	3	4614.73	1538.24	1.3128	
VPA	4	3123.34	780.835	.666399	
VPD	1	672.4	672.4	.573856	
VPR	1	2190.4	2190.4	1.86938	
VTA	12	13135.7	1094.64	.934213	
VTD	3	2625.39	875.13	.746875	
VTR	3	1823.46	607.82	.51874	
VAD	4	9561.74	2390.44	2.0401	
VAR	4	9106.3	2276.58	1.94293	
VDR	1	.31	.31	2.64568E-04	
SPT	3	1520.46	506.82	.432543	
SPA	4	1869.83	467.458	.398949	
SPD	1	27274.5	27274.5	23.2773	**
SPR	1	26910.2	26910.2	22.9663	**
STA	12	25406.7	2117.23	1.80693	*
STD	3	15269.2	5089.72	4.34379	**
STR	3	9411.13	3137.04	2.67729	*
SAD	4	3389.06	847.265	.723093	
SAR	4	2770.24	692.56	.591061	
SDR	1	11289.6	11289.6	9.63504	**
PTA	12	9465.53	788.794	.673192	
PTD	3	64649.3	21549.8	18.3915	**
PTR	3	24581.7	8193.88	6.99302	**
PAD	4	730.88	182.72	.155941	
PAR	4	7632.27	1908.07	1.62843	
PDR	1	2464.9	2464.9	2.10365	
TAD	12	18012.2	1501.02	1.28104	
TAR	12	22576.1	1881.34	1.60562	
TDR	3	165.76	55.2533	4.71556E-02	
ADR	4	4667.41	1166.85	.995844	
RESIDUAL ERRØR	430	503841.	1171.72		
TØTAL	639	17781376	27826.9		

** Significant For $\alpha = .01$
* Significant For $\alpha = .05$

ANOVA For Examining Room Utilization

V	1	1131.56	1131.56	62.3874	**
S	1	143.45	143.45	7.90897	**
P	1	662.17	662.19	36.5092	**
T	3	4277.96	1425.99	78.6203	**
A	4	5686.18	1421.55	78.3754	**
D	1	31374	31374	1729.77	**
R	1	20419.1	20419.1	1125.79	**
VS	1	438.25	438.25	26.9192	**
VP	1	1.91	1.91	.105306	
VT	3	64.99	21.6633	1.19439	
VA	4	126.77	31.6925	1.74733	
VD	1	303.88	303.88	16.7541	**
VR	1	159	159	8.7663	**
SP	1	54.64	54.64	3.01252	
ST	3	209.3	69.7667	3.84651	**
SA	4	341.32	85.33	4.70456	**
SD	1	26	26	1.43348	
SR	1	25.2	25.2	1.38938	
PT	3	359.22	119.74	6.60174	**
PA	4	25.05	6.2625	.345277	
PD	1	27.64	27.64	1.5239	
PR	1	47.85	47.85	2.63816	
TA	12	250.63	20.8858	1.15152	
TD	3	245.2	81.7333	4.50628	**
TR	3	106.25	35.4167	1.95266	
AD	4	640.21	160.053	8.82433	**
AR	4	1099.52	274.88	15.1552	**
DR	1	1515.98	1515.98	83.582	**
VSP	1	33.76	33.76	1.86132	
VST	3	275.65	91.8833	5.06589	**
VSA	4	15.62	3.905	.215298	
VSD	1	12.38	12.38	.682559	
VSR	1	35.63	35.63	1.96442	
VPT	3	40.09	13.3633	.736774	
VPA	4	78.05	19.5125	1.0756	
VPD	1	2.14	2.14	.117987	
VPR	1	1.5	1.5	.082701	
VTA	12	229.89	19.1575	1.05623	
VTD	3	17.98	5.99333	.330436	
VTR	3	49.15	16.3833	.903278	
VAD	4	178.24	44.56	2.45677	*
VAR	4	20.83	5.2075	.28711	
VDR	1	29.33	29.33	1.61708	
SPT	3	39.42	13.14	.72446	
SPA	4	75.7	18.925	1.04341	
SPD	1	159	159	8.7663	**
SPR	1	64.39	64.39	3.55008	
STA	12	603.02	50.2517	2.77057	**
STD	3	95.25	31.75	1.7505	
STR	3	47.15	15.7167	.866522	
SAD	4	16.8	4.2	.231563	
SAR	4	180.45	45.1125	2.48723	*
SDR	1	26.81	26.81	1.47814	
PTA	12	297.38	24.7817	1.36631	
PTD	3	295.47	98.49	5.43015	**
PTR	3	15.95	5.31667	.293129	
PAD	4	32.95	8.2375	.454166	
PAR	4	152.02	38.005	2.09537	
PDR	1	8.79	8.79	.484628	
TAD	12	252.93	21.0775	1.16209	
TAR	12	153.6	12.8	.705715	
TDR	3	64.08	21.36	1.17766	
ADR	4	81.23	20.3075	1.11964	
RESIDUAL ERRØR	430	7799.18	18.1376		
TØTAL	639	81295.1	127.222		

** Significant For $\alpha = .01$
* Significant For $\alpha = .05$

ANOVA For Average Patient Waiting Time

V	1	118483.	118483.	548.402	**
S	1	166862.	166862.	772.324	**
P	1	285948	285948	1323.52	**
T	3	112232.	37410.6	173.156	**
A	4	803201.	200800.	929.408	**
D	1	2003233	2003233	9272.01	**
R	1	60684.1	60684.1	280.878	**
VS	1	9165.75	9165.75	42.4239	**
VP	1	6100.9	6100.9	28.2382	**
VT	3	1785.34	595.113	2.7545	*
VA	4	4216.69	1054.17	4.87926	**
VD	1	1076.41	1076.41	4.98219	*
VR	1	3705.63	3705.63	17.1516	**
SP	1	44122.8	44122.8	204.223	**
ST	3	6869.75	2289.92	10.5989	**
SA	4	62.21	15.5525	7.19851E-02	
SD	1	23040	23040	106.641	**
SR	1	3696.01	3696.01	17.1071	**
PT	3	41795.9	13932.	64.4844	**
PA	4	1804.54	451.135	2.08809	
PD	1	46683.1	46683.1	216.074	**
PR	1	6734.02	6734.02	31.1686	**
TA	12	5912.52	492.71	2.28052	**
TD	3	25130.7	8376.88	38.7726	**
TR	3	2514.66	838.22	3.87972	**
AD	4	175040.	43759.9	202.544	**
AR	4	30329.6	7582.39	35.0953	**
DR	1	7910.16	7910.16	36.6124	**
VSP	1	1215.51	1215.51	5.62602	*
VST	3	3156.58	1052.19	4.8701	**
VSA	4	2198.22	549.555	2.54363	*
VSD	1	319.22	319.22	1.47752	
VSR	1	787.66	787.66	3.6457	
VPT	3	1109.46	369.82	1.71172	
VPA	4	864.15	216.038	.999935	
VPD	1	228.01	228.01	1.05535	
VPR	1	22.5	22.5	.104142	
VTA	12	4335.73	361.311	1.67234	
VTD	3	717.88	239.293	1.10757	
VTR	3	45.61	15.2033	.070369	
VAD	4	979.98	244.995	1.13397	
VAR	4	749.89	187.473	.867721	
VDR	1	267.81	267.81	1.23956	
SPT	3	1354.16	451.387	2.08925	
SPA	4	1495.89	373.973	1.73094	
SPD	1	10112.4	10112.4	46.8055	**
SPR	1	11005.8	11005.8	50.9406	**
STA	12	2032.35	169.363	.783898	
STD	3	294.44	98.1467	.454274	
STR	3	1306.18	435.393	2.01523	
SAD	4	908.3	227.075	1.05102	
SAR	4	1052.35	263.088	1.21771	
SDR	1	1849.6	1849.6	8.56092	**
PTA	12	1378.85	114.904	.531837	
PTD	3	7278.4	2426.13	11.2294	**
PTR	3	9420.84	3140.28	14.5349	**
PAD	4	1054.93	263.733	1.22069	
PAR	4	2276.02	569.005	2.63365	*
PDR	1	796.56	796.56	3.6869	
TAD	12	4674.29	389.524	1.80292	*
TAR	12	5019.04	418.253	1.9359	*
TDR	3	958.03	319.343	1.47809	
ADR	4	1897.61	474.403	2.19578	
RESIDUAL ERROR	430	92902.2	216.052		
TOTAL	639	4174405	6532.72		

** Significant For $\alpha = .01$

* Significant For $\alpha = .05$

ANOVA For Average Physician Waiting Time

V	1	203669.	203669.	278.811 **
S	1	541434.	541434.	741.193 **
P	1	1540660	1540660	2109.08 **
T	3	210298.	70099.4	95.9622 **
A	4	1605.19	401.298	.549354
D	1	594933.	594933.	814.429 **
R	1	110802.	110802.	151.682 **
VS	1	1522.14	1522.14	2.08372
VP	1	5910.98	5910.98	8.0918 **
VT	3	7659.03	2553.01	3.49493 *
VA	4	5430.14	1357.54	1.85839
VD	1	1218.26	1218.26	1.66773
VR	1	5610.98	5610.98	7.68112 **
SP	1	159233.	159233.	217.981 **
ST	3	44480.6	14826.9	20.2971 **
SA	4	2921.37	730.343	.999798
SD	1	164962.	164962.	225.823 **
SR	1	29065.6	29065.6	39.7891 **
PT	3	7087.78	2362.59	3.23426 *
PA	4	532.79	133.198	.18234
PD	1	289553.	289553.	396.381 **
PR	1	60081.9	60081.9	82.2487 **
TA	12	1190.56	99.2133	.135817
TD	3	62917.8	20972.6	28.7103 **
TR	3	3156.58	1052.19	1.44039
AD	4	2046.4	511.6	.700352
AR	4	2893.03	723.258	.990099
DR	1	15494.1	15494.1	21.2105 **
VSP	1	5.44	5.44	7.44705E-03
VST	3	8819.15	2939.72	4.02431 **
VSA	4	3602.4	900.6	1.23287
VSD	1	3190.69	3190.69	4.36788 *
VSR	1	2628.45	2628.45	3.5982
VPT	3	1918.69	639.563	.875526
VPA	4	1864.69	466.173	.638164
VPD	1	2070	2070	2.83371
VPR	1	1354.31	1354.31	1.85397
VTA	12	9671.07	805.923	1.10326
VTD	3	831.2	277.067	.379289
VTR	3	673.44	224.48	.3073
VAD	4	1876.59	469.148	.642237
VAR	4	1631.19	407.798	.558252
VDR	1	18.56	18.56	2.54076E-02
SPT	3	2809.89	936.63	1.28219
SPA	4	8942	2235.5	3.06027 *
SPD	1	36829.7	36829.7	50.4178 **
SPR	1	36436.3	36436.3	49.8792 **
STA	12	8420.17	701.681	.960562
STD	3	18638.4	6212.79	8.50496 **
STR	3	2035.37	678.457	.928769
SAD	4	1430.94	357.735	.489719
SAR	4	580.09	145.023	.198528
SDR	1	14034.4	14034.4	19.2123 **
PTA	12	22675.	1889.58	2.58673 **
PTD	3	10138.6	3379.52	4.62637 **
PTR	3	5556.98	1852.33	2.53573
PAD	4	2459.96	614.99	.841887
PAR	4	1351.04	337.76	.462374
PDR	1	16943.5	16943.5	23.1947 **
TAD	12	4415.22	367.935	.503682
TAR	12	4204.04	350.337	.479591
TDR	3	3490.8	1163.6	1.5929
ADR	4	3638.29	909.573	1.24515
RESIDUAL ERROR	430	314111.	730.49	
TOTAL	639	4635665	7254.56	

** Significant For α =.01

* Significant For α =.05

APPENDIX D

Simulation Program for Examining Room Requirements

```
BLOCK
NUMBER  *LOC   OPERATION  A,B,C,D,E,F,G               COMMENTS

               SIMULATE

        *            MODEL FOR JUNE 1972 EXAMINING ROOM REQUIREMENTS
        *                      ORTHOPEDICS OUTPATIENT CLINIC
        *                      MEDICAL COLLEGE OF GEORGIA
        *                           ANDREW T. SUMNER

        1      FUNCTION   RN1,D12        ARRIVAL DISTRIBUTION
        .34    0     .43  10     .50   20     .56   30     .60   40     .62   50
        .66    60    .77  70     .81   80     .85   90     .88   100    1     110

        2      FUNCTION   RN1,C24        EXPONENTIAL DISTRIBUTION
        0      0     .1   .104   .2    .222   .3    .355   .4    .509   .5    .69
        .6     .915  .7   1.2    .75   1.38   .8    1.6    .84   1.83   .88   2.12
        .9     2.3   .92  2.52   .94   2.81   .95   2.99   .96   3.2    .97   3.5
        .98    3.9   .99  4.6    .995  5.3    .998  6.2    .999  7      .9997 8

        1      VARIABLE   K90-C1
        2      VARIABLE   QT1+QT2+QT3+QT4+QT5+QT6+QT7
        3      VARIABLE   C1-(5R6*C1)/K1000-K90

        *                 BEGINNING OF MAIN SIMULATION PROGRAM


1              GENERATE   ,,,9           APPT FOR 9000
2              TRANSFER   ,NOSHO
3              GENERATE   ,,60,9         APPT FOR 10000
4              TRANSFER   ,NOSHO
5              GENERATE   ,,120,9        APPT FOR 11000
6              TRANSFER   ,NOSHO
7              GENERATE   ,,240,9        APPT FOR 1000
8              TRANSFER   ,NOSHO
9              GENERATE   ,,300,9        APPT FOR 2000
10      NOSHO  TRANSFER   .900,,ARRIV
11             TERMINATE  1
12      ARRIV  ADVANCE    1,FN1          ARRIVAL DISTR (RANGE+,-1HR FOR EACH BLOCK)
13             QUEUE      1
14             ENTER      1              ENTER ADMITTING OFFICE
15             DEPART     1
16             ADVANCE    1,1            DISTR OF CLERK TIME
17             LEAVE      1              LEAVE ADMITTING OFFICE
18             QUEUE      2
19             ENTER      2              ENTER WORKUP ROOM
20             DEPART     2
21             QUEUE      3
22             ENTER      3              NURSE WORKUP
23             DEPART     3
24             ADVANCE    2,1            DISTR OF NURSE WORKUP TIME
25             LEAVE      3
26             LEAVE      2              LEAVE WORKUP ROOM
27             QUEUE      4
28             ENTER      4              ENTER EXAM ROOM
29             DEPART     4
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30            QUEUE       5
31            ENTER       5             STUDENT EXAM
32            DEPART      5
33            ADVANCE     30,5          DISTR OF STUD EXAM TIME
34            LEAVE       5
35            TEST GE     V1,K0,RES
36            ADVANCE     V1
37     RES    QUEUE       6
38            ENTER       6             RESIDENT EXAM
39            DEPART      6
40            ADVANCE     30,FN2        RESIDENT EXAM TIME (EXP DISTR)
41            LEAVE       6
42            ADVANCE     5,1           DISTR OF DRESSING TIME
43            LEAVE       4             LEAVE EXAM ROOM
44            QUEUE       7
45            SEIZE       7             ENTER APPT ROOM
46            DEPART      7
47            ADVANCE     1,1           DISTR OF APPT TIME
48            RELEASE     7             LEAVE APPT ROOM
49            TABULATE    8
50            SAVEVALUE   2,V2
51            SAVEVALUE   3,V3
52            TERMINATE   1
       8      TABLE       M1,40,10,2
       1      STORAGE     2             NUMBER OF ADMITTING CLERKS
       2      STORAGE     10            CAPACITY OF WORKUP ROOM
       3      STORAGE     2             NUMBER OF NURSES IN WORKUP ROOM
       4      STORAGE     4             NUMBER OF EXAMINING ROOMS
       5      STORAGE     5             NUMBER OF STUDENTS
       6      STORAGE     4             NUMBER OF RESIDENTS
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
       4      STORAGE     5             NUMBER OF EXAMINING ROOMS
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
       4      STORAGE     6             NUMBER OF EXAMINING ROOMS
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS

              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
       4      STORAGE     7             NUMBER OF EXAMINING ROOMS
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
              START       45            NUMBER OF APPOINTIVE PATIENTS
              CLEAR
```

```
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
4       STORAGE    8           NUMBER OF EXAMINING ROOMS
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
4       STORAGE    9           NUMBER OF EXAMINING ROOMS
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
4       STORAGE    10          NUMBER OF EXAMINING ROOMS
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
4       STORAGE    11          NUMBER OF EXAMINING ROOMS
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
4       STORAGE    12          NUMBER OF EXAMINING ROOMS
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        CLEAR
        START      45          NUMBER OF APPOINTIVE PATIENTS
        END
```

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