RESOURCE ALLOCATIONS AND OTHER MANAGERIAL USES OF A GENERAL SIMULATION MODEL FOR OUTPATIENT CLINICS

Edward F. Stafford, Jr., University of Oklahoma
F. Paul Wyman, Bechtel Corporation

ABSTRACT

This paper demonstrates certain managerial uses of a general simulation model for multifacility outpatient clinics. A major experiment involving the allocation of scarce funds is described; this experiment involved either adding more staff or converting a clinic to an appointments system. Cost/benefit ratios were determined for each possible decision in the experiment. A variety of other model uses is also presented, and future directions for outpatient clinic modeling research are suggested.

INTRODUCTION

The enactment of the Health Maintenance Organization Act of 1973 and the Health Services Research, Health Statistics, and Medical Libraries Act of 1974 are just two of many indications of strong and growing interests among various sectors of the Federal government that support exists for the correction of the maldistribution of the availability of primary health care in the United States. This strong legislative and executive support, along with indications from the general medical community, strongly suggest that the Health Maintenance Organization (HMO) will be a growing means of delivery of such primary care in the future. Clearly, the most efficient design for such systems will be the outpatient clinic. An in-depth survey of the health care and management science literature indicated a lack of general model for such systems. (This general model includes the necessary analytical methodologies for such parameter estimation, system design or redesign, and system analyses.)

The model reported in this paper was developed, validated, tested, and investigated as a first major step in the development of a general model for multifacility outpatient clinics that would be usable for managers of various such clinics. The specific purpose of this research was threefold:

1. To develop a model that would represent the general characteristics of most multifacility outpatient clinics;
2. To test and validate this model by applying it to a real-life outpatient clinic; and
3. To use this model to demonstrate potential managerial uses for administrators of outpatient clinics.

Recent investigators such as Bailey [2], Fetter and Thompson [6]; Rising, Baron, and Averill [9]; and Rockart and Hofmann [10] reported studies involving the outpatient clinic setting. These studies involved single facilities, or groups of single facilities within a single clinic. No other investigators reported a multiple facility model. Thus the research reported here should serve as a starting point for the development of a truly general multifacility clinic model.

THE SIMULATION MODEL

The general simulation model for multifacility outpatient clinics, used in the development of this paper, is described in full detail elsewhere by Stafford [15], and is only briefly described here. This model consisted of two major elements: (1) a calling population, which demanded medical care; and (2) the clinic, which consisted of a set of facilities, each of which could provide a particular type of health care services. These two elements were linked by a (multiple linear regression) demand function which was developed to predict the population's demand for health care services, based on the various characteristics of the population, and on certain characteristics of the clinic itself. This function provides estimates of the mean daily demand for services; the pattern of arrivals for these services (negative exponential within hours of the day, with different mean arrival rates from hour to hour) was established through many days of direct observation of the clinic modeled for this study. It should be noted here that the general model allows any mathematical or empirical arrival process, and that the one mentioned above was established for a particular clinic.

The clinic itself was modeled from the viewpoint of the facilities rather than from that of individual patients. Each facility could consist of one or more servers (medical staff personnel) who would provide certain medical services at the particular facility. The patients were viewed as entities that arrived at a facility from the calling population or from other facilities within the clinic; that were served by one of the facility's staff members; and that then were sent on to another facility within the clinic, or back to the calling population as a treated patient. The model allows any number of servers at a particular facility, any number of facilities within a clinic, a wide variety of service time distributions for each of the facility's servers, and either a single queue for a facility, or a single queue for each server of a particular facility. All system parameters are specified with data cards at program execution time.

Patient arrivals to the clinic are generated stochastically with a mean arrival rate established by the population demand equation, and with an arrival distribution determined by statistical analysis of the particular clinic being examined with this model. A particular patient's route through the clinic is determined stochastically, based on historic patient load data at the various facilities. Multiple linear regression and input-output analysis were used to estimate the patient flow probabilities that, in turn, were used to generate these patient paths. Details of this estimation procedure are detailed elsewhere by Stafford and Wyman [20].

The SIMSCRIPT II.5 Simulation Language was choosen for writing the computer program version of this simulation model. The excellent list processing capabilities of this language allowed easy representation of the complex queuing systems inherent to most outpatient clinics. This language also has built-in process generators for most common statistical distrubutions that would be found in empirical studies of queuing systems. The event notice feature of this language allowed the actual program to be written in rather general routines and events, which would become operational for specific clinic configurations through data input decks. Thus a single program was written that would represent a variety of clinics with virtually no reprogramming. Then too, for complex simulation models, SIMSCRIPT II.5 proved to be highly efficient at program execution time. (One day of simulated activity, for a clinic serving over 600 patients a day, was less than one second on an IBM 370/168 computer.)

Data from the Ritenour Health Center, the Pennsylvania State University, were used to test and validate the model. These data included five years of daily patient loads for each facility of the Center's outpatient clinic; hundreds of observations of patient arrivals, delays, and services at the various facilities; and student enrollment figures and demographics at this university for this same five-year period. These data were used to extensively examine the technical validity of the model, and to estimate system parameters for a multifactor investigation of the controllable variable-system performance measures interactions of this clinic. Full details of this technical validation procedure are detailed elsewhere by Stafford [18], as are the details of the parameter estimation techniques [15].

To date, a variety of experiments have been conducted with the general simulation model described above; this paper details one of the administrator-oriented experiments that demonstrates some of the analytical powers available with the simualtion model. Other experiments have been detailed by Stafford [15], and by Aggarwal and Stafford [1], and are only briefly discussed below.

AN EXPERIMENT WITH THE MODEL

At the time of the initial research investigations that eventually led to the general simulation model, there was strong feelings among the students at the Pennsylvania State University, and also among the administrators and medical staff personnel of the Ritenour Clinic, that clinic patients were experiencing unnecessarily long delays waiting for service, especially at certain key facilities such as General Physicians and the Pharmacy. Further, the clinic administration felt that demand fluctuated so much within an operating day, that they would have to maintain uneconomically large medical staffs to meet peak demands on the timely basis, and that this staff would experience large amounts of idleness during non-peak hours of operation. These complaints and feelings suggested the following simulation experiment to analyze various alternatives available to clinic administrators.

First, the clinic administrators could selectively add staff at facilities which were experiencing inordinate patient delays. These clinics were identified as the key facilities, above. Second, more receptionists could be added to speed the patient's input to the critical facilities in the clinic, thus giving the patients a feeling of starting service sooner. Third, the administrators could modify the patient's arrival patterns by installing some sort of an appointments system. In this way, demand could be spread over the working hours, thus eliminating some of the peak-time delays, and reducing the need to immediately add more medical staff personnel. (At that time, there seemed to be no funds available for such staff increases, as inflation was eating yearly clinic budget increases, and the University was in a general holding pattern vis a vis staff increases, due to pressures from the State Legislature.)

Experimental Setting

The outpatient clinic of the Ritenour Helath Center, The Pennsylvania State University, was also used in the experiment described in this section of the paper. This clinic provides primary health care services for practically all of the 30,000 students who are enrolled at the main campus during each of the three regular terms; and most of these services are also provided during the Summer Term, when enrollments are less than half of this 30,000 figure. University employees can receive emergency treatment for job-related injuries and illnesses at this clinic, but the number of such calls are negligible compared to the number of student visits. Additional services avialable at this clinic include a health education program; an emergency room where students may receive treatment during the hours in which the clinic is closed; and a 50 bed hospital, which is used to provide care for students who are too ill to care for themselves.

The 14 main facilities of this clinic are listed in Table 1. The Reception clerks retrieve the patient's medical records from the clinic's files and dispatch these records to the facility to which the patient goes next. The Triage nurses interview a patient to determine his relevant medical symptoms. Based on these symptoms, the nurses choose the appropriate facility to which the patient must go for care. Injection nurses administer injections to allergy patients on a continuing basis, immunize students who plan to study in foreign countries, and administer injections prescribed by the clinic's physicians. Treatment nurses dress and redress injuries as directed by the clinic physicians. The Cold Clinic nurse provides primary diagnostic services to patients whose reported symptoms indicate that they have common colds; here more severe cases are forwarded to the general physicians for further diagnostics and for regimen specification. These general physicians provide primary diagnostic services and regimen specification; in addition, they may refer the patients to local or distant medical specialists if the patient's illness or injury is beyond the scope of the Penn State outpatient clinic's primary health care responsibilities. The gynecologists provide any of the primary gynecological services available from a modern gynecologist in private practice. The dentist provides only emergency care for those students unable to obtain care from a local, private dentist. The physical therapist provides a wide variety of treatments as prescribed by either a clinic physician or by the patient's private physician. The Mental Health staff provides emergency or continuing help on a confidential basis to any student requesting such help. More serious cases are referred to private practitioners or inpatient clinics near the patient's permanent home. Basic diagnostic X-rays are made at the X-ray facility, and basic diagnostic laboratory tests are performed at the Laboratory facility. Most common drugs, except Class I and Class II controlled substances, are available on prescription from the Pharmacy facility. The team physicians provide medical care for the members of the varsity sport teams of the University; occasionally, they will also treat patients from the general student body who have sports-related injuries.

TABLE 1

Facilities of Ritenour Outpatient Clinic

	Facility	NPS[a]	QS[b]	SC[c]
1	Reception	2	M	$ 2.82
2	Triage	1	S	4.25
3	Injection	1	S	4.25
4	Treatment	1	S	4.25
5	Cold Clinic	1	S	4.25
6	General Phys.	6	M	13.85
7	Gynecology	2	M	13.85
8	Dentist	1	S	10.71
9	Phys. Therapy	1	S	8.06
10	Mental Health	2	M	14.43
11	X-ray	1	S	4.25
12	Laboratory	3	S	4.25
13	Pharmacy	1	M	7.23
14	Team Physicians	2	S	13.85

[a] Number of primary servers at time of study.

[b] Queue structure: M = one queue per server; S = one queue per facility

[c] Staff costs expressed in dollars per manhour of idleness.

The clinic is open weekdays 8-5, and on Saturdays 8:00 A.M. to noon, during the weeks when classes are in session at the University. The clinic is also operated on most of the days between academic terms. The clinic is closed for holidays and for 2 weeks during Christmas season. Most patients come to the clinic as walk-ins. Starting 1972, an informal appointment system was established for Physical Therapy facility.

In the past, gynecologists were grouped with general practitioners, but their increased demand resulted in the establishment of a separate gynecology facility during 1972. Early morning, a queue is formed and some of the patients at the head of the queue can get appointments for the day, others are expected to come to the queue early next morning. But starting in 1973, appointments were being made for several days in advance.

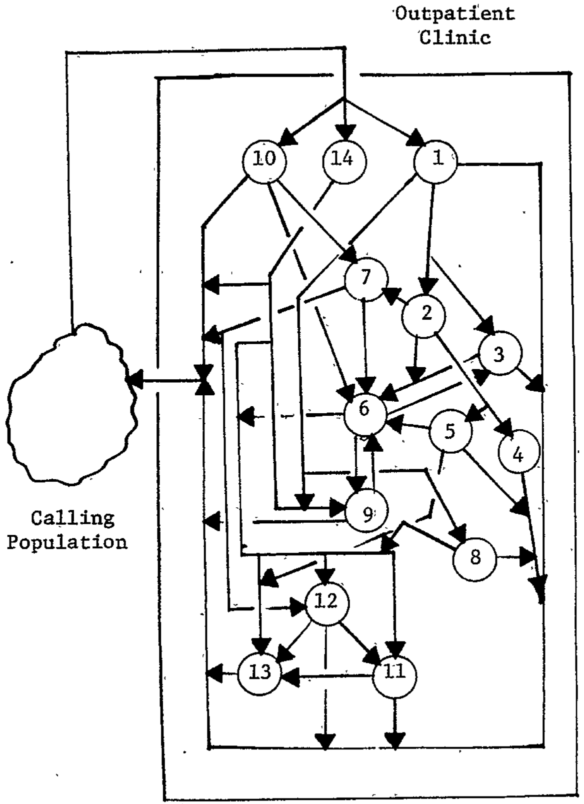
Incoming patients report to reception facility, and they are screened by a Triage nurse. Patients coming to physicians could report to a physician directly. Students coming to mental health are directly sent in because their records are confidential and are maintained separately from basic health records of the general student body. This way, there are three input channels to the clinic. These input channels and the subsequent flowpaths through the other facilities of the clinic are shown in Figure 1.

A four-factor experimental design was established for this experiment. Three of the factors were the staff sizes at the three "critical" facilities: (1) Reception; (2) General Physicians; and (3) Pharmacy. The levels of each of these factors were the numbers of staff to be employed at each of the critical facilities, including the then current numbers. The fourth factor was the type of arrival pattern established for the entire clinic. The base level was the existing patterns, described above. A second level was a poorly controlled appointments system, and the third level was a tightly controlled appointments system. Each of the appointments systems would schedule arrivals to the clinic's input channel facilities, but these arriving patients would then proceed through the clinic as they would without an appointment system; that is, an arriving patient would not go to the X-ray facility, for example, by appointment, but would instead be sent by an attending physician directly from the General Physician facility.

The levels of each of the four experimental factors are identified in Table 2. Levels A1, B1, and C1 represent the numbers of staff personnel assigned

FIGURE 1

PATIENT FLOWPATHS IN THE RITENOUR OUTPATIENT CLINIC (Numbers in the circles correspond to the facility identification numbers given in Table 1)



to the Reception, General Physician, and Pharmacy Facilities, respectively, at the time this study was conducted. The levels of the fourth factor, Arrival Process, need to be discussed in greater detail. As stated above, the observed arrival process to the Ritenour Clinic was cyclic exponential; that is, within each hour of an operating day, the interarrival times of successive patients were distributed as a negative exponential random variable, but the mean interarrival time changed (cycled) over the various operating hours of each day. This arrival process served as the base level for the fourth factor. The rationales for levels D2 and D3 stem from previous studies on appointments systems [4, 11, 12] which show that unpunctuality and excessive walkins can transform a supposedly deterministic input (an appointments system) into a random series of interarrival times, which are exponentially distributed. Hence, an "unsuccessful" or improperly enforced appointments system is here approximated by a negative exponential interarrival time process, while a reasonably well enforced appointments system is approximated by an Erlang-distributed process with parameter k = 4. This later approximation represents an arrival process in which one half of the variance, that would be associated with a purely exponential process, is removed, relative to a perfect appointments system.

TABLE 2

Experimental Factors and Levels

Factor	Level
A - Reception Staff	A1 - 2 Receptionists A2 - 3 Receptionists
B - General M.D.'s	B1 - 6 M.D.'s B2 - 7 M.D.'s B3 - 8 M.D.'s
C - Pharmacy Staff	C1 - 1 Pharmacist C2 - 2 Pharmacists
D - Arrival Process	D1 - Cyclic Exponential D2 - Stationary Exponential D3 - Stationary Erlang (k=4)

The various levels of these four factors, when combined for the multifactor experiment, form a 2 x 3 x 2 x 3 = 36 cell full factorial design. Repeated measures analysis of variance was selected as the analytical tool for this experiment in order to fully exploit this experimental design [21, p. 298]. Identical random number streams were used for the simulation of each cell configuration of the experiment. In this manner, the experiment acted as if exactly the same sequence, for each cell of the design. The patient routings and treatment times were also duplicated for each cell, through this use of identical random number streams. Only the treatments (staff levels and arrival process) were varied. Therefore, the systematic variance attributable to constant differences between subjects was removed by using the repeated measures analysis of variance.

The unit of analysis for this experiment was a single day of clinic operation, since the clinic "emptied" at the end of each working day. Using the concepts of statistical power [21, p. 657], and the results of a pilot test of the simulation model, it was determined that a cell size of 25 replications (days of clinic operation) yielded a Type II risk smaller than $\beta = 0.10$ for $\alpha = 0.05$, so N = 25 was used for each cell of this experiment. Thus for the repeated measures analysis of variance, a "subject" became a batch of one day's patients being passed through the clinic. The basic assumption of the repeated measures technique, that background differences between any pair of subjects remain constant over all trials, may be tested rigorously by assessing whether the variance-covariance matrix of observations exhibits equal variances along the major diagonal and equal covariances off the diagonal. A chi-square test may be applied to test this condition [21, p. 371]. For this experiment, $\chi^2 = 17.47$ for 76 degrees of freedom, thus supporting the assumptions underlying this technique.

Discussion of Results

Two system performance measures (dependent variables) were monitored for this experiment: (1) patient's mean time in the system; (2) patient's mean time waiting for services. Because the first is theoretically a constant plus the value of the second, and because the results were essentially identical for both measures, only the second one will be discussed here.

The analysis of variance summary table for patient mean waiting time is given in Table 3. Since none of the 11 interaction effects approached statistical significance, they are combined in this table instead of being presented individually. It is clear from the results reported in Table 3 that the most sensitive experimental factor was Pharmacist (C), with Arrival Process (D), General Physicians (B), and Receptionists (A) in descending order of importance. Analysis of the individual cell means suggested that an additional pharmacist could reduce the average waiting time by as much as the implementation of a successful appointments system. The stronger F ratio for the added pharmacist suggests that the variance of the pharmacy improvement could be less than the effect of an appointment system. Clearly, the appointment system effect is more potent than additional general physicians or receptionists.

TABLE 3

ANOVA Summary for Patient Waiting Time

Source	df	F	
Receptionists	1	2.34	$p < 0.135$
General MD's	2	30.54	$p < 0.001$
Pharmacists	1	251.39	$p < 0.001$
Arrival Pattern	2	83.11	$p < 0.001$
(All Interactions)	(25)		
Error	864		
Total	895		

The reader is reminded of the assumptions that the manipulation of the arrival pattern represents the *essential benefit* that would accompany an appointments system, and that appointments were not *explicitly* built into the simulation model. With this in mind, the simulation evidence suggests that additional pharmacy capacity should be given priority over an appointments system, but that an appointments system is superior to additional general physicians or receptionists for sheer reduction of patient waiting time. The results also suggest that the benefit of an appointments system, even when poorly accepted (Factor D2), exceeds the benefit of an additional receptionist, and about equals the benefit of an additional general physician.

Cost Benefit Analysis

Of course reduced waiting times must be offset by possible increases in staff idleness, and weighted by the question of cost relative to the benefit obtained. The former consideration is explored later in this paper, while the latter is discussed in this section.

By assuming various cost factors it was possible to estimate a table of cost/benefit ratios. The benefit was defined as reduction in waiting time per patient, for each experimental cell, as compared to the current system (all factors at level "1"). Physician salaries were assumed to average $17,000 (the actual average at the time of the simulation runs), with receptionists and pharmacists costing $4,800 and $12,000 per year, respectively. The University's estimates of overhead at 65 percent of salary cost was used. In their study of a similar university outpatient clinic at the University of Massachusetts, Baron and Rising [3] calculated a cost of $0.72 per appointment established. Assuming that this figure reasonably reflects the cost of establishing an appointment at the Ritenour Clinic, a yearly cost of $60,000 was assumed for an overall appointments system.

The ratios of cost per unit (minute) of benefit obtained are presented in Table 4. Using this table, clinic administrators can combine the factors of staff changes and appointments systems to identify promising combinations of decisions. Non-quantitative factors, such as university budget policy, market availability of staff, and supporting government funds for health center innovations, may then be taken into account. As can be seen in Table 4, the cost/benefit ratio is greatest for an unsuccessful appointments system with no added staff (row 1). A successful appointments system with no staff changes dominates some, but not all, of the staff changes without appointments system additions. In the entire matrix, the minimum cost/benefit value is associated with the addition of a single pharmacist. A clinic administrator can visualize the relative preferences of numerous alternatives in this fashion.

It should be noted that this study was conducted without funding, and without the Ritenour's administrator's commitment to implement any recommendations derived from the study. Nonetheless, based at least in part on the evidence presented in Table 4, this administrator did decide to add another pharmacist to his staff, and followup observation and statistical analyses confirmed that mean patient waiting time did significantly decrease within the Ritenour clinic.

OTHER USES OF THE MODEL

The general simulation model for outpatient clinics, briefly described above, has been used for a number of other experiments related to clinic administrator decision making. Two of these are reported in this section, while the others, having not yet been reported in the literature, are presented later in this paper as future uses of the model and its related analytical techniques.

Examination of Major Clinic Design Factors

To demonstrate the general model's usefulness to a clinic administrator in the design or redesign of his clinic, and also to examine the validity of the model from another viewpoint, the model descirbed above was used to examine the nature and inter-

TABLE 4

Cost/Benefit Analysis

Added Staff					Cost/Benefit Ratios		
Recep'n.	MD's	Pharm.	Benefit (cyclic)	Cost (cyclic)	No Appointment System	Low Success Appointment System	High Success Appointment System
0[a]	0	0	------	------	------	14,051	6036
1	0	0	0.84	$ 7,920	$ 9,428	12,851	6490
0	1	0	3.54	28,049	7,934	11,383	7106
1	1	0	4.55	35.969	7,905	11,425	7430
0	2	0	4.83	56,099	11,614	13,008	8822
1	2	0	5.71	64,019	11,221	12,979	9132
0	0	1	8.37	19,799	2,367	6,951	4861
1	0	1	9.24	27,719	3,000	7,020	5188
0	1	1	12.74	47,849	3,755	7,035	5643
1	1	1	13.62	55,769	4,096	7,159	5938
0	2	1	14.18	75,899	5,354	8,157	6800
1	2	1	15.05	83,819	5,569	8,267	7060

[a] A zero indicates the base level of staff personnel; nonzero numbers indicate numbers of staff personnel added to the clinic.

relationships of three of the major design factors of an outpatient clinic. The three factors examined in this study were: (1) size of the calling population serviced by the clinic; (2) number of input channels for the clinic; and (3) level of staffing at the individual facilities within the clinic. The first factor is, of course, generally beyond the control of the administrator, although he must design his clinic to meet this demand for services. The second factor could help reduce congestion at a limited number of input facilities by adding more facilities; or better control over admissions to the clinic could be maintained through the reduction in the number of input channels allowed. (This last possibility was the basis for including the number of input channels in this experiment.) The third factor is defined to be the ratio of the existing service capacity of each facility to the capacity required for the total actual processing times of the existing demand on that same facility. For example, let the mean service time at a facility be 10 minutes, and let the average patient demand be 60 patients per 8-hour arrival period. If the number of primary staff in the facility is 2, then level of staffing (denoted LS) for that facility can be calculated to be: $LS = 2(480)/10(60) = 1.60$. A LS value of 1.00 means that the staff members are theoretically never idle, a condition that is never obtained in real-life clinics. A clinic administrator can increase level of staffing at a facility (or at all facilities within the clinic), but at an increased cost of staff idleness. Again, cost/benefit analyses would assist the administrator in selecting an "optimal" staffing pattern for his clinic.

The parameter values established for the Ritenour clinic were also used in this study; five levels of potential calling population size, ranging from 5,000 to 50,000 were chosen. Two configurations of input channels, three as currently exist, and a single channel (the Reception Facility), were chosen; and four levels of staffing, ranging from 1.2 to 2.0, were also chosen. Each cell of this 5 x 4 x 3 = 60-cell experiment was replicated for 25 days of clinic operation, and the results were combined into average statistics for each facility of the clinic, and for the clinic as a whole. This 60-cell, 25-day experiment was replicated three times, using different locations of the random number generator streams for each replication. The important measures of system performance monitered for this experiment were as follows:

1. Daily number of patients serviced by a facility (LOAD);
2. Average time a patient spends at a facility waiting for service (MTIQ);
3. Average time a patients spends at a facility both waiting for, and receiving the services (MTIS);
4. Average number of patients waiting in the queues before a facility (MNIQ);
5. Average number of patients waiting in the queues or receiving services from that facility (MNISO; and
6. Man-hours of staff idleness at each facility.

Each of these measures were analyzed using full-factorial analysis of variance with repeated measures. Full details of the experiment, and its results, are reported elsewhere by Stafford [15]. A summary of the results of this experiment are presented in Table 5. These results indicate that number of input channels to Ritenour's outpatient clinic will have little effect other than to increase the number of patients passing through the Reception Facility, and to add a little congestion to that facility and to the next facility immediately downstream in the patient flowpaths. On the other hand, the other major factors strongly affected many of the performance measures, and there was also a strong interaction effect between these two factors. This latter finding suggested that a nonlinear, rather than a linear, relationship existed

TABLE 5

Summary of Analysis of Variance Results for the Clinic Design Factor Study

Source of Variation	Facility 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1[a]	LOAD MNIQ MNIS IDLE	MTIQ MNIQ													
2	---------------------------------Significant for all performance measures----------------														
3	MTIQ MNIQ MTIS MNIS IDLE	MTIQ MNIQ MTIS MNIS IDLE	MTIQ MNIQ MTIS MNIS		MTIQ MNIQ MTIS MNIS IDLE	MTIQ MNIQ MTIS MNIS IDLE	MNIQ MNIS IDLE		MTIQ MNIQ MTIS MNIS IDLE		MNIQ MNIS	MTIQ MNIQ MTIS MNIS	MTIQ MNIQ MTIS MNIS IDLE		MTIQ MNIQ MTIS MNIS IDLE
12	LOAD MTIQ MNIQ MTIS MNIS IDLE														
13	-------------Not significant for any of the performance measures----------------------														
23	LOAD MTIQ MNIQ MTIS MNIS IDLE	LOAD MTIQ MNIQ MTIS MNIS IDLE	MTIQ MNIQ MTIS MNIS	IDLE	MTIQ MNIQ MTIS MNIS IDLE	LOAD MTIQ MNIQ MTIS MNIS IDLE	MNIQ MNIS IDLE		LOAD MTIQ MNIQ MTIS MNIS IDLE		MNIQ MNIS	MTIQ MNIQ MTIS MNIS	LOAD MTIQ MNIQ MTIS MNIS IDLE		LOAD MTIQ MNIQ MTIS MNIS IDLE
123	MNIQ	MITQ MNIQ MTIS													

[a] Factor Identification: 1 = # input channels; 2 = size of calling population; 3 = level of staffing.

between these two factors, for the operation of the clinic. This nonlinear relationship also was indicated by the microeconomic analyses reported elsewhere [1, 15].

Aggregation of Clinic Facilities

Another major study, conducted simultaneously with the experiment described in the preceding paragraphs, involved the analyses of the impact of aggregating two or more facilities within a clinic into a single facility. An administrator might consider aggregating two facilities to reduce the number of staff personnel required to man his clinic. Two or more facilities may be considered for aggregation if they each satisfy the following two conditions: (1) the same type of primary staff personnel is assigned to each of the facilities; and (2) this staff type is able to perform (or is willing to learn to perform) all the major health-service duties assigned to each of these facilities being considered for aggregation. The cost savings, realized through reductions in staff size and in physical plant and equipment required, will at least partially be offset by increases in system performance measures such as staff utilization, patient delays, and general congestion. Variants of cost/benefit analyses for assisting in analyzing these tradeoffs are reported elsewhere [1, 15].

The 3-replication, 60-cell, 3-factor experiment reported above was replicated for a configuration of Ritenour clinic that included three aggregated into one facility; the General Physicians and Gynecology Facilities were aggregated into a second facility; and the Laboratory and X-ray Facilities were aggregated into a third facility. The details of how exact patient paths were maintained for these two large experiments are discussed by Stafford [15]. The results of the aggregated and nonaggregated versions of the clinic simulation were combined to form a dependent sample paired statistic, which is testable with the student-t testing procedures [14, p. 93]. The results of the analyses for the six performance measures stated above, for each of the nonaggregated facilities, are given in Table 6.

Detailed explanations of the results of this study are reported by Stafford [15].

FUTURE USES OF THE MODEL

To date, the model described above, and its related tools of analysis, have been applied to only a single multifacility outpatient clinic. Clearly, these modeling and analytical techniques should be applied to one or more other outpatient clinic systems before the model can be said to be truly general, even for a limited variety of clinics. Nonetheless, there are several other uses of this model which cannot wait for these other major studies, and which are important in their own right. Some of these are described in the following paragraphs.

Allocation of Staff to Facilities

The results of the cost/benefit analysis described earlier in this paper suggest that the overall performance measure, mean patient delay in the clinic, is a linear function of the staff levels of the various facilities. At least, the interaction effects of the experiment were statistically not significant. If this result could be generalized to all facilities of the clinic, then an optimal algorithm for allocating staff to the various facilities, given constraints such as limited budget, minimum staffing requirements, and so on, could be derived with dynamic programming. Further, this staffing problem would decompose into smaller problems if each facility were to be manned by just one type of primary medical staff personnel. Even if the minimizing function were not linear within a facility (a strong likelihood exists that this is true), dynamic programming will work as long as the effects of the individual facilities remain dependent. Such a dynamic programming algorithm would enable the clinic administrator to allocate, and reallocate staff personnel as budgets, labor costs, or other factors change. An initial study of this problem is currently being conducted by Stafford and Gowens [19].

Demand for Services

In the general description of the simulation model at the beginning of this paper, it was mentioned that demand for services, for the whole clinic, was estimated using multiple regression analysis. This analysis could be expanded to include demand esti-

TABLE 6

Test Statistics[a] for Examining the Effects of Facility Aggregation on Various Performance Measures of The Nonaggregated Facilities

Performance Measure	Entire Clinic	Facility 1	Facility 2	Facility 8	Facility 9	Facility 10	Facility 13
Number of Patients[b]	0.0	0.0	0.0	0.0	0.0	0.0	0.0
MTIQ[c]	3.315 (.001)[d]	0.0	0.0	0.0	-1.312 (.20)	0.0	5.323 (.001)
MNIQ[e]	-1.064 (.30)	2.579 (.01)	1.802 (.10)	3.743 (.001)	1.942 (.10)	2.953 (.005)	4.954 (.001)
MTIS[f]	3.315 (.001)	0.0	0.0	0.0	-1.363 (.20)	0.0	5.293 (.001)
MNIS[g]	-0.843 (.39)	2.813 (.005)	2.555 (.025)	2.696 (.01)	2.276 (.025)	2.975 (.005)	4.586 (.001)
Idle Time[h]	-10.693 (.001)	0.0	0.0	0.0	0.0	0.0	0.0

[a] Dependent paired differences, following a Student-t distribution with 119 degrees of freedom (source: [15, p. 93]).

[b] Mean number of patients using a facility per day.

[c] Average time a patient waits for service to begin.

[d] Probability of a Type I error if the hypothesis is rejected.

[e] Average number of patients waiting for service at a facility.

[f] Average time a patient spends at a facility, including his service time.

[g] Average number of patients at a facility, including those being served.

[h] Average daily staff idle time at a facility, minutes.

mations for each of the facilities of the clinic. Such analyses, especially if demand were found to be dependent on time-related factors, would allow a clinic administrator to prepare to meet the future demands based on his or other estimates of future characteristics of the calling population. Stafford [17] is currently developing these analyses.

Estimation of Operating Costs

In addition to the identification of staff personnel costs, as suggested by the analyses described above, a clinic administrator could use this model to determine a reliable estimates of the total operating costs for his clinic. The missing elements to the total operating cost equation include the non-labor direct and indirect costs such as housekeeping, medical supplies, utilities, and equipment repairs. Evaluation of the various historical cost elements of a clinic should reveal approximate cost functions based on a cost per patient served. This could be broken down to facility costs, or kept at the aggregated clinic costs. In either case, proper analyses should establish per-patient cost estimates for the administrator. Then, using either the simulation model itself, or perhaps another type of model (see Stafford [15] for suggestions), the administrator could predict his total system operating costs based on forecasted demands for services. A pilor study regarding such cost estimates is currently being conducted by Stafford [16].

SUMMARY

It was shown in this paper that a general simulation model for multifacility outpatient clinics had a variety of uses with regard to clinic design and administration. Further, several future uses of the model were identified and briefly discussed. In addition to these, it seems reasonable to expect that the model will fulfill many of the uses of simulation models as identified in the literature [5, 7, 8, 13]. Not the least valuable use of this model will be its pedigogical use in the classroom and in the training sessions for future clinic administrators. The logic of the simulation program for the model will prove useful in developing job shop types of simulation models for any number of applications.

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