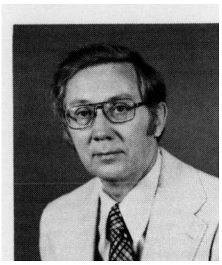
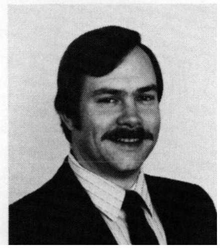
Keywords: hospital admissions, hospital occupancy, simulation

The use of admissions simulation to stabilize ancillary workloads





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ABSTRACT

As part of the planning of a new hospital, an analysis was performed to determine the number of procedures that would be performed in each of nineteen ancillary departments on a day of the week basis. Because the planned occupancy was not the maximum possible, attempts were made using simulation to smooth the daily ancillary loads by varying the admission day of elective, urgent inpatient and outpatient loads. The methodology, sample outputs, and main conclusions are presented.

INTRODUCTION

As part of the planning process for a new hospital facility, questions arose regarding the relationship between patient flows – both inpatient and outpatient – the expected load and the variation in load by day of the week on the ancillary facilities. Earlier work made it possible to determine bed capacities of each clinical unit via simulation after having first predicted the changes in the patient arrival rates and length of stay distributions from the base year (1976) to the planning year (1990) and then to simulate the patient flows to determine the number of beds for each service.[6] The Admission Scheduling and Control System Simulator (ASCSS) allowed simulating patient flows under a number of scenarios and with extensions, to determine the average number of procedures that the ancillary departments of interest would have to perform on a daily basis. This work was accomplished by construction of several models: an inpatient load model based on patient flow, and an outpatient procedures loading model, and a combined inpatient and outpatient model.

To pursue the quantification and investigation of the patient flow ancillary demand relationship, the first model was structured so as to allow analysis of ancillary usage as a function of two factors. The first factor, the patient flows, was to be derived from the ASCSS assuming that inpatient decision rules based on the ASCSS would be functioning in the hospital.[3,5] The second factor, the ancillary activity generated by a given inpatient, was determined by assuming that a patient of a given type (clinic and type of admission) would generate the same total quantity of ancillary demand in 1990, as in 1976, but that it would be distributed over the predicted shorter length of stay. By structuring the inpatient model in the manner described above, answers are obtainable to the following questions:

How does the mean level of ancillary activity, due to inpatient demand, vary by day of week? and day of stay?

How should patient flows be altered to smooth demand of ancillary services?

What type of trade-offs occur when pursuing the objectives to maximize average occupancy? or minimize ancillary activity variation at planned occupancy?

For the outpatient loading of the ancillary services, 1976 outpatient data were used to project the 1990 demand. The assumption was made that the distribution of outpatient demand would remain the same for each day of the week but would increase by a multiplying factor. The combined inpatient/outpatient ancillary service activity was then determined by adding the demands. By analyzing the results of the three outputs (inpatient load, outpatient load, and the total load) the following questions could be answered:

How much impact would inpatient flow have on the overall demand for each ancillary service?

What would be the best method of smoothing ancillary demand for each ancillary service by manipulation of inpatient flows? or by manipulation of outpatient scheduled visits? or by both?

How would overall demand vary by day of the week for each of the ancillary services?

The following assumptions were made in performing this study:

(1) The elective schedules could be changed to accomplish the manipulation of inpatient flows; the rationale was that the introduction of the Admission Scheduling and Control System decision algorithms would cause this to happen anyway. The authors have experience in getting surgeons to change their scheduling practices provided that the same number or more procedures can be done on an annual basis and that the number of elective cancellations can be reduced sharply. Also, since the hospital's operating room (OR) utilization was comparable to the average for the industry (approximately 55%)[8] shifts in schedules were possible without incurring a need to increase OR capacity.

(2) The outpatient loading could be changed if necessary to accomplish the objectives. In 1976, there was a tendency to have more outpatient activity early in the week because of a desire to admit the patient, if necessary, in time to get diagnostic services performed before the weekend. However, the hospital was very concerned about the length of stay and its inability to explain why it was over two days longer than that of community hospitals. Thus, the hospital wanted to assess the level of staffing on weekends in order to reduce length of stay. Proper weekend staffing would render the constraint of seeing outpatients earlier in the week no longer necessary.

(3) That even though there would be resistance to change, the combination of building a new hospital and the fact that a new hospital would have a substantially reduced bed capacity over an old hospital would cause many changes; the analyses should provide a best direction for change and not be constrained by present attitudes concerning OR and outpatient scheduling.

PREVIOUS WORK

The methodology presented in this paper is unique; it is based on the premise that ancillary load is driven by the type and frequency of patients serviced by a hospital. By merging patient demand data with the accounts receivable computer files, one can provide good estimates of ancillary loads once the type and number of patients to be admitted are forecasted.

More traditional methods treat each of the ancillary departments as separate entities and base estimates of changes in ancillary demand on much more gross figures of patient activity such as patient days and/or admissions for the total hospital.[1] Other simulations of inpatient flows have been done by Dumas and Stapleton,[2] but their work has not been extended to ancillary loads.

THE DATA USED

All data collected in the bed determining process[4] was used including admission data, type of admission, service of admission, transfer dates, transfer services, and discharge date. Information about each fee code record generated by the patients discharged from the hospital during the 1976 calendar year was obtained as well as fee code data generated by all outpatients in 1976. After eliminating data which was not necessary for the ancillary departments under consideration, sets of data items for each of the 24,698 error free records of inpatients were constructed. The data included the following items:

(1) Patient registration number
(2) Admission and discharge dates
(3) Age
(4) Sex
(5) Billing zip code
(6) Type of admission
(7) Discharge status
(8) Total length of stay
(9) Number of days on pass
(10) Codes for up to six diagnoses explaining admission
(11) Codes for up to six operative procedures including dates of occurrence
(12) Discharge service
(13) Lengths of stay and clinical services corresponding to each of up to six rooms in which the patient stayed
(14) Fee code data:
- Fee code number
- Account number
- Insurance code
- Quantity of service provided
- Service date.

Additionally, a set of data items was constructed for 137,886 outpatients seen at the hospital during the 1976 calendar year who used the ancillary departments of interest. This set included the following data items for each patient:

(1) Patient registration number
(2) Fee code data:
- Fee code number
- Account number
- Quantity of service provided
- Service date
- Location code, indicating clinical unit of fee code origin.

MODEL CONSTRUCTION

Briefly, the ASCSS uses a Monte Carlo type simulator. Simulation models were constructed based on analysis of historical data providing for the definition of patient arrival rates, crossflows between clinical units and all associated length of stay distributions for each type of admission for each clinical unit. The simulator accounts for both emergency and scheduled admissions and also restores census with patients called in from waiting lists of urgent patients as discharges occur.

In essence, the model is a study in network analysis of patient flows into, out of, and between each of the model's clinics with assigned bed capacities. Patient flows are vectors and are defined by their arrival rates, cumulative length of stay distributions and the hospital policies constraining their use. The simulator can handle up to 16 clinical units in one model. Some simulation models, especially teaching hospitals, may have up to 200 random number generators and cumulative probability distributions. Simulation objectives consist of maximizing model occupancy within predefined ranges of constraints on cancellation of scheduled admissions and times when beds are not available for emergency arrivals. The simulator, written in PL/1 and assembly language, is operational on the University of Michigan's Amdahl computer under the MTS operating system.

To construct the inpatient output, patient flows were simulated and the ancillary services' demands associated with the individually simulated patients were tabulated based on each patient's clinical unit of residence, type of admission, day of admission, and day of stay. For the outpatient output, it was necessary to determine the level of demand for each ancillary activity and tabulate the demands based on the total expected number of outpatient visits for each day of the week in the planning year of 1990. The tabulated demands from both inpatient and outpatient outputs were then used together to form the combined model and produce the final result.

UNIQUE MODEL ASSUMPTIONS

Since the data available for analysis was from calendar year 1976 and the output was to reflect the 1990 expected activity, analysis was based on two unique assumptions. The first was that in 1990 ancillary services rendered per patient would be the same as in 1976, except that the rate per day would be increased due to the predicted shorter average length of stay (LOS). After adjusting for factors determined to reduce LOS such as changes in patient mix, preadmissions testing and outpatient surgery, length of stay was prorated so that overall LOS would be 8.9 days as compared to the 1976 LOS of 10.3 days. A major implication of this assumption was that ancillary service "turnaround" time would thus be shortened by the ratio of the 1990 to 1976 LOS.

The second assumption was that ancillary load data reflected the load imposed on the ancillary services by the clinical services. In the ancillary data base, the date recorded included the "day of request or day of service." Ideally, we would have liked to have used only "day of request" as the basic measure of load. Since the day of service was the day service was initiated, in the vast majority of cases, except possibly requests made on weekends, the day of request and day of service were assumed to be the same. Since the same amount of ancillary work was to be accomplished with fewer inpatient days, a scheme had to be devised to redistribute the ancillary activities to the appropriate days in 1990. Briefly, this was accomplished by:

(1) Generating an intermediate data set

(2) Redistributing the ancillary services to the 1990 predicted length of stay by a linear transform for each patient in the 1976 data base

(3) Developing a summary matrix of ancillary load by clinical service, type of admission (elective, emergent, urgent, or transfer), day of stay, and ancillary department.

COMPUTER PROGRAMS AND ORDER OF PROCESSING

In order to perform the analysis of ancillary activity due to inpatient flow, it was necessary to modify the ASCSS so that it could produce patient flow matrices based on ASCSS model simulations. These modifications, though not extensive, were time-consuming given the existing complexities of the simulator and its model support routines. The modifications included adding the capability to record and tally each patient within the model for each day of stay the patient was in the model as well as the patient's admission and transfer statistics. These data had to be tallied on the basis of the clinical unit with which the patient was associated as well as the admission type by which the patient was admitted to the hospital.

Figure 1 is a graphical representation of the methodology used to produce the ancillary activity models. In the upper left corner is the "Data Processing Program" which used both patient data and ancillary activity data as input. A number of inpatient data items used by other programs were generated:

(1) All arrival rates and distributions needed to define and build the ASCSS models

(2) The inpatient portion of the ancillary activity measures matrix

(3) The patient flow matrix used in the production of a run reflecting the way the hospital operated in 1976.

The lower left-hand corner of Figure 1 shows the program that processed the outpatient ancillary activity data. It too was a multipurpose program and produced:

(1) The outpatient portion of the ancillary activity measures matrix

(2) Hard copy figures detailing the numbers of outpatients participating in the ancillary activities under study

(3) A MICRO formatted data set of outpatient ancillary activity to be used eventually in the production of graphs.

The ASCSS (upper right-hand corner of Figure 1) functioned in the following manner: For each scenario of patient flow under study, a separate model was constructed. Each model was simulated as many times as necessary until the simulation statistics reflected the desired hospital setting.

A computation program (upper middle of Figure 1) was run using a different patient flow matrix each time to be integrated with the inpatient ancillary activities measures matrix to produce MICRO formatted data sets with hard copy statistics.[7]

Aggregation of graph data resulted from the use of the MICRO formatted data sets in conjunction with the MICRO Information Management System. From this program and the formatted data, approximately 400 different sets of data were produced. Further manipulation was necessary before the SOPH:GRAF and the SCH3:COMPOSE canned programs were used to produce the 67 graphs and composite graphs of the study.

RESULTS AND CONCLUSIONS

(1) *Day Of Stay Graphical Summaries.* For each of the 19 ancillary departments of interest, graphical summaries were produced that displayed the effect of day of stay on ancillary load. Figure 2 is an example of the inpatient procedure load on the Biochemistry Laboratory as a function of the day of stay. One should note that this laboratory has

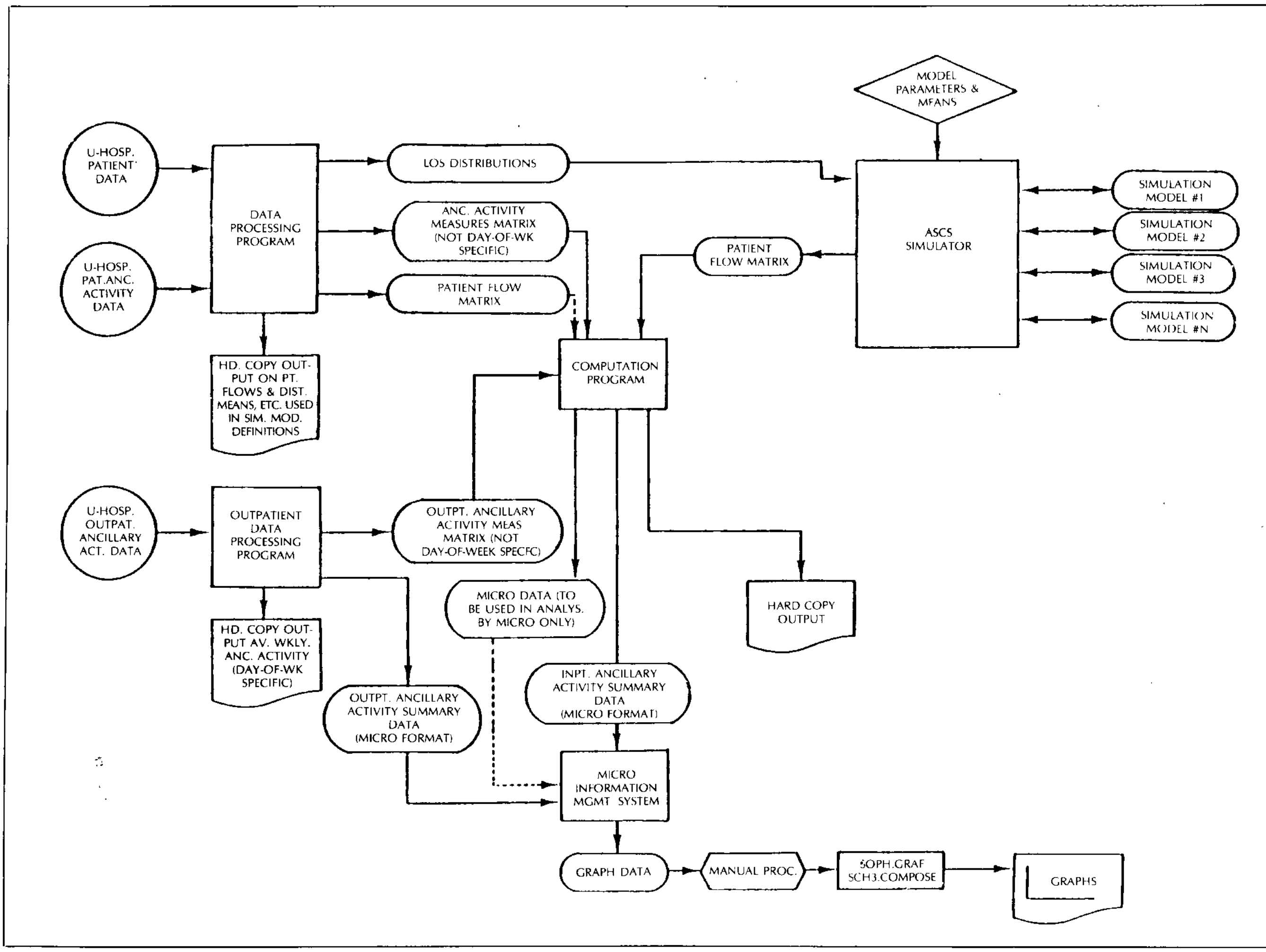

Figure 1. Activity simulation model.

a relatively higher load the first few days of stay. Other laboratories such as Physical Therapy (Figure 3) exhibited a procedure load that was higher as the day of stay increased. Of the 19 laboratories of interest, 14 exhibited higher loads the first few days of stay (Table 1). This observation is somewhat misleading, as discussed later, because the impact of higher loads was found to be considerably dampened by the "steady state" loads that had to be met every day.

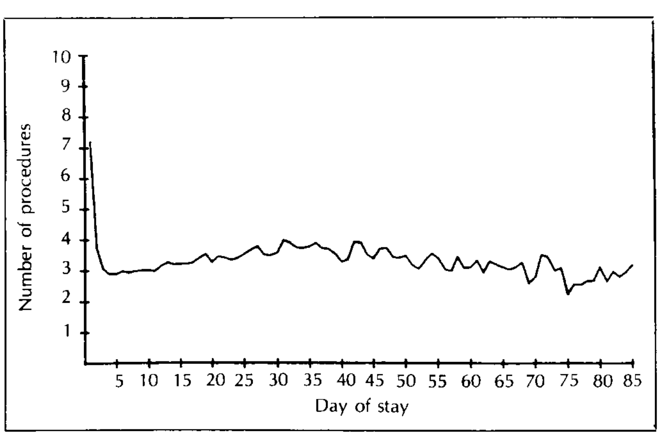

Figure 2. Average daily ancillary load for Biochemistry Laboratory.

(2) *The Effect Of Varying Inpatient Patient Flows.* Table 2 defines the experimental scenarios for the simulation runs. The analysis was complicated by the use of two bed capacities. At this point in the planning process, the number of beds that the hospital administration had decided to build was 739. The minimum number needed to care for the predicted patient demand under maximum average occupancy considerations was determined to be 660. The higher number (739) gave much more flexibility regarding when scheduled elective patients could be admitted, whereas the lower number (660) gave no flexibility except whether or not urgent elective patients were to be admitted on the weekends. Thus, all except runs 4 and 6 used the 739 bed capacity. The "Smooth Scheduled Admissions" was an attempt to smooth the workload on the ancillary services. It was chosen as an approach because so many of the ancillary departments (14 of 19) had higher procedure loads on the first few days of stay. Run 0 was not included as

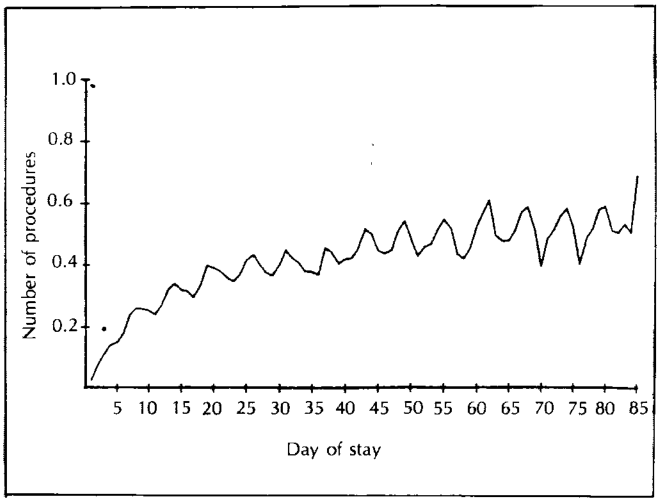

Figure 3. Average daily ancillary load for Physical Therapy.

Table 1. A list of the laboratories having higher procedure loads the first few days of stay.

Ancillary service	Approximate ratio of first or second day procedure rate to the average of the following 18 days of stay
Heart Station-EKG	10.0
Bacteriology/Microbiology Lab	2.4
Biochemistry Lab	2.3
Immunology Lab	7.5
Lab Test Panel	59.0
Hematology Lab	13.0
Pathology Lab	4.5
Ligand Assay Lab	2.0
SMI Coagulation Lab	4.8
Pediatrics Lab	3.3
Nuclear Medicine	4.9
Radiology – Main	4.8
Radiology – Mott	5.3
Blood Bank	4.4

a simulation but as the 1976 admission data transformed (LOS, admissions rate) to the 1990 planning year, so that the hospital administration could compare any new admissions policies with those they were using in 1976.

The weekend call-ins factor was included to show the effect of the presence or absence of urgent elective admissions on weekends because some third party reimbursers were not paying for urgent elective patients admitted on weekends.

(3) *The Graphical Output.* The major output of the effort was a series of three graphs for each of the ancillary departments: average inpatient procedure load, the average outpatient procedure load, and the combined average procedure load. Examples of these graphs are presented using the Biochemistry Laboratory as an example (Figures 4, 5, and 6). In these figures the average number of procedures is plotted for each day of week for each of the simulation runs. The numbers superimposed on the graphs are the simulation run numbers of Table 2. For the inpatient and total loads, a relative scale is presented along the right side with 100 being the lowest point, so that one can get an idea of the relative change in load from day to day, which is presumed to be related to staff size.

The following items represent our conclusions concerning the total ancillary loads:

A. The variation in average load by day of week was different for each of the ancillary departments. Thus, no single inpatient admission policy would provide a stable workload for all 19 departments.

B. Outpatient loads tended to mask and dominate variation in load due to inpatient policies. Thus, outpatient clinic scheduling was a critical aspect of the stability for ancillary demands.

C. Maximum occupancies at the planned capacities (739 beds) gave much higher loads (runs 1 and 5) than loads imposed by projected occupancies. Thus, if 739 beds were to be built, ancillary capacities should be based on maximum occupancy conditions *not* planned occupancy conditions.

D. The differences in inpatient admissions policies were primarily reflected in total loads on Saturday and Sunday when outpatient demand was the lowest.

Table 2. A scenario of the inpatient simulation runs.

Simulation run	Capacity	Simulation objective	Weekend call-ins
0	1976 Data projected to 1990 - not simulated		
1	739	Max. occ. (A)	No (C)
2	739	Smooth scheduled adm. Sun - Thur Planned occ. (B)	No
3	739	Smooth scheduled adm. Sun - Sat Planned occ.	Yes
4	660	Max. occ.	No
5	739	Max. occ.	Yes
6	660	Max. occ.	Yes
7	739	Smooth adm. Mon - Thur Planned occ.	Yes
8	739	Smooth adm. Sun - Thur Planned occ.	Yes

Note: (A) Max. occ. is where hospital beds would be used to maximum extent subject to scheduled admission cancellations and no beds for emergency constraints. This gives an upper bound to the use of ancillary facilities.

(B) Planned occ. is the planned occupancy for 1990.

(C) Weekend call-ins "no" is where urgent electives cannot be admitted on weekends.

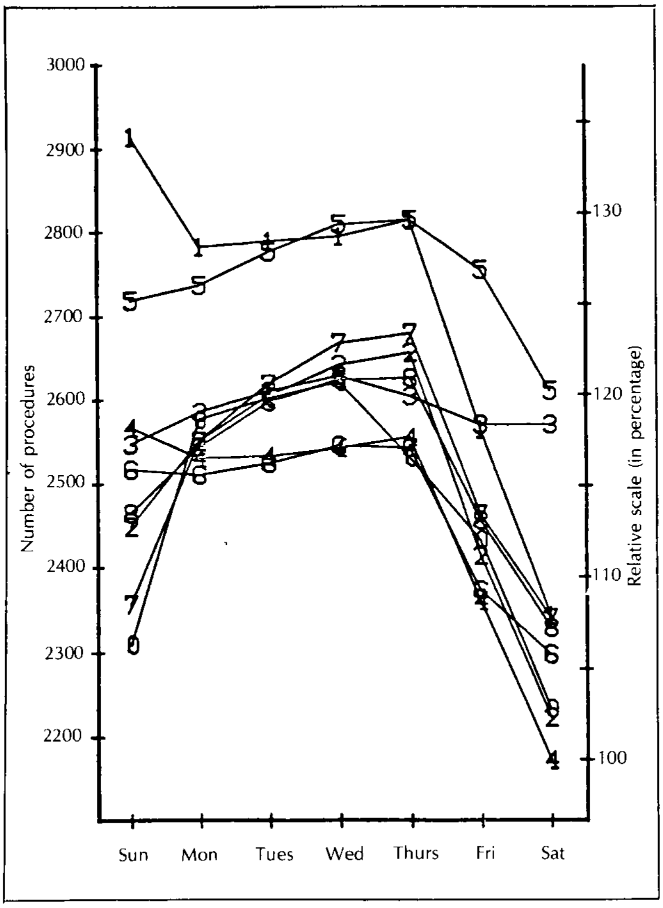

Figure 4. Average number of inpatient procedures versus day of the week for Biochemistry Laboratory (for the simulation runs of Table 2).

E. The generally higher activity of the outpatient departments on Monday and Tuesday versus Wednesday, Thursday and Friday was generally reflected in the total load curves. Thus, if at all possible, outpatient activity needed to be reduced on Monday and Tuesday and increased on Wednesday, Thursday, and Friday to smooth the total load.

F. Preventing weekend urgent elective call-ins on Friday and Saturday decreased ancillary loads on Friday and Saturday, but substantially raised them on Sunday, so that in many ancillary departments, Sunday had the highest load of any day of the week.

G. Most of the ancillary departments are labor intensive so that the number of procedures are probably linearly related to the staff size, both on an absolute and a relative basis. Thus, staffing on a daily basis could be determined using the data of this methodology plus the labor hours per procedure data for any given ancillary department. Using the following data as an example of staffing for the Biochemistry Laboratory:

(i) Let the load predicted by simulation run #8 be the planned load and the load predicted by run #5 be the maximum load

(ii) Assume an average time per procedure of 5.0 minutes

(iii) Assume a 450.0 minute working day.

Table 3 gives the required staffs by day of the week. Please note the high staffing required on Saturday and Sunday and the differences between planned and maximum average loads.

(4) *Outputs versus Present Practice.* A cursory examination of the staffing patterns indicated by run 0 (1976 policies) and the actual staff used in the hospital revealed a tendency to substantially understaff on weekends and to overstaff on Fridays. These practices probably:

- Substantially raised the ancillary loads on Monday and Tuesday, which in many cases were already relatively high due to outpatient policies. If this demand is to be met with full-time staff, overstaffing toward the end of the week will occur if the units are correctly staffed during the first part of the week.
- Substantially increased LOS due to the delay of servicing of requests for service on the weekends.
- Caused physicians to minimize treatment on weekends because of the poor ancillary response.

(5) *Predictions of Weekend Staffing By Department.* Examination of Table 4, which compares Monday to Friday loads versus Saturday and Sunday loads, reveals that the staffing on the weekend is surprisingly high. This result is due

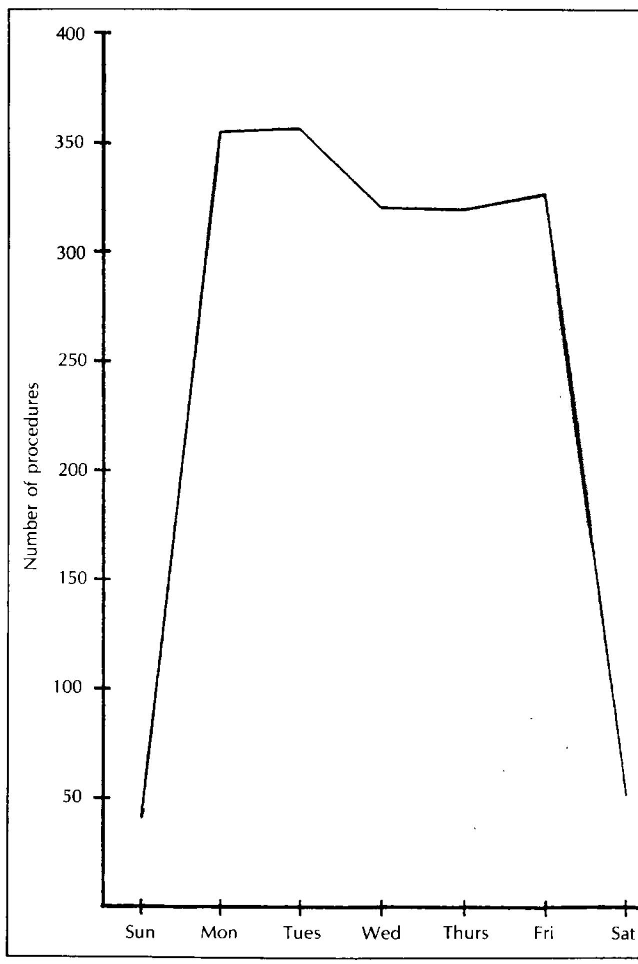

Figure 5. Projected average number of procedures caused by outpatient activity in 1990 for Biochemistry Laboratory.

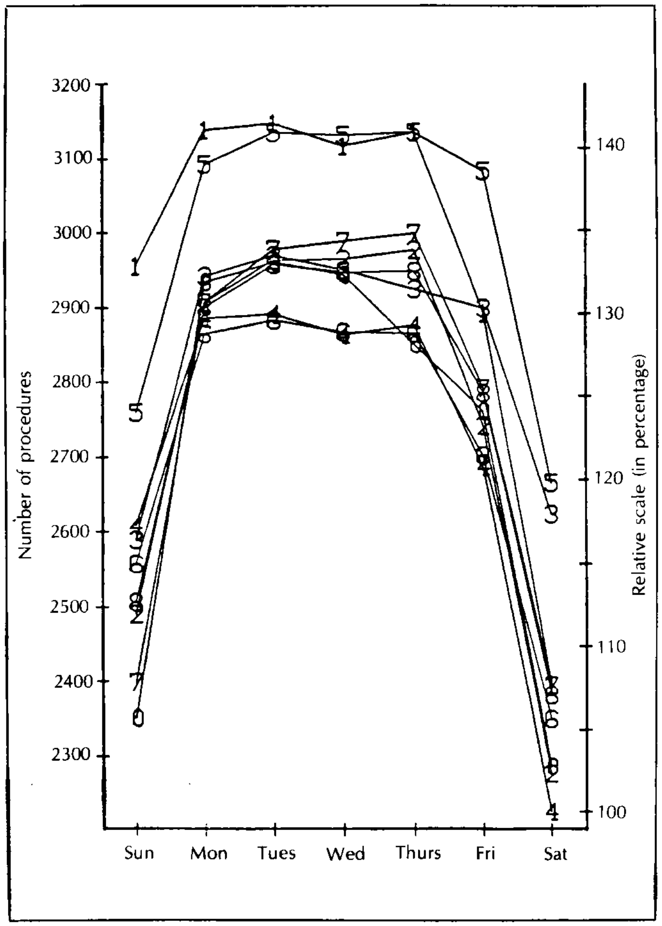

Figure 6. Total average number of procedures (inpatient plus outpatient) for Biochemistry Laboratory.

Table 3. Predicted average daily staff at planned and maximum average load for the Biochemistry Laboratory.

	Sun.	Mon.	Tues.	Wed.	Thurs.	Fri.	Sat.
Planned average load (Run #8)	27.8	32.2	32.8	32.6	32.4	30.9	26.4
Maximum average load (Run #5)	30.7	34.4	34.8	34.8	34.8	34.3	29.6

[redacted]

to the "Steady State Load" of many of the ancillary services after the first few days of stay and to the assumption that was made that the number of procedures for a patient was due to the type of patient and the day of stay, not to the day of the week. This assumption was justified on the basis that there was great interest in reducing the LOS of patients and that one of the ways to do this was to provide the same intensive service on weekends as during the week. If staffing is related linearly to load, then the percent figures give an indication of the Saturday and Sunday staff. The following is observed:

- Saturday to Sunday staff varied between ancillary departments, but in all cases needed to be higher than anticipated.

Table 4. A comparison of the Saturday and Sunday average ancillary load with the Monday through Friday load using simulation run #8 (from Table 2).

[redacted] Ancillary department	Load range MON.-FRI.	SUN. load (as a percent of range midpoint)	SAT. load (as a percent of range midpoint)
Ligand Assay	48-53	61	61
Respiratory Therapy-Main	488-496	97	97
Respiratory Therapy-Mott	74-77	94	97
Physical Therapy	219-227	78	78
Pharmacy	950-970	72	72
Heart Station	82-110	80	57
Bacti/Micro	278-292	80	78
Biochemistry	2780-2960	87	83
Immunology	76-87	47	42
Lab Test Panel	130-168	48	27
Hematology	90-124	83	50
Pathology	132-144	45	44
SMI Coagulation	225-265	93	79
Pediatrics	173-191	64	60
Nuclear medicine	66-74	44	39
Hemodialysis	3.2-3.5	34	36
Radiology-Main	430-480	53	46
Radiology-Mott	96-110	62	53
Blood-Bank	470-560	97	78
Overall total (average) ancillary activity	6800-7400	80	74

- Overall average is 80% on Sunday and 74% on Saturday indicating the weekend staffs needed to be roughly three-fourths of the staff during the week. This is substantially different than the present staffing of the hospital.

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