DIGITAL SIMULATION FOR DETECTING CONGESTION IN HOSPITAL FACILITIES

G. Miles Johnson
Sacramento Airlogistics Center
McClellan Air Force Base
Sacramento, CA.

William W. Happ
Department of Computer Science
University of California, Berkeley, CA.

SUMMARY

Alternatives to eliminate hospital congestion are tested quantitatively by simulating the flow of patients, materials, and decisions. Critical parameters are determined by (i) layout of facilities (ii) time of day or (iii) scheduling of services. With the aid of GERTS GQ (Graphical Evaluation and Review Technique for Simulation - Gated Queue network simulation program), it is possible to identify causes of congestion and low productivity. The technique is useful in projecting planned modifications in the system, including scheduling strategies, changes in resources or in patient load.

1. CONGESTION IN HOSPITAL FACILITIES

Components in health delivery systems are particularly prone to congestion, such as in radiology and outpatient emergency services. Patient flow in hospitals depends upon arrival processes, facility layout, and on service rates in hospital services. Whenever hospital procedures prove inadequate, makeshift measures such as augmenting inadequate X-ray facilities with portable equipment are the usual resort. Had the flow patterns due to increased patient influx been simulated to predict bottlenecks and slack areas in health facilities, deficiencies in facility design, patient scheduling, and facility utilization could have been detected before they occurred, thus alleviating the need for costly remedial action afterwards.

1.1 TECHNIQUES FOR DETECTING CONGESTION IN HOSPITAL FACILITIES

Queueing theory is one technique for evaluating scheduling systems and patient waiting times. This theory has been applied to such problems as appointment systems analysis by Bailey and Welch (1,2). Gupta et al (3) applied queueing theory to a simple problem in manpower planning in a hospital messenger unit stating:

"It was found that the data on service times and arrival rates were adequately represented by the theoretical distributions. In more complex cases, these distributions may not approximate the real life situation. For example, in an emergency department, there may be priorities of service dependent on the condition of each newly arrived patient. The analysis of such a situation is involved and may sometimes be impossible, so that computer simulation would be necessary to provide an objective basis for decisions on staffing."

Computer simulation provides quantitative data concerning the movement of patients and materials through the hospital facility in terms of arrival patterns, delays, and waiting lines.

Swartzman (4) points out the importance of well-designed data collection techniques for developing a "general hospital arrival process model" and concludes that:

'Once the arrival process, service process, and queueing discipline are known, a complete queueing model for the system can be obtained. With such a model, simulation techniques would permit determination of various measures of patient waiting time, number waiting, and probabilities of exceeding certain values for these, as well as the percentage of time the servers are idle. The effect of altering the service or arrival processes may then be investigated for these measures or some combination of them without instituting the actual changes in the system. When some value is placed on each of these measures, the overall effect of various changes may be evaluated, and a system more desirable than the present one may be developed and implemented. Some method to detect changes (e.g. yearly increases in the arrival rate of emergency patients) in the arrival or service processes over time would make it possible to institute proper feedback to maintain system operation at a desirable level."

1.2 THE HOSPITAL AS A STOCHASTIC SYSTEM

A deterministic system will produce a unique output given a set of inputs and the state of the system under investigation. Stochastic systems, however, can be expected to produce any one of a distribution of outputs in response to a set of inputs. Therefore, outputs must be described in terms of mean values, ranges, or variance. Processes within

a health delivery system, for example, consist of both repetitive and non-recurrent flows of transactions, personnel, materials, decisions, and/or other entities. These entities flow through a network of interrelated queues, activities, operations and processes. The day-to-day time succession of these entity flows appears irregular and unpredictable. Although any single event may be unpredictable, long-term regularities emerge which make it possible to predict characteristics such as averages, ranges of fluctuations, and frequencies of occurrence. Random phenomena with predictable long-run regularities are termed stochastic. Clearly many operations and processes in hospital administration are inherently stochastic. Consequently, optimization of hospital services must take into account these random fluctuations in patient demand.

2. SIMULATION CASE STUDY: ELIMINATION OF CONGESTION IN RADIOLOGY SERVICES

The simulation of radiology services required techniques such as data collection and analysis, problem formulation and experimental design, model building and programming, model validation, and output analysis. Specific patient arrival/waiting line relationships are obtained by establishing and utilizing a discrete event simulation model of radiology patient flow for facility planning. Modular network methodologies adopted from case studies (5, 6, 7, 8, 9, 10, 11, 12, 13, 14) for modeling hospital operations are utilized in this presentation. For brevity, a discussion of the simulation technique used has been omitted and the reader is referred to one of the above case studies. The network modules used here and in previous case studies are an extension of GERTS, an acronym for Graphical Evaluation and Review Technique for Simulation, a simulation language. Over 500 simulation runs will illustrate how hospital planners are provided with forecasts concerning:

Needed radiology facilities based upon current and projected facility demand

Improvements in patient scheduling during periods of peak demand

Guidelines for facility expansion

2.1 DATA ACQUISITION

Daily monitoring of patient flows and queue times is carried out on special forms containing items such as arrival time, department, procedure to be performed, room, and service time. Hospital records provide aggregate data such as number of patients served at a particular station, or number of examinations of a specific type carried out per month. Distributions are then compiled from "goodness-of-fit" tests. The hospital provides diagnostic and therapeutic radiology services classified as:

(1) Routine diagnostic procedure for patients who require X-rays only with no special preparation, e.g. chest X-ray.

(2) Scheduled special diagnostic procedure for patients requiring special preparation with injections of radio opaque dyes or swallowing a radio opaque solution. I.V.P. procedures, barium enemas, or gall bladder examinations fall into this category.

(3) Scheduled surgical procedure for patients requiring X-ray technicians to assist surgical personnel to perform diagnostic procedures such as angiograms and cystoscopies.

(4) Scheduled therapeutic procedure which includes teletherapy, i.e. the use of X-ray and other high energy modalities, radium, cobalt, etc. and bracly therapy, i.e. the surface, intracurvatory or interstitial application of contained radioactive sources.

(5) Nonscheduled emergency - emergency patients have priority over all others in that routine and special procedure patients may be preempted whenever emergency patients enter the system.

2.2 PATIENT FLOW

Fig. 1 describes the flow of patients referred to from the following departments:

Gynecology	Orthopedics
Opthalmology	Oral Surgery
Plastic Surgery	Ortholate Surgery
Proctology	Urology
Thoracic Surgery	Medicine
Psychiatry	Pediatrics
General Surgery	Outpatient Clinics

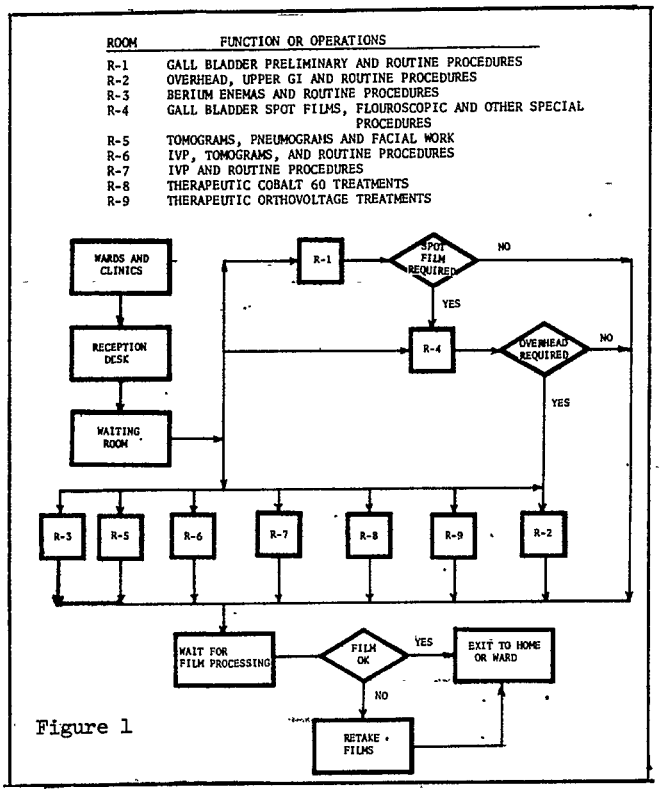

Figure 1

Patients are routed through the receptionist area unless they are confined to wheeled conveyors and wait in a separate room while reception procedures are completed. A few patients arriving at this point are new or do not have their requisitions available and consequently require a longer processing time to prepare the required records.

After reception procedures are completed, special patients are seated and wait until the appropriate room becomes available. Routine patients also wait and then are routed to the first available room that has a routine procedure classification. Parametric data considered in this study are:

PARAMETERS EMPLOYED IN SIMULATION

PATIENT ARRIVALS	RECEPTION SERVICE TIME
EXAMINATION SERVICE TIME	# OF EXAMINATION ROOMS
FILM PROCESSING TIME	PROBABILITY OF USING A SERVICE
FILM PROOFING TIME	PROBABILITY OF FILM ERROR

2.3 DATA ANALYSIS

At the reception desk, the hospital employs two receptionists who process requisitions and locate records for each patient. This takes an average of 9 minutes for patients whose requisitions are available and 15 minutes if the requisition is not available.

TABLE 1

DAY OF WEEK	MO	TU	WE	TH	FR	SA
WAITING TIME	15	13	29	21	18	15
INTERARRIVAL TIME	19	7	14	8	25	21
ORTHOPEDICS DAY	NO	YES	NO	YES	NO	NO

The number of examinations per month in Fig. 2 shows considerable fluctuation. The average daily patient interarrival distributions in Table 2 demonstrate significant variation in demand (1) between "orthopedics" days, Tuesdays, Thursdays, and some other days, and (2) between mornings and afternoons. An "orthopedics" day is one in which orthopedics patients are sent as a group to radiology for examination of previously set broken bones.

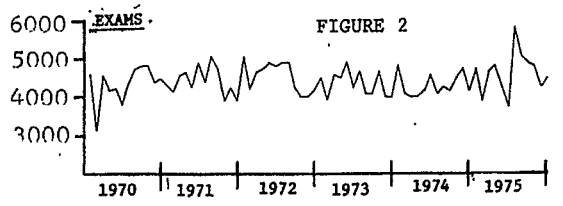

FIGURE 2

Several important conclusions result:

Congestion phases as defined in Table 1 constitute an appropriate set of criteria.

Examination delays, Table 1, are uniformly distributed from day to day indicating a "state dependent" service rate. That is, the technicians relinquish allocated break times to attenuate long patient waiting lines on busy days.

2.4 RESULTS

Table 2 describes not only observed congestion data but defines parameters to be predicted by simulation. Desirable predictions include:

Simulation of patient flow under currently existing conditions

Simulation of hypothetical 30% increase in patient flow representing a projected demand for services by the presentation of new patient case types

Simulation of improved patient scheduling to more evenly distribute patient demand throughout the day

Simulation with additional personnel and physical resources

TABLE 2

ORTHOPEDIC DAY	YES		NO	
FROM 7AM to 12 NOON	I		II	
FROM 12 NOON TO 6 PM	III		IV	
CONGESTION PHASE	**I**	**II**	**III**	**IV**
ARRIVAL RATE - PATIENTS PER HOUR				
OBSERVED	15	9	5	4
SIMULATED	14	8	6	4
SIMULATED PLUS 30%	18	13	8	6
PATIENT STATUS - MINUTES PER PATIENT				
WAITING - OBSERVED	17	15	13	19
SIMULATED	16	16	14	18
IN SYSTEM-OBSERVED	33	32	23	28
SIMULATED	33	32	28	30
PATIENT LOAD - PATIENTS IN QUEUE				
FLUCTUATING - EXPECTED	10	8	8	4
SIMULATED: CURRENT CONDITION	9.6	9.1	7.4	3.4
SIMULATED: PLUS 30%	15.6	10.2	13.3	5.1
EVENLY DISTRIBUTED SIMULATED	7.9	6.4	6.4	6.4

2.5 BETTER SCHEDULING OF RADIOLOGY FACILITY

Scheduling practices that contribute to facility congestion include:

(1) Physicians requesting examinations in the morning when an afternoon examination would be as effective.

(2) High frequency of short-term routine procedures performed on orthopedics days, particularly in the mornings.

(3) Uneven dispersion of orthopedics days throughout the week.

(4) Scheduling many routine examinations when the demand for more time-consuming "special procedure" examinations is expected.

(5) Uncoordinated patient scheduling by outpatient clinics.

Alternative patient scheduling can more evenly distribute the demand for radiology services, for example,

(1) Scheduling orthopedics examinations daily rather than 2 or 3 days per week

(2) Scheduling orthopedic examinations for the relatively slack afternoon hours between 1:00 p.m. and 5:00 p.m.

(3) Securing the cooperation of physicians to request examinations in the afternoon unless more expedient results are required

Payoffs accrue from effective patient scheduling in terms of:

(1) Timely patient service

(2) Enhanced technician efficiency as a result of reduced pressure to attenuate long patient waiting lines

(3) Allowing radiology managers to perform administrative duties without interruption by irrelevant tasks

2.6 UNDERSTANDING CAUSES OF CONGESTION

This simulation study identified causes of congestion in a radiology facility. As patient demand approaches operating capacity, waiting lines develop in the main reception area. Empirical and simulation data, Table 2, indicates that congestion in patient flow is at maximum for two periods each day: between 7:00 a.m. and 12:00 noon, Monday through Friday, and between 1:00 p.m. and 3:00 p.m. Monday through Friday. Patient congestion in the afternoon, however, is substantially smaller relative to the 7:00 a.m. to 12:00 noon period. Consequently, facility idle time is increased in the afternoon, which is neither productive nor cost effective. This dichotomy of patient demand becomes even more critical on orthoperics days when patient arrival rates double.

CONCLUSION

This project was undertaken to improve patient services in a health care delivery system for a county hospital. This requirement was met simulating flow of 10,000 patients through each of more than 500 "runs" of distinct simulated constraints, specifically:

Patient arrival rates

Patient reception delay times

Average patient waiting times for examination

Patient queue in main waiting room

Examination service times

Total patient transit times

Patient queue in main waiting room when the patient arrival rate is more evenly distributed throughout the day

Simulation of patient traffic flow encompassed data collection and analysis techniques, modeling strategies, validation and evaluation tools. Simulated patient flow through a radiology facility identified causes of congestion and low productivity, and projected effects of changes in the system. These changes include planned modifications such as scheduling schemes, increases in resources, and a possible increase in patient load.

Simulation studies of hospital systems are a concrete step towards long-term goals, such as:

(1) A comprehensive evaluation of existing facilities and resources

(2) The assessment of congestion as a function of safety, cost effectiveness, and life cycle utilization

(3) Forecasting changes in resources and demand

REFERENCES

(1) Bailey, N. T. J., "A Study of Queues and Appointment Systems in Hospital Outpatient Departments with Special Reference to Waiting Time," J. Roy. Stat. Soc. (Ser. B) 14:185, 1952.

(2) Bailey, N. T. J. and J. D. Welch, "Appointment Systems in Hospital Outpatient Departments," Lancet 262:1105, 1952.

(3) Gupta, I. J., J. Zoreda and N. Kramer, "Hospital Manpower Planning by Use of Queueing Theory," Health Services Research, Vol. 6, No. 1 76-82, 1976.

(4) Swartzman, G., "The Patient Arrival Process in Hospitals: Statistical Analysis," Health Services Research, Vol. 4, No. 5, 320-329, 1970.

(5) Johnson, G. M. and W. W. Happ, "Modular Models for Network Simulation of Hospital Components," Proceedings, Tenth Annual Asilomar Conference on Circuits, Systems, and Computers, Pacific Grove, California, Nov. 22-24, 1976.

(6) Johnson, G. M. and W. W. Happ, "Modeling and Simulation for Reducing Congestion in a Hospital Radiology Facility," Proceedings, Tenth Annual Asilomar Conference on Circuits, Systems, and Computers, Pacific Grove, California, Nov. 22-24, 1976.

(7) Kho, J. W. and G. M. Johnson, "Computer Simulation of a Hospital Health Care Delivery System," Proceedings, 1976 Bicentennial Winter Simulation Conference, December 1976.

(8) Johnson, G. M. and Winter, J. A., "Modular Modeling for Planning Hospital Emergency Facilities," Simuletter (to appear 1977).

(9) Johnson, G. M. and W. W. Happ, "Modular Modeling for Simulation of Health Facilities," Proceedings, Winter Simulation Conference, Sacramento, December 1975.

(10) H. A. Porte, W. W. Happ, C. T. Lee and L. P. McNamee, "A Stochastic Network to Model Air Cargo Terminal," Proceedings, Army Science Conference, West Point, June 1972.

(11) Happ, W. W., "Topological Models of Industrial Processes and Their Digital Simulation," Proceedings, IEEE International Convention, New York, March 1973.

(12) Dabaghian, L. and W. W. Happ, "Computer-Oriented Models as a Conceptual Tool in Applied Sociology," Proceedings, Collective Phenomena and the Application of Physics to Other Fields of Science, Moscow, USSR, July 1974.

(13) Happ, W. W. and L. Dabaghian, "Decision Flow Models to Enhance Communication for Industrial Manager or Administrator," Proceedings, Collective Phenomena and the Application of Physics to Other Fields of Science, Moscow, USSR, July 1974.

(14) Happ, W. W., "Modular Networks: A Modeling and Simulation Technique for Construction Management," Proceedings, II Congreso Interamericano de Sistemas e Informatica, Ciudad de Mexico, November 1974.