MODULAR MODELING FOR SIMULATION OF HEALTH FACILITIES

G. Miles Johnson
California State Department of Health
Sacramento, California 95814

and

William W. Happ
California State University
Sacramento, California 95819

ABSTRACT:

Modular building blocks are used to represent frequently recurring operations in health facilities. These modules permit the health analyst to describe a system under study concisely at an adequate level of detail. Representative health facility problems are modeled:

a. Parametric study of patient flow in an Air Force radiology facility.

b. Emergency admission procedures.

c. Waiting lines for nursing home attendance.

Results of simulation runs are interpreted and examined in terms of effectiveness of modeling procedures. Modeling procedures are presented.

PLANNING NEEDS FOR HOSPITAL FACILITIES

Where is Planning Deficiency?

The effective utilization of hospital facilities is often limited by congestion in a few critical areas. Congestion of patient and material flows particular hamper the interfacing of the different treatment modes which converge within the hospital. Remedial efforts in redesigning health facilities and updating operations for treatment, service and material handling routes frequently fail with increased patient flux. Primarily because of improved patient treatment modes, many hospitals now face a staggering task of updating their facilities to accommodate new equipment and material flow.

To maintain adequate patient care, hospital management and planning personnel must continually evaluate equipment, functional relationships between departments, and patient and physician flow. There is ample evidence that failure to promptly identify potential congestion hazards in building design commonly impel building users to change facilities to suit their needs, diverting rooms from their intended use or avoiding areas that have no relevance to their activities. All too often, shortcomings in traffic flow through examination facilities are met by procuring more facilities and more equipment. Until the concurrent correction of design deficiencies is provided, this is frequently a remedial solution. Support facilities, traffic patterns, and patient management policies are factors susceptible to operational analysis and deserve to be considered to provide efficient utilization of equipment and facilities. Reliable user-oriented modeling techniques, which permit timely evaluation of decision options available to hospital planning personnel, are at present lacking.

How Can Congestion be Detected and Examined?

Patient flow parameters depend upon facility layout construction and on available equipment such as x-ray, emergency stations, storage areas, and material conveyors. Whenever hospital design proves 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 and utilization could have been detected before they occurred, thus alleviating the need for costly remedial action afterwards. Obsolescence and congestion present an ever-present threat to any hospital facility. Its layout, location of equipment and services require constant vigilance by hospital management of procedures and factors affecting the utilization of physical facilities. This necessitates efficient planning techniques preceded by effective data collection and analysis.

How is the Gap Between Management and the Systems Analyst Bridged?

Modular modeling and simulation techniques to facilitate data analysis and projection of needs prior to or concurrent with systems planning, have been developed, which:

- Serve the planner and operations manager and presupposes no programming background,
- Can help pinpoint design-induced bottlenecks, often from the arthitect's sketches, before construction begins.
- Provides a step-by-step description of patient/personnel decision flow.
- Allow consecutive updating in the event that modernization or expansion programs become necessary.
- Allow construction strategies to be quantitatively examined by simulated parameter variation and, therefore,
- Reduce costly mistakes in planning prior to implementation.

The modules to be discussed serve as a common communication tool which facilitates a productive interdisciplinary team approach among hospital administrators and their technical staff. This is important since an increasing degree of abstraction exists when modeling organizational and patient processing problems.

MODULAR NETWORK TERMINOLOGY

Currently Available Modeling Systems

Widely used modeling systems are denoted by such acronyms as:

GPSS - General Purpose Simulation System

GASP - General All-Purpose Simulation Programming

PERT - Program Evaluation and Review Technique

CPS - Critical Path Method

GERTS - an acronym for Graphical Evaluation and Review Techniques for Simulation.

Some useful terms commonly used in GERTS are:

- GERTS network - graphical network representing each activity in the project as a branch and each event as a node.
- Branch - an activity relating to two successive events or nodes.
- Nodes - decision-making elements denoting events functionally related by branches.
- Realization - occurrence of the event represented by a node.
- Release - realization of an event, exactly once, as an entity transverses an activity branch to enter a node.
- Scheduling an activity - initiating an activity along a branch which departs from a node upon its realization.

In addition, this investigation will employ the following terminology:

- Project - a one-time chain of events resulting in the successive realization of an interrelated set of activities and events.
- Module - a subsystem consisting of several nodes and branches to simulate a frequently recurring entity-handling operation.
- Queue - represents a holding action or temporary storage in a waiting line.

- Stochastic - a random phenomenon with predictable long-run regularities such as mean value and standard deviation.
- Entity flow network - a graphical presentation of interconnected elements within the decision structure describing the flow of entities: decisions, information and commodities.

Nodes as Decision Making Elements

Nodes provide decisions with properties summarized in Tables 1-3 using the following terminology.

- Realization of a deterministic node causes all output activities emanating from the node to be scheduled.
- Realization of a probabilistic node causes only one randomly selected output branch to be scheduled.
- The number of releases needed to realize a node of either of the above types is a user-prescribed parameter.
- Nodes, user-specified as statistical nodes, count events at strategically selected points in the network compiling statistical summaries on the time for realization.
- The Q node provides a storage or waiting capability for activities which are in progress and replaces the requirement of a prescribed number of releases in order to schedule an output activity.
- The term item represents an entity, a transaction, or an information bit which arrives at a node to permit a service activity.

Branches Representing Activities

When branches are initiated, the time for completion obeys a prescribed time distribution which include: constant, uniform, erlang, lognormal, poisson, beta, gamma, and beta fitted to three parameters as in PERT.

Only one randomly selected output branch of a probabilistic node is scheduled whenever it is realized. Thus a complete execution of the network may not include all activities in the network. This feature, unique to the GERTS technique, permits modeling probabilistic processes by direct insertion of alternatives into the network structure. Each time an activity or branch is realized, associated characteristics such as total time incurred by execution of the complete network are then included.

Network Modification

The GERTS III Q program permits simulation of complex queuing networks utilizing several unique features:

- Network modification, structural alterations made while the simulation is actually in progress.
- Activity numbers are placed on particular branches to identify activities whose completion will trigger switching actions, which restructure the network. Subsequent activity realizations may, upon the user's option, be utilized to revert to the original structure.
- Removal, cancellation of all in-progress activities already scheduled into a node immediately upon its release, may be requested by the user during problem input.

The Modular Library for Systems Planning

The library of modules provide a further step intended to facilitate modeling with accuracy and versatility. Modules now in use have been tested and are compatible not only internally, but with all primitives utilized in GERTS III Q.

Table 4A lists the criteria to consider:

- the relationship between the number of entities incident to a module and the number of entities emitted from the module over a significant time interval;
- the priority of flow of incident or emitted entities, for example, patient traffic control; or the character of emergency patient "processing."
- Other relevant factors such as delay.

These modules consist of four categories identified by input/output relationships (Table 4B).

- Proliferative Modules - emits a greater number of entities than the number of incoming impulses; function as sources of entities or as multipliers of the entity flow.
- Consolidative Modules - emit fewer entities than entered, thereby consolidating the entity flow.
- Flow-through Modules - entity flow is emitted altered only by delay or storage.
- Channeled Modules - pulses are selected and distributed with priority constraints.

Modular models have significant advantages over other techniques:

- they represent a standard and convenient translation from concept to model
- they constitute a user-oriented technique which replaces intuitive approaches of formulating models
- they are easier to formulate than GERTS networks which consist of interlinked deterministic and probabilistic summing and sampling nodes
- they constitute a step upward within a hierarchy of flow modeling concepts
- they closely resemble operations as they are perceived by the analyst
- they allow an intimate correspondence between the modular network and the entity flow network of the project
- they reduce the modeling procedure to a succession of "translations" from conceptualization through final computer print-out.

Simulation Using Modular Components

Modular models permit assembly procedures which draw from a library of standard network modules. For example, for a modular representation of the hospital facility, architects' sketches often provide adequate data. Modular modeling facilities experimentation with facilities modifications by the hospital planning team.

Simulation modules, in common with other modeling techniques, have these advantages:

- they presuppose no programming background
- they provide an adaptive approach to systems analysis
- they serve to evaluate the impact of alternative system configurations
- they permit comparison of strategies for resource allocation
- they provide visual display of system interrelations
- they allow ready interjection of personal system knowledge
- they assure proper recognition of levels of detail
- they are adaptable appropriately to the intended utilization, and
- they are capable of consecutive updating.

Exploring alternative configurations provides insight into hospital operations to help identify "bottlenecks" and forecast critical parameters without disturbing the physical system.

Modeling Procedure

Four sequential steps identify:

- a concept definition in words only describing the process,
- entity flow network depicts the entity flows through the network,
- the modular network is a translation of the entity flow network with the aid of the library of modules and
- the nodal network represents the modular network in which each module is replaced by its GERTS micro network.

In a typical case of a hospital, the planning committee would generate the concept definitions and, with the aid of the systems analyst, the entity flow network. The modular network is obtained by replacing concepts by modular networks from the library. An alternative view of this step is a comparison with a "dictionary" for translating concepts into network modules.

The following examples provide a detailed procedure for implementing this approach.

CASE STUDY: SIMULATION OF AN X-RAY FACILITY

Need for Simulation Study

Management of a recently completed Air Force hospital located near Sacramento, California, recognized design deficiencies impairing the efficiency of its x-ray department. Obvious problems included inefficient facilities for examination and film processing and an excessive main waiting room. To identify subtler problems and to examine alternatives, the x-ray department was modeled using modular networks. Repeated simulations based on strategies of parameter changes blocked out performance envelopes over a range of configurations.

Facility Structure and Patient Flow

The department provides adjunct diagnostic and therapeutic radiology services as required for medical examinations and radiologic treatment procedures. Examinations encompass "routine" procedures as well as special diagnostic procedures such as: intravenous pyelograms, upper G.I.'s or gall bladder diagnosis which requires that the patient fast or that he be injected with radio-opaque dyes.

The entity flow network (Figure 1) identifies eight sources of patient flow through the x-ray department:

emergency unit	orthopedics
dermatology	surgery
medicine	aerospace medicine
pediatrics	psychiatry

An entering patient checks into the x-ray facility with the clerk who validates the appointment. If the patient's record is in order, he receives a number, is routed to the main waiting room, and is assigned to one of three categories:

- Scheduled routine - This patient requires no pre-examination treatment, such as injections of radio-opaque dye. Typically the patient needs x-rays for broken bones and is routinely seen on afternoons only.
- Scheduled special procedure - This patient requires special preparation for the x-ray examination such as fasting prior to appointment or ingestion and injection with contrast media. Special procedures require a "scout" x-ray which confirms that the patient has been properly prepared and which must be proof-read by the radiologist prior to this procedure. Examples include intravenous pyelogram, barium enema, and upper G.I. tract examinations. Special procedures are scheduled during morning hours.
- Non-scheduled emergency - The emergency patient always has priority by preempting any routine and special procedure patient.

Examination Facilities and Patient Flow

Examination facilities - There are three examination rooms, one room for routine examination and two rooms for special procedures. Emergency cases, however, are immediately routed to any available room.

X-ray facilities - The patient is required to wait while the x-rays are developed and "proof-read" by technicians. If there are technical errors, the x-ray is repeated. Occasionally the dark room becomes inoperable, as when waste water from the film processors overloads inadequately planned plumbing, and usually occurs when patient flow is high. Also, x-ray films may become trapped in the tunnel transporting them into the dark room from the three examination rooms.

Work flow in x-ray processing requires:

X-Ray Operations

- Receive patients from wards, emergency room and out-patient medical clinic.
- Make x-ray, examine by diagnostic procedures.
- Process x-ray film.
- Technician proof-reads film to identify technical errors.
- Radiologist examines the film to determine extent and internal pathology or injury.

Operational Parameters

Time parameters are described in Table 6.

- Number of examination rooms.
- Number of x-ray technicians.
- Number of radiologists to examine x-rays.
- Time to process x-ray film.
- Time to proof-read x-ray film.
- Time for radiologist to critique films.
- Number of emergency radiology units.
- Number of special radiology procedures.

Constructing the Modular Network

The modular network in Figure 2 is obtained by substituting modules from the library of modules for the conceptual description of the entity flow network. A subsequent second translation replaces each modular network with a micro-network composed of GERTS nodes. Modules in the network are assigned parametric specifications such as time durations for different activities, such as probabilities and arrival rates.

Repeated program execution consists of Simulation and permits:

- Collection of statistic at key points in the system to provide timely and pertinent information.
- Evaluation of critical parameters, such as queuing lengths or typical processing times or average busy time for each work station.
- Identification of bottlenecks and slack areas.
- Forecast of performance under modified conditions, such as the addition of more technicians or of more x-ray rooms.

Interpretation of Simulation Runs

To validate the model several simulations were run for each month. Table 5 shows patient flow into the x-ray facility for April, May and June, which are representative of monthly patient flow fluctuations. After the model was validated, tentative parameter adjustments were made to anticipate and ameliorate design induced bottlenecks. Parameter experimentation consisted of:

- holding the number of exam rooms constant and varying the patient load within the context of monthly fluctuations, and
- augmenting the number of examination rooms with patient fluctuations for April, May and June.

By assuming that the x-ray rooms and the number of technicians and radiologists remain the same, it was possible to determine the effects of monthly patient fluctuations on the average waiting line and the average service time. Figures 3 and 4 chart variations in the average number of patients waiting to be examined over a three month period. Figure 4 shows that the number of emergency, routine and special procedure patients awaiting examination declines substantially.

Recommendations for Improvements

A. Waiting times can be substantially reduced by increasing the number of examination rooms to four. This is especially significant for the emergency patient who requires immediate access to examination. Moreover, expansion of the examination facility will prevent a potentially serious bottleneck anticipated from projected population increase. Such increases in patient load, however, were not simulated.

B. Facility expansion within the scope of present structural characteristics is possible. The floor plan for the x-ray unit, Figure 5, provides sufficient space to expand. Two space options for construction of a new examination room are noted:

- use part of the excessively large waiting room or
- utilize the seldom used interior court adjacent to the x-ray faciltiy.

C. The addition of portable x-ray equipment was suggested but provides at best a partial solution for the correction of design deficiencies cited. Support facilities, traffic patterns, and patient management are essential to efficient utilization of equipment and should be accorded appropriate recognition as early as feasible in the planning cycle.

CONCEPTUAL STUDY: EMERGENCY ADMISSION PROCEDURES

The decision structure for emergency processing is detailed in a form suitable for modular translation.

Functions - The emergency room is the entry point for three types of patients:

emergency out-patient and psychiatric

The patient arrives at the emergency unit either (1) on his physician's orders or (2) because he needs emergency treatment.

Emergency Record - The clerk compiles available requisite information including the patient's physical condition and insurance coverage. Persons without insurance or lacking sufficient funds are routed to a social worker.

Para-Medical Screening - The patient without an apparently serious condition is seated in the waiting room. Patients with serious problems are routed to immediate treatment. Access to treatment by a low priority patient is preempted whenever a seriously ill patient enters.

Physician-Decision Flow - After a brief waiting period, the patient sees the emergency physician who establishes a diagnosis and administers treatment upon his discretion.

Discharge-Decision Flow - Patients who require no hospitalization arrange payment for services after emergency treatment in accord with business office procedures before leaving the hospital.

Modular Translation - Figure 6 describes patient flow through the emergency unit. This is translated in terms of network modules (Figure 7). Modules are then assigned parametric values such as time intervals for specific services, probability that an activity is initiated and patient arrival rates.

TUTORIAL STUDY: NURSING HOME QUEUING MODEL

This example is intended to demonstrate by a simple application how modules serve as elementary building blocks for modeling. A model must be initially simple and can be expanded later as greater detail is required. Thus the model of a nursing home is here represented only by its essential waiting line characteristics:

- Patient Arrivals
- Patient Queues
- Average time patient stays, and
- Nursing care requirements.

Assumptions about Model

A. Characteristics governing arrivals

- Random rate of arrivals governed by the poisson distribution with a mean of about two days.
- Time to admit new patients ranges uniformly from half to a full day.

B. Characteristics governing length of stay

- 30% of the patients require 30-170 days of skilled nursing care
- 50% of the patients require 10-110 days of intermediate nursing care
- 20% of the patients require 40-600 days of long term care
- Patients are admitted only as beds become available.

C. Characteristics governing flow

The entity flow network modular and nodal networks in Figures 8 and 9 describe the activity of the nursing home. The nodal network is described in Figure 10. The parameters are described in Table 8. Statistics are collected at critical points in the system by statistical sampling nodes which are described in Table 9.

REFERENCES

COMPUTER SIMULATION OF HEALTH SERVICES

1974

Johnson, G.M., Chuyen, D., Nguyen, H. "Simulating Components of Health Care Systems: A Radiological Facility." Report to NSE, Grant GY-11496, School of Engineering, California State University, Sacramento, California, November, 1974.

1973

Health Services Research Group. "Computer Application in Health Services Delivery." Federal Health Program Service. H.E.W., April, 1973.

1972

Abranovic, W. A. "Computer Simulation Approach for Planning in Hospital Ancillary Services," Socio-Econ. Plan. Sci., Vol. 5, pp. 429-448, 1972.

Manson, D.J.; Lehr, J.L.; and Lodwick, G.S. "MARS--Missouri Automated Radiology System, Computer Graphics in an Automated Department." Proceedings, Association for Computing Machinery, Special Interest Group for Graphics, Symposium on Computer Graphics in Medicine, Pittsburgh, Pennsylvania, March 1972.

Wuesthoff Memorial Hospital Comprehensive Hospital Computer Applications Program-V. 1, 2, 3 and 4, National Technical Information Service, April, 1972.

1971

Abranovic, W.A., W.A. Wallace. "A Computer Simulation Approach for Planning Hospital Ancillary Services," Socio. Econ. Plan. Sci., Vol. 5, pp. 429-448, 1971.

Lodwick, G.S. "Computer Simulation and Information Systems in Radiologic Departmental Operations (I, II, III)." EDV in Medizin und Biologie Vol. 2, Nos. 2, 3, 4. Stuttgart. Gustav Fischer and Eugen Ulmer. 1971.

1960's

Lodwick, G.S. "Simulator Program for Diagnostic Radiology Department," Dept. of Radiology University Missouri School of Med. May 1968.

Lodwick, G.S., and Convert, R.P. "A Generalized Simulation Model for a Diagnostic Radiology Department." Digest of the 7th International Conference on Medical and Biological Engineering, Stockholm, 1967.

Sauas, E. "Simulation and Cost Effectiveness Analysis of New York's Ambulance Service," Management Science, August 1969.

Thomson, John D. "Simulation of Hospital Systems." Operations Research, 13:October 19, 1965.

COMPUTER SIMULATION

1974

Akiba, Y. and Dabaghian, L. "Simulation Techniques Using Modular Networks Applied to Customer Traffic Flow." Proceedings, NorthWest 74 CIPS-ACM Pacific Regional Symposium, Vancouver, Canada, May 23-24, 1974.

Akiba, Y., Dabaghian, L. and Happ, W.W. "Network Models to Display Entity and Information Flow in Industrial Systems," submitted to Conference on Computer Graphics and Interactive Techniques, Boulder, Colo., July 1974.

Akiba, Y. "Decision and Commodity Flow for Cargo Facilities," Proceedings, 3rd Annual Greater Los Angeles Area Transportation Symposium, October 3, 1974.

Akiba, Y. "Modular Networks for Simulation: A University/Industry Summer Workshop," Proceedings, Eighth Asilmar Conference on Circuits, Systems and Computers, Monterey, Calif., December 3, 1974.

Akiba, Y., W.W. Happ. "Activity Profiles: A Validation Technique for Logic Modules in Pulse Network," Proceedings, Eighth Asilomar Conference on Circuits, Systems and Computers, Monterey, Calif., December 3, 1974.

Akiba, Y. "Modelling and Simulation for the Construction Industry," The CSUS Engineering Journal, California State University, Sacramento, Calif., 1974.

Akiba, Y., Blom, N., Duran, G., Dabaghian, L. "GERTS GQ Simulator for Systems Simulation," Report to NSF, Grant GY-11496, School of Engineering, California State University, Sacramento, Calif., November, 1974.

Dabaghian, L., Akiba, Y., and Happ, W.W. "User-Oriented Modular Components for Network Modelling of Industrial Systems," Proceedings, 1974 IEEE International Symposium on Circuit and Systems Theory, San Francisco, Calif., April 1974.

Dabaghian, L. and Happ, W.W. "Simulation Techniques Using Modular Networks Applied to Cargo Facility Design," Proceedings, NorthWest 74 CIPS-ACM Pacific Regional Symposium, Vancouver, Canada, May 23-24, 1974.

Dabaghian, L., Akiba, Y., and Happ, W.W. "Network Modules to Simulate Quantized Entity Flow," Proceedings, Joint Automatic Control Conf., Austin, Texas, June 19, 1974.

Dabaghian, L., Melnicoe, W.B., and Dabaghian, J. "Decision Flow Structure to Simulate Alternatives for Resource Allocation in Crime Control Systems," Proceedings, 1974 Carnahan and Inter-Crime Countermeasures Conference, Lexington, Ky., April 1974.

Happ, W.W. and Akiba, Y. "Simulation Techniques Using Modular Network Applied to Construction Equipment Allocation," Proceedings, NorthWest 74 CIPS-ACM Pacific Regional Symposium, Vancouver, Canada, May 23-24, 1974.

Melnicoe, W.B., Dabaghian, J., Dabaghian, L. "Decision Flow Structures to Model Alternatives in Resource Allocation," Proceedings, 1974 Carnahan and International Crime Countermeasures Conference, Lexington, Ky., April 1974.

1973

Akiba, Y., Dabaghian, L. and Happ, W.W. "Validation of Component and System Performance in Modular Queueing Networks," Proceedings, Seventh Asilomar Conference on Circuits, Systems, and Computers, Monterey, Calif., November 1973.

Dabaghian, L., Akiba, Y. and Happ, W.W. "Simulation and Modelling Techniques for "Q" Networks," Proceedings, Seventh Asilomar Conference on Circuits, Systems, and Computers, Monterey, Calif., November 1973.

Fishman, G.S. "Concepts and Methods in Discrete Event Digital Simulation." New York: John Wiley and Sons, Inc., 1973.

Golden, D.G., and J.D. Schoeffler. "GSL-A Combined Continuous and Discrete Simulation Language," SIMULATION, Vol. 20, January 1973, pp. 1-8.

Golden, D.G., and J.D. Schoeffler. "Implementation Problems of a Combined Continuous-Discrete Simulation Language," SIMULATION, Vol. 20, February 1973, pp. 49-52.

Halpin, D.W. "An Investigation of the Use of Simulation Networks for Modelling Construction Operations," PhD Dissertation, Graduate College of the University of Illinois, Urbana-Champaign, 1973.

Halpin, D.W. and Woodhead, R.W. CONSTRUCTO - A Heuristic Game for Construction Management, University of Illinois Press, Urbana, Illinois, March 1973.

Hurst, N.R. "GASP IV: A Combined Continuous/Discrete FORTRAN based Simulation Language," unpublished Ph.D. Thesis, Purdue University, Indiana, 1973.

Hurst, N.R., and A.A.B. Pritsker. "Simulation of a Chemical Reaction Process Using GASP IV," SIMULATION, Vol. 21, September 1973, pp. 71-75

1972

Ashour, S., and S.D. Vaswani. "A GASP Simulation Study of Job-School Scheduling," SIMULATION, Vol. 19, January 1972, pp. 1-10.

Clayton, E.R., and L.J. Moore. "GERT vs. PERT," J. Syst. Management, Vol. 23, February 1972, pp. 18-19.

Golden, D.G. "A Generalized Language for Discrete/Continuous Simulation," unpublished Ph.D. Thesis, Case Western Reserve University, Ohio, January, 1972.

Halpin, D.W. and Happ, W.W. "Network Simulation of Construction Operations," Proceedings, Third International Congress on Project Planning by Network Techniques, pp. 222-232, Stockholm, March 1972.

Halpin, D.W. and Woodhead, R.W. "A Network-Based Methodology for the Management Modelling of Complex Projects," Proceedings, Third International Congress on Project Planning by Network Techniques, Stockholm, May 1972.

Ignall, E.J. "On Experimental Designs for Computer Simulation Experiments," Manage. Sci., Vol. 18, March 1972, pp. 384-389.

Guetzkow, H., P. Kotler, and R.L. Schultz. "Simulation in Social and Administrative Science," Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1972.

Kay, Ira M. "An Over-the-Shoulder Look at Discrete Simulation Languages," AFIPS Conference Proceedings 40, Spring 1972, pp. 791-798.

Kiviat, P.J. "System Simulation," International Symposium on System Engineering, Vol. 1, Purdue University, Indiana, October 23-27, 1972, pp. 85-90.

1971

Enlow, R.A. "An Application of GERT Network Techniques to the Selection and Management of Research and Development Projects," Proceedings, AIIE Conference, Boston, Mass., May 1971.

Fishman, G.S. "Estimating Sample Size in Computer Simulation Experiments," Manage. Sci., Vol. 18, September 1971, pp. 21-38.

Halpin, D.W., and W.W. Happ. "Digital Simulation of Equipment Allocation for Corps of Engineer Construction Planning," U.S. Army, CERL, Champaign, Ill., 1971.

Hixson, H.G. "CLASS Composite Language Approach for System Simulation (A Tutorial)," Fifth Conference on Applications of Simulation, December 8-10, 1971, pp. 94-109.

Hogg, G.L. "An Analysis of Labor Limited Queueing Systems with a GERTS Simulation," PhD Dissertation, Graduate School, University of Texas, Austin, December 1971.

IBM Corporation. "Continuous System Simulation for the Management Scientist," Form GE20-0349-0, White Plains, N.Y., 1971.

1970

CONTROL DATA MIMIC--A Digital Simulation Language Reference Manual, Publication No. 44610400, Revision D, Control Data Corporation, Minneapolis, Minn., 1970.

Fahrland, D.A. "Combined Discrete Event/Continuous Systems Simulation," SIMULATION, Vol. 14, February 1970, pp. 61-72.

Hunter, J.S., and T.H. Naylor. "Experimental Design for Computer Simulation Experiments," Manage. Sci., Vol. 16, March 1970, pp. 422-435.

IBM Corporation. "Introduction to 1130 Systems Modeling Program II (CSMP II), GH20-0848-1, White Plains, N.Y., 1970.

Pritsker, A.A.B. and Burgess, R.R. The GERT Simulation Programs: GERTS III, GERTS III Q, GERTS III C, and GERTS III R. NASA/ERC Contract NAS-12-2113, Departmental Report, Virginia Polytechnic Institute, Dept. of Industrial Engineering, 1970.

Randall, R. "Computer Networks," in Courant Computer Science Symposium 3, Prentice-Hall, Inc., Englewood Cliffs, New Jersey, December 1970.

Whitehouse, G.E. and Klein, K.T. "Application of the GERTS II Simulator in the Industrial Environment," Proceedings, Fourth Conference on Applications of Simulation, pp. 170-177, 1970.

1969

Chu, Y. Digital Simulation of Continuous Systems, New York: McGraw-Hill Book Company, 1969.

Clymer, A.B. "The Modeling of Hierarchical Systems," Conference on Applications of Continuous System Simulation Languages, June 30th and July 1st, 1969, pp. 1-16.

Gordon, G. System Simulation, Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1969.

Hixson, H.G. "Equipment Maintenance Studies Using a Combination of Discrete Event and Continuous System Simulation," Third Conference on Applications of Simulation, December 5-7, 1969, pp. 209-219.

IBM Corporation. "General Purpose Simulation System/360 OS and DOS Version 2 User's Manual," SH20-0694-0, White Plains, N.Y., 1969.

Kiviat, P.J., R. Villanueva, and H. Markowitz. The SIMSCRIPT II Programming Language, Englewood Cliffs, N.J.: Prentice-Hall, 1969.

Kiviat, P.J. Digital Computer Simulation: Computer Programming Languages, The Rand Corporation, RM-5883-PR, Santa Monica, Calif., 1969.

1968

Buxton, J.N. Simulation Programming Languages, Amsterdam: North-Holland Publishing Company, 1968.

Fahrland, D.A. "Combined Discrete Event/Continuous Systems Simulation," SRC-68-16, Systems Research Center, Case Western Reserve University, Ohio, July 1968.

1967

Evans, G.W., H.G.F. Wallace, and G.L. Sutherland, "Simulation Using Digital Computers," Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1967.

Fishman, G.S. "Problems in the Statistical Analysis of Simulation Experiments: The Comparison of Means and the Length of Sample Records," Comm. ACM, Vol. 10, February 1967, pp. 91-99.

Fishman, G.S., and P.J. Kiviat. "The Analysis of Simulation-Generated Time Series," Manage. Sci., Vol. 13, March 1967, pp. 525-557.

Kiviat, P.J. "Digital Event Simulation: Modeling Concepts," The Rand Corporation, RM-5378-PR, Santa Monica, Calif., 1967.

Kiviat, P.J. "Development of Discrete Digital Simulation Languages," SIMULATION, Vol. 8, February 1967, pp. 65-70.

Krasnow, H.S. "Computer Languages for System Simulation," in Digital Computer User's Handbook, Melvin Klerer and Granino A. Korn, Eds., New York: McGraw-Hill Book Company, 1967, pp. 258-277.

Parente, R.J., and H.S. Krasnow. "A Language for Modeling and Simulating Dynamic Systems," Comm. ACM, X, No. 9, September 1967, pp. 559-567.

1966

Teichroew, Daniel, and John Francis Lubin. "Computer Simulation: Discussion of the Technique and Comparison of Languages," Comm. ACM, IX, No. 10, October 1966, pp. 723-741.

Tocher, K.D. "Some Techniques of Model Building," Proceedings of the IBM Scientific Computing Symposium: Simulation Models and Gaming, IBM Corp., Data Processing Division, White Plains, N.Y., 1966, pp. 117-155.

Davis, E.W. "Resource Allocation in Project Networks Models--A Survey," J.Ind.Eng., Vol. XVII, April 1966, pp. 177-188.

HOSPITAL OPERATIONS RESEARCH

1975

Ahuja, H. and R. Sheppard. "Computerized Nurse Scheduling," Industrial Engineering, Vol. 7, No. 10, Oct. 1975.

Bunch, J.J. "The Design, Application and Evaluation of the Management of Productivity in Hospital Pathology and Clinic Laboratories." Proceedings, Systems Engineering Conference, Las Vegas, Nevada, November 19-21, 1975.

Pike, R.W. and Durby, R.D. "Diagnostic Radiology Replacement Model." Proceedings, Systems Engineering Conference, Las Vegas, Nevada, November 19-21, 1975.

Presby, L. "Materials Handling." Proceedings, Systems Engineering Conference, Las Vegas, Nevada, November 19-21, 1975.

Sanuzano, P.J. "Health Services Research and Development." J. Med. Education, 45, 725-730, 1975.

Taylor, W.R. "System Engineering in Small Hospitals." Proceedings, Systems Engineering Conference, Las Vegas, Nevada, November 19-21, 1975.

Jessiman, A.G., M.D., and Erat, K. "Automated Appointment System to Facilitate Medical Care Management," Medical Care 8 (1970): 234-246.

1974

Collem, M.F.(Ed.). "Hospital Computer Systems," John Wiley and Sons, New York, 1974.

Ferman, M. (Ed.). "The Economics of Health Medical Care," John Wiley and Sons, Inc., New York, 1974.

1973

Garrett, R.D. "Hospitals: A Systems Approach," Auerbach Publishers, Inc., Philadelphia, Pa., 1973.

Jelinek, R.C. "Tell the Computer How Sick the Patients Are and It Will Tell How Many Nurses They Need," Modern Hospital, December 1973.

1972

Abernathy, W.J., and Hershey, J.D. "A Spatial-Allocation Model for Regional Health Services Planning," Operations Research, 2, 3, May-June 1972.

Jelinek, R.C.; Zinn, T.K.; Delon, G.L.; and Aleman, R.A. "A Nurse Scheduling and Allocation System in Operation," The Medicus Corp., Chicago, 1972.

Newheiser, J.R. and Schoeman, M.E.F. "A Stochastic Model for Health Care Resource Planning," Socio.-Econ. Plan. Sci., Vol. 6, pp. 197-213 (1972).

Simborg, D. "Impact of Computerized Information Systems on Hospital Nurse Staffing." Proceedings of the Invitational Conference on Research on Nurse Staffing in Hospitals, 1972. Washington, D.C., Division of Nursing, Bureau of Health Manpower Education, National Institute of Health, 1972.

Stimson, R.H., Stimson, D.H. "Operations Research and the Nursing Staffing Problem." Hosp. Admin., pp. 61-69, Winter 1972.

Turk, C.W. "An On-Line Assignment System," IBM Corporation, San Francisco, California, 1972.

1970

Carr, W.J. "Economic Efficiency in the Allocation of Hospital Resources: Central Planning vs. Evolutionary Development," in Empirical Studies in Health Economics. Edited by H.E. Karlman. Baltimore: The Johns Hopkins Press, pp. 195-221, 1970.

Gorry, G.A. "Modeling the Diagnostic Process." J. Med. Educ., 45, 293-302, 1970.

Hubbard, R.M. "Hospital Food Service Adapts to Systems Approach." Hospitals, 44:87-92, April, 1970.

Kamp. W. "Operations Research and the Management of Mental Health Systems." Amer. Diversified Research Corp. Sept. 4, 1970.

Saren, M. "Nursing Service Effectiveness." Hospitals, 44:Jan. 1970.

Zemuch, R. "A Model of Health Service Modification and Resource Allocation." Operations Res., 18, 1071-1086, 1970.

1969

Bellin, S.F., Geiger, H.J., and Gibson, C.D. "Impact of Ambulatory Health Care Services on the Demand for Hospital Beds." N. Engl. J. Med., 280, 808-812, 1969.

Cronkhite, Leonard W., Jr., M.D. "Computer Brings Order to Clinic Scheduling System." Hospitals, J.A.H.A., 43 (1969): 55-57.

Gue, R.L. "Introduction to Systems and Approach in Dietary Department." Hospitals, 43:100-1, Sept. 1, 1969.

Hoffman, Paul B., and Grossman, Jerome H., et. al. "Automated Patient Census Operation: Design, Development, Evaluation." Hospital Topics 47 (1969): 39-41.

Konnensmen, P.M. "Forecasting Production Demand in the Dietary Department." Hospitals, 43:85-6, Sept. 16, 1969.

Moon, J.E. "Computerized Pharmacy System Solves Hospital Drug Inventory Problems." Mod. Hosp. 113:118-24, Nov. 1969.

Morril, R. and Kelly, P.H. "Optimum Allocation of Services: A Hospital Example." Annals of Regional Science, June 1969.

Navarro, V. "A Systems Approach to Health Planning." Health Services Res. 4, 96-111, 1969.

Needles, B., Jr. "Single Information Flow System for Hospital Data Processing." Management Services, Sept.-Oct., 1969.

Rockart, J.F., et al. "A Symptom-Scoring Technique for Scheduling Patients in a Group Practice." Proc. IEEE 57 (1969): 1926-1933.

Rockart, J.F., and Hoffman, P.B. "Physician and Patient Behavior Under Different Scheduling Systems in a Hospital Outpatient Department." Medical Care 7 (1969): 463-470.

Williams, G.N. "Work Measurement: How Many on the Job? How Long? How?" Modern Hosp. 113: 117-20, Sept. 1969.

Spitzer, M. "The Computer Art of Schedule Making." Datamation, April 1969.

1968

Hechinger, S. "Computerized Scheduling Helps Control Maintenance Work." Modern Hospital, 110: May, 1968.

Jelinek. R.C. "Operational Analysis of the Patient Care Function." Inquiry, 6:53-8, 1968.

Jelinek, R.C. "Nurse Scheduling Control System." The Univ. of Michigan, Ann Arbor, Michigan, March, 1968.

Packer, A.H.; Shellard, G.D. "Measures of Health System Effectiveness." Operations Research, 16, 227-253, 1968.

1967

Dunn, R.G. "Scheduling Elective Admissions." Health Services Research, 2:181-215, Summer 1967.

Mainland, D. (Ed.). "Health Services Research." New York: Mibank Memorial Fund, 1967.

Wing, P. "Automated System for Scheduling Admissions." Hosp. Mgmt. 104: 536, Oct. 1967.

Villegas, E.L. "Outpatient Appointment System Saves Time for Patients and Doctors." Hospitals 41 (1967): 52.

1966

Fetter, R.B.; Thompson, J.D. "Patients Waiting Time and Doctors Idle Time in the Outpatient Setting." Health Services Research 1, 66-90, 1966.

Leighton, E. "Computer Analysis of Length of Stay." Annual Mtg. Amer. Public Health Association, 1966.

Smalley, H.E. and Freeman, J.R. Hospital Industrial Engineering. Reinhold Pub. Co., New York, 1966.

1965

Feldstein, M.S. "Hospital Cost Variations and Case Mix Differences." Med. Care 3, 95-103, 1965.

Jelinek, R. "A New Approach to Analysis of Nursing Activities." Hospitals, Oct. 1965.

Kolouch, F.T. "Computer Shows How Patient Stay Varies." Modern Hospital, 105:130-4, Nov. 1965.

Rosenthal, G.D. "Factors Affecting the Utilization of Short-term General Hospitals." Am. J. Public Health, 55, 1734-1746, 1965.

Young, J.P.; Wolfe, H. "Staffing the Nursing Unit. Part I. Controlled Variable Staffing." Nursing Research 14 (1965): 236-243.

Young, J.P.; Wolfe, H. "Staffing the Nursing Unit. Part II. The Multiple Assignment Technique." Nursing Research 14 (1965): 299-303.

TABLE 1

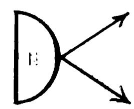
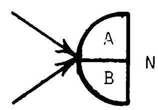
PURPOSE	SYMBOL	PARAMETERS
SOURCE NODE		N - NODE NUMBER A - NO. OF ACTIVITIES FOR INITIAL REALIZATION
SINK NODE		B - NO. OF ACTIVITIES FOR SUBSEQUENT REALIZATION

TABLE 2. EVENT NODES

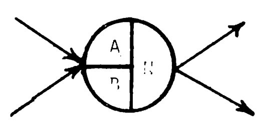
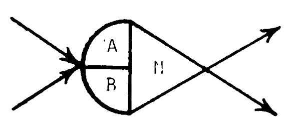
OUTPUT	SYMBOL	PARAMETERS
DETERMINISTIC		N - NODE NUMBER A - NO. OF ACTIVITIES FOR INITIAL REALIZATION
PROBABILISTIC		B - NO. OF ACTIVITIES FOR SUBSEQUENT REALIZATION

TABLE 3. QUEUE NODES

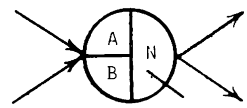
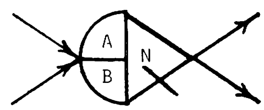
OUTPUT	PARAMETERS	PROBABILISTIC
DETERMINISTIC		N - NODE NUMBER A - INITIAL NUMBER IN QUEUE
PROBABILISTIC		B - MAXIMUM NUMBER ALLOWED IN QUEUE

TABLE 4B. NETWORK MODULES

I = Module ID Number

N = Proliferate Number

D = Diversion Destination

K, L, M = Consolidate Number

C = Maximum Capacity

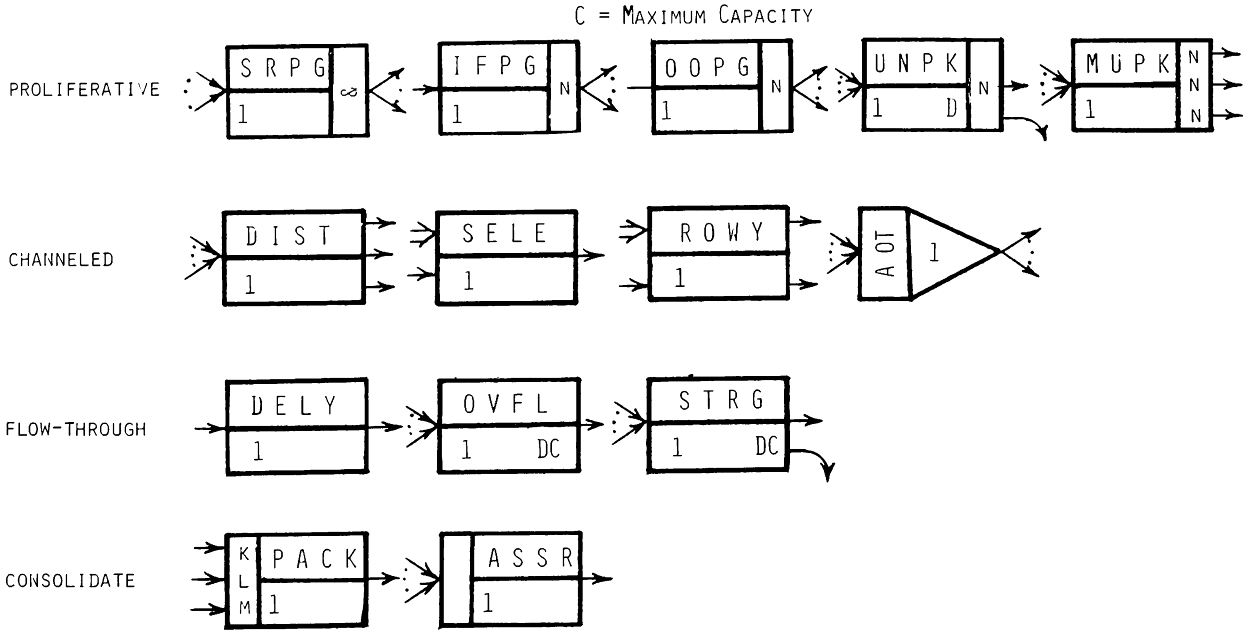


TABLE 5

PATIENTS	APRIL 1974		MAY 1974		JUNE 1974	
EMERGENCY	1038	25%	1137	37%	831	30%
REGULAR	1228	30%	1153	38%	1360	50%
SPECIAL PROCEDURE	1570	45%	775	25%	547	20%
TOTAL	4107	100%	3064	100%	2738	100%

TABLE 6

TIME PARAMETERS (MINUTES)

MINUTES	MIN.	MAX.	DISTRIBUTION	OPERATION
T_1	λ=15.		POISSON	Patient Arrivals
T_2	0.	0.	CONSTANT	Branch time between substates
T_3	2.	5.	UNIFORM	Reception
T_4	10.	20.	UNIFORM	Routine waiting time
T_5	10.	40.	UNIFORM	Special waiting time
T_6	5.	15.	UNIFORM	Time to retake film
T_7	5.	20.	UNIFORM	Time for routine or scout film
T_8	15.	40.	UNIFORM	Time for special procedure film

TABLE 8

ACTIVITY PROFILE FOR NURSING HOME MODEL

NO	MODUAL	BRANCHES (n-m)	Pnb	PARAMETER (Days)	DEFINITION
1	SRPG	3-3	1.0	1-2	Generates 100 patient arrivals
	None	4-5	1.0	.5-1	Admittance delay
2	APOT	5-9	0.3	0	Prob. of required skilled care
	——	5-11	0.5	0	Prob. of required intermediate care
	——	5-13	0.2	0	Prob. of Gen. long term care
3	DELY	9-10	1.0	30-170	Time for skilled care
4	DELY	11-12	1.0	10-110	Time for intermediate care
5	DELY	13-14	1.0	90-600	Time for Gen. long term care

TABLE 9

STATISTICS NODES		
NODE NO.	NODE TYPE	ACTIVITY
4	Q	Patients waiting for service and gates input according to patient discharge
6	Q	Patients waiting for skilled care
7	Q	Patients waiting for intermediate care
8	Q	Patients waiting for general care
10	Interval	$\bar{x}$, Sd, Min-Max time for skilled care
12	Interval	$\bar{x}$, Sd, Min-Max time for intermediate care
14	Interval	$\bar{x}$, Sd, Min-Max time for general care
15	Sampling	$\bar{x}$, Sd, Min-Max time between patient release
16	Sink	$\bar{x}$, Sd, Min-Max time to process 100 patients and terminates program.

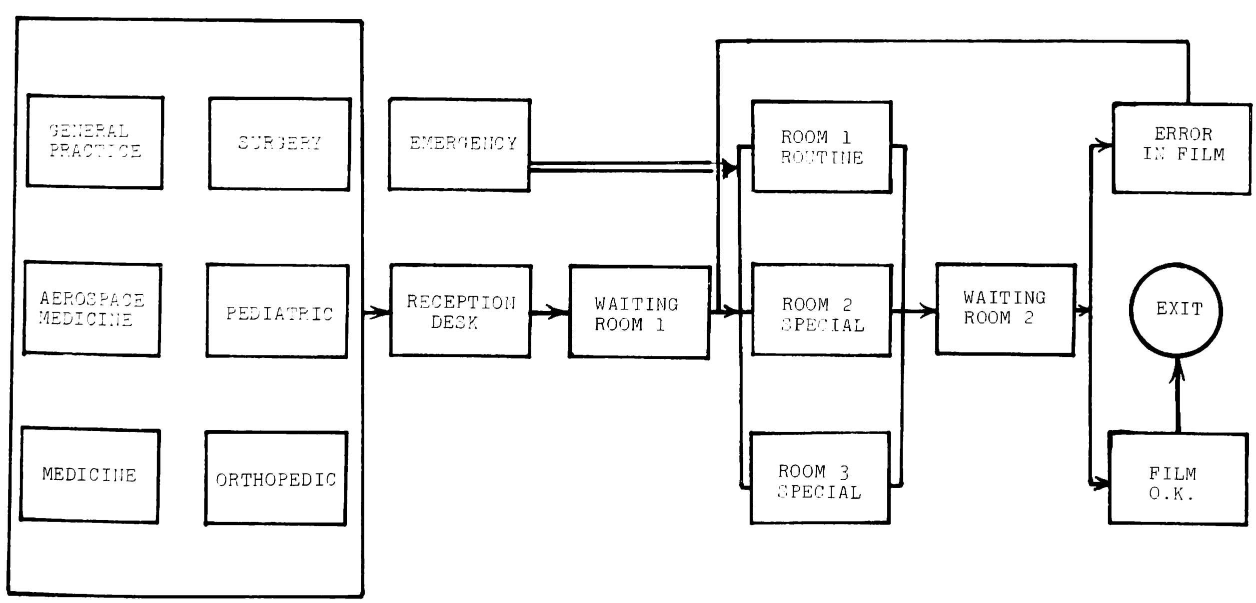


FIGURE 1 - X-RAY ENTITY FLOW NETWORK

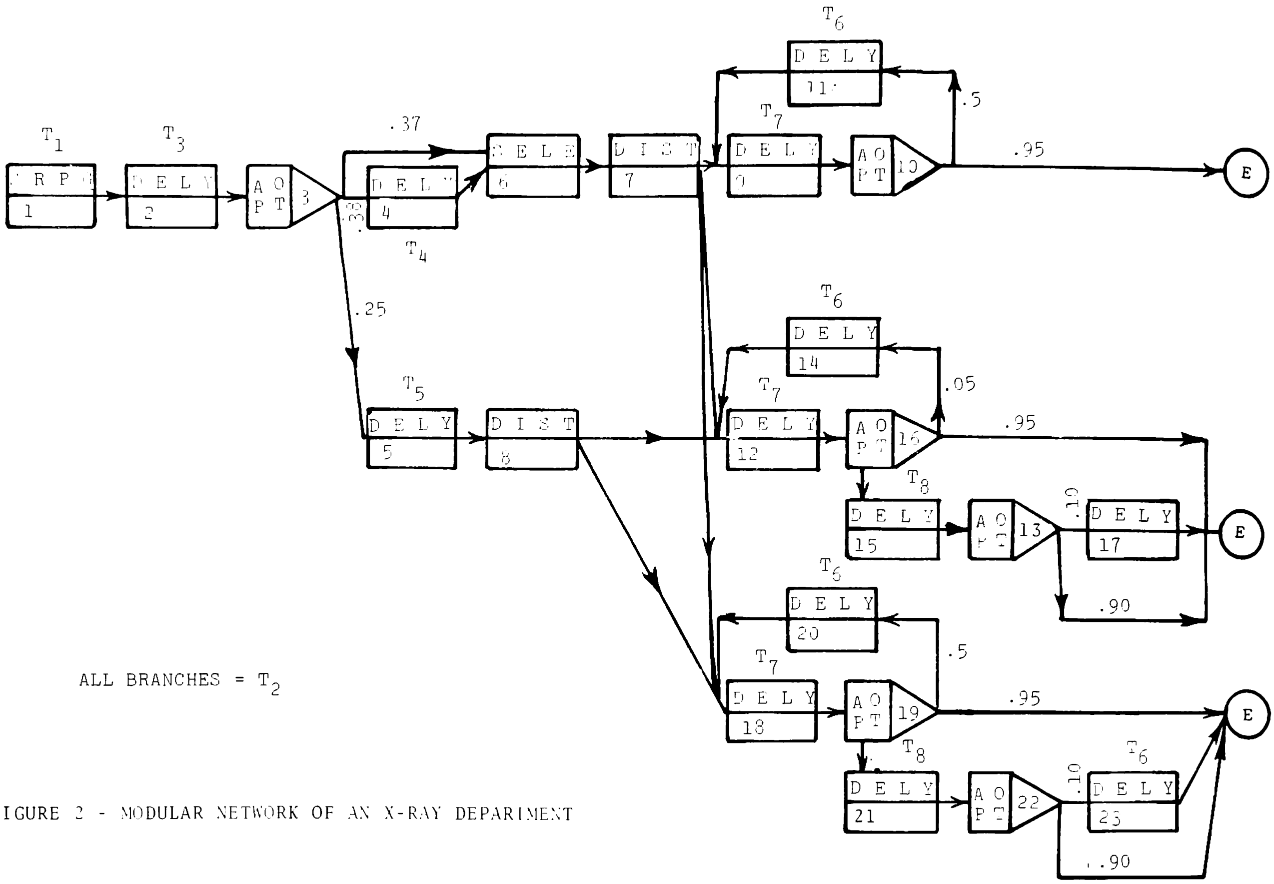


FIGURE 2 - MODULAR NETWORK OF AN X-RAY DEPARTMENT

FIGURE 3 - THREE EXAMINATION ROOMS

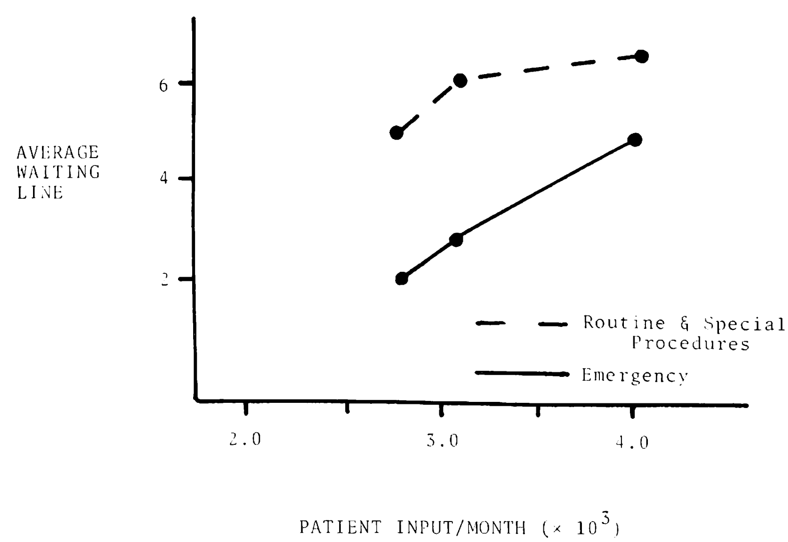
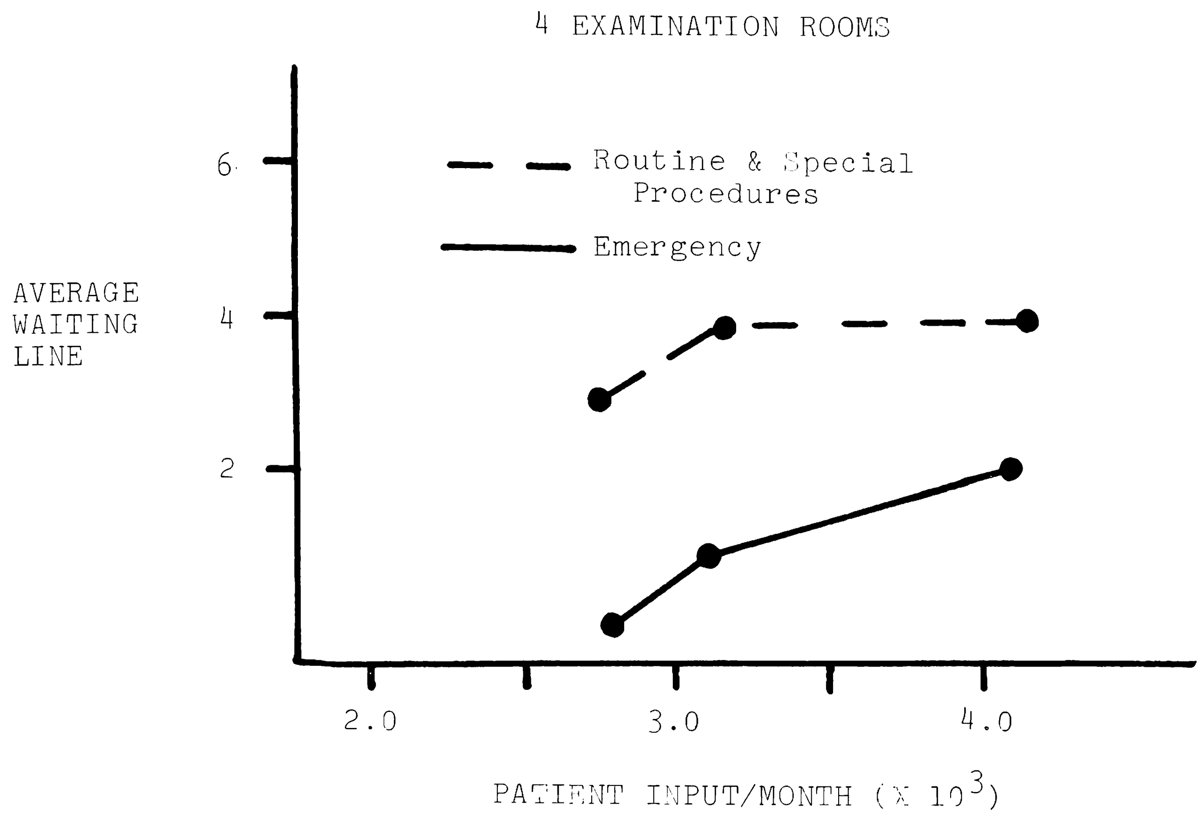


FIGURE 4



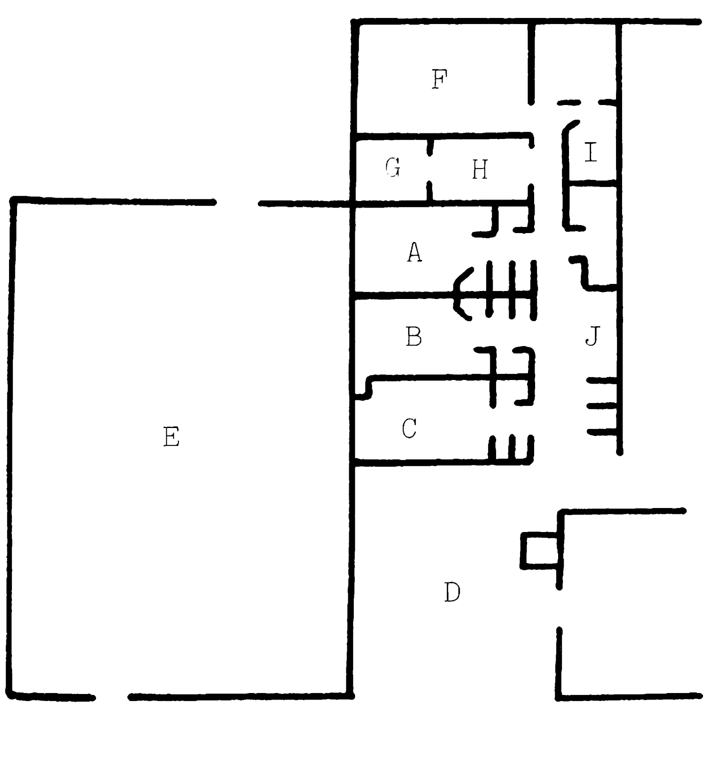


FIGURE 5

L E G E N D

A. Radiographic-Flouroscopic
B. Radiographic-Diagnostic
C. Radiographic-Diagnostic
D. Main Waiting Room
E. Interior Court
F. Film Files
G. Dark Room
H. Work Area - Wee View
I. Radiologist Office
J. Patient Holding

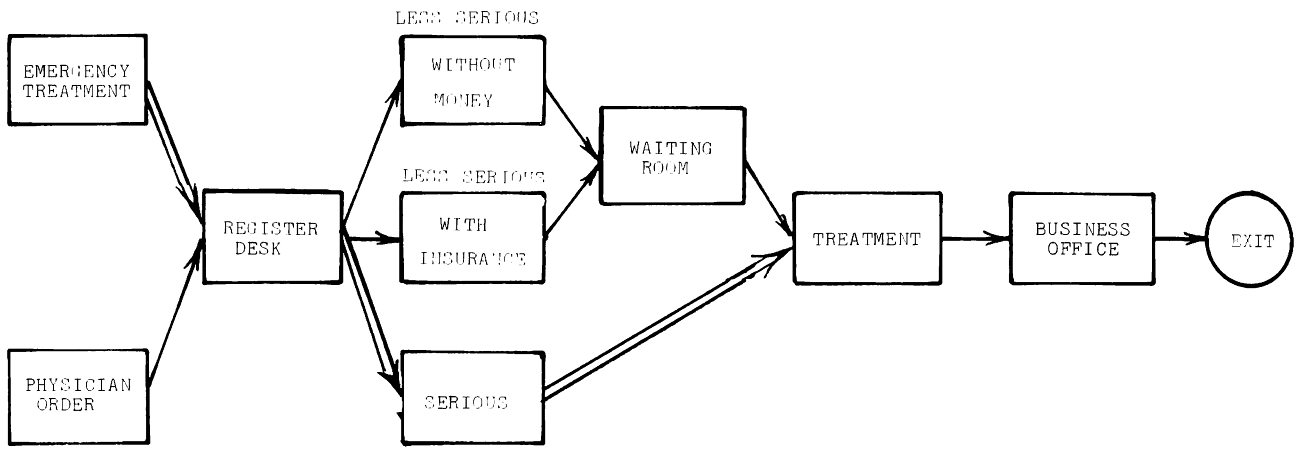


FIGURE 6 - EMERGENCY ROOM ENTITY FLOW NETWORK

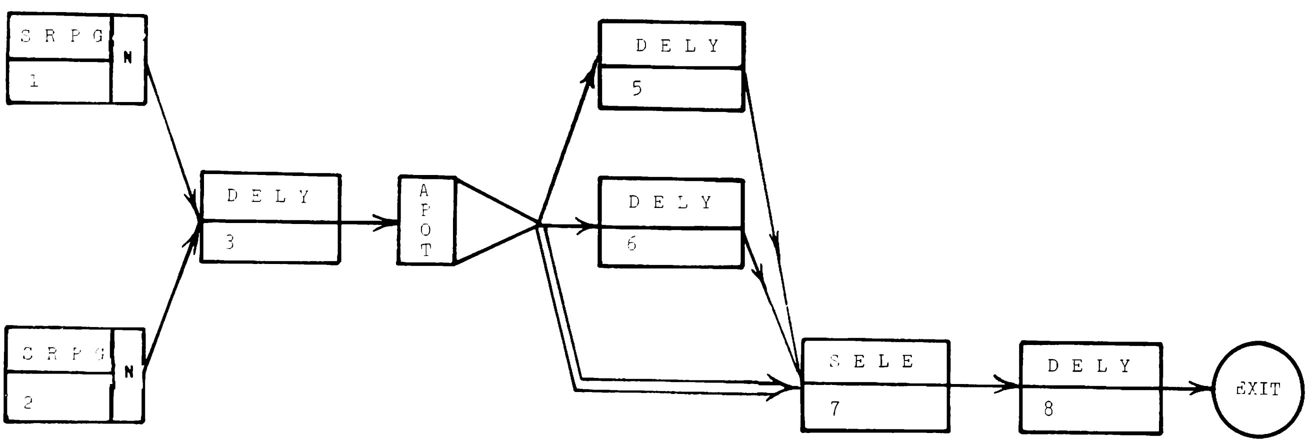


FIGURE 7 - MODULAR NETWORK OF AN EMERGENCY ROOM

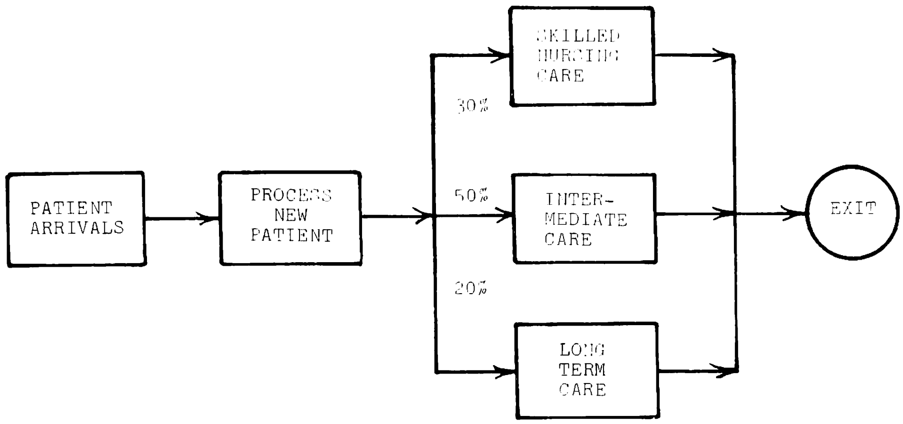


FIGURE 8 - NURSING HOME ENTITY FLOW NETWORK

TIME PARAMETERS

DAYS	MIN	MAX	DISTRIBUTION
T_1	.0	.0	CONSTANT
T_2	λ = 1.2		POISSON
T_3	0.5	1.0	UNIFORM
T_4	30.0	170.0	UNIFORM
T_5	10.0	110.0	UNIFORM
T_6	90.0	600.0	UNIFORM

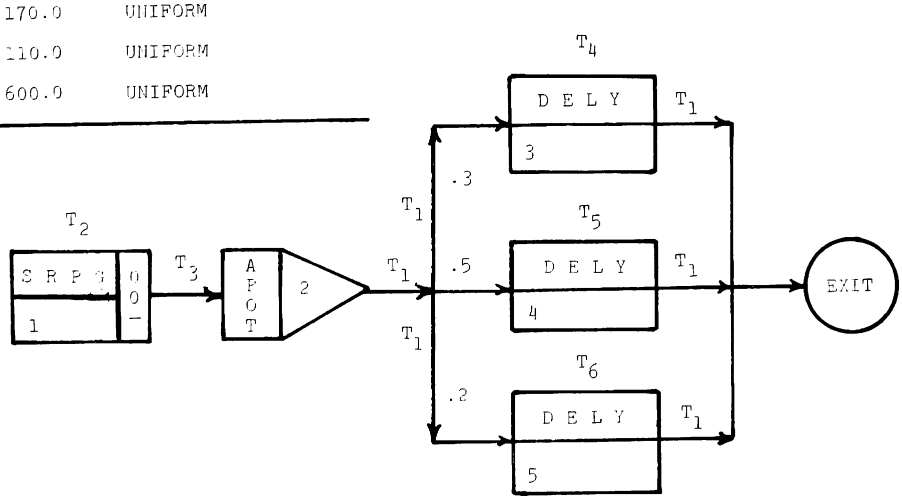


FIGURE 9 - NURSING HOME MODULAR NETWORK

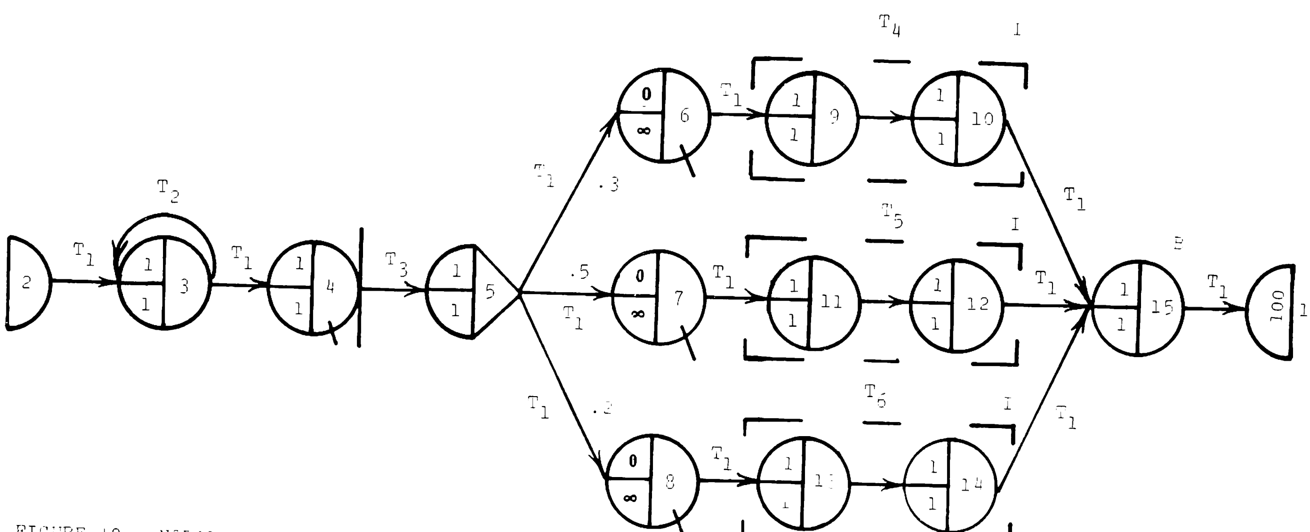


FIGURE 10 - NODAL NETWORK

4 B

SYMBOL	DESCRIPTION
	PROLIFERATIVE MODULES
S R P G	Simple Repetitive Pulse Generator: generates transactions at constant or random time intervals throughout the simulation run.
I F P G	Initial Finite Pulse Train Generator: creates a sequence, consisting of a pre-assigned finite number of transactions, for entering into the system at random or at constant time intervals.
O O P G	On and Off Pulse Generator: generates a sequence of transactions into a system and can be set and reset by pre-assigned activities.
U N P K	UNPacK: divides the units of an entity flow into a larger number of subunits. A single flow unit arriving at this module generates a pre-assigned number of flow units at its output.
M U P K	The Multiple UnPacK: combines the features of the UNPK and the DIST modules. A single entity enters the module and searches for a server which is available to unpack it.
	CONSOLIDATIVE MODULES
P A C K	PACK: consolidates transactions; entering transactions can accumulate in the module until a specified capacity N is attained.
A S S R	ASSemblеR: combines a pre-defined set of entities for future processing. The output activity cannot be scheduled until at least one unit has entered along each input branch.
	FLOW-THROUGH MODULES
D E L Y	DELaY: delays or holds up transactions at a particular point in the network.
O V F L	OVerFLow: a queueing module providing for diversion of transactions to alternate locations whenever the queue is full.
S T R G	SToRaGe: Incoming transactions are accumulated ("stockpiled") and are withdrawn, individually or in groups, only as service facilities outside the module become available.
	CHANNELED
D I S T	DISTributor: routes an incoming entity to the first idle server encountered in a sequential search of the processors being supplied by the module.
S E L E	SELEctor: preferentially routes higher ranking entities to a server while holding back lower ranking ones in a queue.
R O W Y	Right Of WaY: preferentially controls entity flow through a traffic intersection with a high (H) and a low (L) priority entry path and with two probabilistically selected exit paths.
A P O T	APpOrTion: probabilistically directs each entering entity to one of its output branches.