SIMULATION AND HEALTH CARE DELIVERY

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Over two hundred simulation models have been developed to solve problems in health care delivery. We review their contributions and describe them within their areas of application to health care. Further, we reflect on the use of simulation in health care and conjecture about its future role.

1. BACKGROUND

The past 25 years have witnessed enormous changes in health care and created significant problems in health care delivery. The need to improve health care delivery has not gone unnoticed by simulation modelers. As simulation has developed, it has been applied to the delivery of health care. Here we review the status of simulation and health care from a historical perspective. We speculate on the future with the hope that our analysis will benefit those who will contribute to solving these very important problems.

1.1 Resource Material

Literature describing simulation applications to health care is diverse and it is almost impossible to identify all the relevant literature because important work is found not only in the publications and conferences for simulation, management science, statistics, industrial engineering, etc., but also in the publications and conferences of health care related professions such as public health, clinical medicine, etc. Furthermore, participants in analysis of health care are not limited to the above mentioned professions because social and behavioral scientists, like economists, sociologists, educators, etc. are very active in examining health care delivery problems. Their literature cannot be ignored by the simulator because health care, whether refering to a hospital department or a health planning agency, is a mixture of politics, economics, sociology, medicine, and so forth. Being ignorant of these perspectives may lead to irrelevant and unimportant simulations. We state this as a caveat, recognizing that this paper contains only a simulation perspective. We also exclude many other types of operations research modeling that have been used (Shuman 1975, Warner 1978), and comment that we agree with Valinsky (1975) and Flagle (1966) that simulation provides a more comprehensive and flexible approach to modeling health care systems than can the relatively more restrictive analytical procedures.

There are many sources of material describing systems engineering in health care. Two standard abstract references are Abstracts of Hospital Management Studies and the Hospital Literature Index. Index Medicus contains material on all medical care. Excellent case studies of simulation in health care are often presented at the Winter Simulation Conference, the Annual Simulation Symposium, the ORSA/TIMS meetings, the meetings of the Hospital Management Systems Society (HMSS), and the American Institute of Industrial Engineering (AIIE). In particular, the latter two organizations annually sponsor a joint meeting specifically oriented to practicing systems engineers in health care fields.

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The most recent reviews are those of England and Roberts (1978) and Valinsky (1975). Together, their bibliographies exceed 200 references covering most areas of health care delivery. More recently, the Summer 1979 issue of Simuletter (Volume 10, Number 4) is devoted to simulation and health care delivery. This issue contains short and informal articles describing very informatively many areas of simulation applications to health care delivery, and is highly recommended.

Of a general interest are the books by Warner and Holloway (1978) and Griffith, Hancock, and Munson (1976) that present quantitative approaches to problems of health care delivery. The first is in textbook form while the second presents the results of analysis of hospital systems. For a critical analysis of the field of operations research accomplishments in health care, the books by Stimson and Stimson (1972) and Shuman, Speas, and Young (1975) are important. These writings review the contributions of operations research very critically and offer numerous suggestions on improving the application of operations research and systems engineering to health care delivery.

1.2 Classification of Literature

The organization of literature is difficult because of the diversity of applications and the nature of the simulation approach. There are many simulation models that can describe a variety of health and hospital environments and are difficult to categorize. Also the exact definition of a computer simulation model becomes arbitrary.

We have chosen to describe the various applications according to the topical areas listed below:

- Hospitals
  - Admissions
  - Facility planning
  - Emergency service
  - Laboratory
  - Radiology
  - Surgery and recovery
  - Material handling and support services
  - Nursing services
  - General hospital models
- Ambulatory care
  - Outpatient appointment systems
  - Outpatient clinics and physician's offices
  - Dental practice
  - Pharmacy
  - Public health
  - Multiphasic screening
- Other Health Care Institutions
  - Nursing homes
  - Blood banks
  - Health maintenance organizations
- Health Planning
  - Health manpower planning and forecasting
  - Planning health care delivery systems
- Education

Although some models are applicable to several categories, they will be assigned to only one category for organizational purposes in this paper.

The notion of simulation modeling can be interpreted in many ways. It is not uncommon for any computerized model to be called a simulation model, including economic, mathematical programming, and stochastic models. Here we confine our attention to strict discrete/continuous simulation. Sometimes, it is not possible to interpret whether a model is a "true" simulation, so we no doubt have excluded some simulation models and unknowingly included some non-simulation models.

2. HOSPITALS

The hospital is the largest single segment of health care (Health 1979). Its almost 7,000 institutions generate over 50% of all health care costs and to many, the hospital is the hub of the health care delivery system. The hospital is a microcosm of health care as a whole and has legitimately been the principal focus for simulation. Each hospital must respond to a statistically varying set of demands for service. Its resources are diverse involving labor, facilities, and equipment while the demand for care is just as diverse sometimes involving many services. The complexity of the total hospital has given emphasis to simulation of individual subsystems within the hospital, although few subsystems can be examined entirely in isolation.

2.1 Admissions

It is not difficult to recognize that if the variability of patient arrival to the hospital can be controlled, then maximum resource requirements can be reduced resulting in better utilization of hospital facilities and personnel.

However, the problem of controlling demand for hospital care is more complicated than its industrial equivalent. The hospital simply cannot turn away patients since to do so can have serious consequences. Some analyses of hospital demand shows that not all admissions are absolutely necessary. Those that are not are often termed elective. Among the earliest of the admissions models to characterize hospital admissions was that of Bailey (1952, 1954) who employed queuing theory to characterize the stochastic system. The notion of a set of non-emergency "elective" patients which can be "called-in" to compensate for fluctuations in hospital occupancy caused by emergency admissions was studied by Young (1962). He used simulation to test the analytical models of the admissions process. His work did demonstrate the importance of the length-of-stay distribution and the concern with length-of-stay continues to be an important issue.

Also in the early development of admissions models it was recognized that some services of the hospital should be examined individually. A simulation model by Fetter and Thompson (1963) evaluated admissions for the maternity suite. In addition to evaluating such factors as lengths of stay and admissions rate, their work also contained an attempt to resolve several tactical problems of simulation such as sample size and initial conditions (Fetter and Thompson 1965). Barr (1965) at Oxford also constructed a simulation of a maternity suite that focused on the impact of admissions policies on various measurements of performance such as bed occupancy and turnaways.

A more recent study of admission and discharges in a single unit is that of Rath, Wright, and Karp (1969) for the Intensive Care Unit. Their simulation was based largely on the patient's state of health and pointed to the need for including various patient characteristics in the scheduling of patient admissions. Robinson, Wing, and Davis (1968) produced a simulation which included many characteristics such as desired admission date, flexibility of this date, potential length of stay, and hospital services requirements. Among other conclusions, this study indicated that admissions must be measured by several methods of effectiveness including average hospital census, standard deviation of census, number of overflows, and mean daily cost. Furthermore, a good admissions system, they found, needs to be based on several fundamental assumptions with respect to information; for example, a known set of admissions that are requested in advance, accurate estimation of discharge dates in advance, and medically determined priorities for admissions. These observations have continued to be refined by the most recent investigators, and admissions rules continue to be enhanced.

The most active of recent investigations into admissions control, as well as other hospital functions, is that led by Hancock and his associates at the University of Michigan (Hancock and Walter 1979). They have evolved a general simulator called ASCS (Admissions Scheduling and Control System) which accepts ICU/CCU patients, Emergency patients, scheduled surgial patients, scheduled medical patients, call-in medical patients, scheduled GYN surgical patients, and OB patients seeking admission to the hospital, and routes these patients to hospital units from which they are transferred and eventually discharged. The ASCS is capable of handling a variety of scheduling rules and produces statistics for a variety of effectiveness measures related to use of resources and the admissions process. The system is described several times (Hamilton 1975; Hancock, Warner, Heda, Fuhs 1976) and has been the basis for many studies (Hancock and Walter 1979), including a simulation game to teach admissions personnel (Johnston, Hancock, and Fuhs 1975). Among other results, the work at the University of Michigan has shown it is important to distinguish between a hospital that is overbedded and one that is not. Overbedding means that average census in Medical/Surgical units is 80% or below. These results have often been due to the use of Hill-Burton and Poisson formulas for hospital size. When a hospital is overbedded, admissions systems must be designed according to different criteria. Briggs (1972), for example, devised several different admission policies primarily based on minimizing the variation in census. However, even these rules met with resistance when it was attempted to apply them to an overbedded hospital. Therefore, admissions control seems suitable only for underbedded facilities where motivation for admission control exists. Experience (Hancock and Walter 1979) with setting decision rules for admissions shows that occupancy levels of over 90% can be achieved even if a computer-aided system is unavailable. Success with admissions scheduling and control is reported in Strande and Hancock (1978).

The application of simulation to examine admissions policies has given rise to important tactical considerations. McClain (1976) notes the existance of autocorrelation in the output and points to the need for more careful statistical analysis of differences. Schruben (1975) explores the use of induced variance reduction in designed experiments with a simulation model of a hospital patient unit.

2.2 Facilities Planning

The size of hospital facilities has been a central concern of many facilities planners. This has been true for existing facilities as well as in planning new facilities. An additional hospital bed may cost $100,000, so the question of size has significant cost ramifications. The optimal size of a hospital service has been a significant research question and continues to be a topical issue.

Simulation approaches to the problems of facility design have varied. A major project by Au and his associates (1970) began in 1968 with its objective being a systems analysis approach to hospital design. In particular, they offered a comprehensive set of planning procedures for the design of hospital facilities. A part of the planning program is the use of a simulation model for the study of the effect of alternative designs on personnel and facility levels (Groome and Au 1969, Wong and Au 1970).

Health Services Research devoted its Fall 1970 issue to health facilities design. This issue dealt with a number of important problems including interdepartmental traffic and patterns of travel between and within departments. In this issue, Rikkers (1970) simulated a hospital having a wheel and spoke design. The design permits flexible care unit boundaries to be defined for all hospital bed units. The idea of increasing the utilization of hospital facilities by increasing the flexibility of design has been employed in several simulation models. The early research in bed modeling by Thompson and Fetter (1966) in the mid 1960s demonstrated the increase in cost-effectiveness of larger maternity services. This idea was pursued by Fischer (1968) in his simulation of the potential savings that hospitals could obtain by pooling their maternity services. Blewett, et.al. (1972) considered the sharing of beds between separate surgical services with the goal of increasing the average bed occupancy and keeping the variance of bed occupancy low.

To expand the notion of flexible facilities, Thompson and Fetter (1969) tested the theory that all single room hospitals have higher occupancy levels and a resultant economic advantage because there are reduced bed moves when sex conflicts necessitate changes in multi-patient rooms. A similar simulation was done by Goldman, Knappenberger, and Eller (1968a), who examined the effect of different mixes of private, semiprivate, and ward facilities within the hospital unit.

The recognition that hospital facilities should be flexible and beds made as interchangeable as possible has been the subject of a number of special studies of particular units. For example, the size of the intensive care unit and coronary care unit has been a subject of several studies (Kao 1973, Rath 1969, Stallings 1970, Segal and Strande 1979b). In these cases, movement between intermediate care facilities and the special care facilities is particularly important to alleviate potential bed shortages. In an effort to minimize the effect of emergency admissions, Handyside and Morris (1967) simulated an admissions system which rotated emergencies among hospitals in order to increase overall bed utilization.

While much work has gone into the design of facilities with flexible bed use, there has been interest in the design of care facilities according to the patient's severity of illness. This philosophy of design is termed "progressive patient care". Fetter and Thompson (1969) were among the pioneers in this area in 1969, and their model was used by Hartman (1971) a few years later to estimate the bed requirements for a five level progressive patient care hospital expansion program. Within these designs, patients can be moved throughout care areas depending upon their particular service needs. The notion of constructing hospitals based on the progressive care concept was described earlier by Flagle (1963).

2.3 Emergency Service

Simulation models of emergency services usually focus on one of two problems. The first is the simulation of emergency services within the hospital. In this case, the analyst is usually interested in operational problems in the Emergency Room. For example, the simulation by Hannan (1975) considered the staffing patterns within the emergency room and various triage policies for handling emergency cases as they arrived. In each of these cases the arrival pattern was most critical. Ladany and Turban (1974) formulated a model with a goal of optimizing the cost of emergency room facilities considering the very high cost of patients having to wait for ER services. Segal and Strande (1979a) constructed a simulation model of the emergency department as a planning tool.

The second category of emergency models includes ambulance systems. These models are similar in concept to those for police and fire systems. The questions usually raised in these models include the location of ambulances, the number and type of vehicles, and the level of service required. For example, Savas (1969) addressed the problem of cost-effective alternative systems of ambulatory service in New York City in 1969 to show that a regionally dispersed system was preferable to a centrally located system. A model by Messer (1977) provided an interactive simulation where vehicle routing could be done by a dispatcher at a computer terminal. Other models have been developed for Los Angeles (Fitzsimmons 1971), Detroit (Dekar 1975), Philadelphia (Hamilton 1974), and Kansas City (Ashley, Graham, Welch 1980). Often, such models are used in combination with optimization routines in order to schedule and route vehicles. An example is that of Swoveland, Uyeno, Vertinsky, and Vickson (1973). Uyeno and Vertinsky (1979) have recently surveyed their work and offered a number of suggestions for improving ambulance simulations so that more comprehensive solutions to the problem of emergency service can be examined. Finally, an interesting study by Chaiken (1978) described the dissemination of an emergency service deployment model to various operating agencies. He later surveyed those who requested and actually used the simulation model that was developed. The report is an excellent study of dissemination, use, and implementation of simulation models.

2.4 Laboratory

Relatively few comprehensive simulation models of hospital laboratory facilities have been developed. The most general is by Vaananen, et.al. (1974) whose simulation model contains the ability to handle a variety of technicians, equipment types, and test types within a laboratory. The model is an excellent case of a specialized simulation model developed for a general department and can be used to determine the need for equipment, staff, and the time it takes to process lab results. A model by Dumas and Valinsky (1970) considered several aspects of a clinical laboratory including testing facilities, personnel, equipment, specimen collection and delivery, and reporting procedures. Their model produces information on the utilization of personnel and equipment, system productivity, and costs. Rath, Balbas, Ikeda, and Kennedy (1970) also designed a simulation model for a hemotology lab with the intent that this be incorporated into a more general model of a complete hospital.

2.5 Radiology

Like laboratory models, radiology departments conceptually represent a multi-channel network of queues where multiple servers service patients requiring various sequences of tests. In this case, since patients are the primary element of demand, output measures usually include queue length, patient waiting time, as well as facility and staff utilization. The early work in radiology department simulation was done largely by Covert and Lodwick (1967) at the University of Missouri in 1966. Their model involved explicit consideration of the exam room, x-ray technicians, major exam types, and a variety of patient scheduling options. The model was adapted and used at the University of Pittsburgh by Kirsch (1970). Lev, Caltagirone, Shea (1972) built further upon the model and created a block structured patient flow model. Their patient flow data diagrams are excellent representations of the radiology department and would be useful in planning simulation models for any hospital radiology facility (Lev, Revesz, Shea, Caltagirone 1976).

Simulation models which consider the effect of staffing and scheduling on patient waiting time (Revesz 1973) and the use of radiographic films storage and retrieval also have been developed (Evans, Falvey, Jost, Hill 1974). In 1974, Lim and Baum (1974) summarized four major radiology department simulations and offered numerous comments on their utility. With different objectives, Sullivan (1971), Widegren and Mathews (1971), and others (Luckey 1971; Radhakrishman, Sullivan 1971; Sullivan, Smalley, Brown, Mathews, Luckey 1971; Sullivan, Luckey, Brown 1971) at the University of Georgia extensively examined questions of location of hospital radiographic facilities. Other models have examined scheduling of residents (Raeside, Traub 1974) and patients (Steidley, Vanloh 1977) in radiology. Kenny and Murray (1971) modeled scheduling as well as staff and equipment needs whereas Dumas, Rabinowitz, and Valinsky (1972) incorporated a comprehensive set of activities in their radiology model including patient transport and multishift, multiroom complications. Harvey (1979) presents a radiology model used in a consulting environment.

2.6 Surgery and Recovery

The high cost of surgical suites and recovery rooms has received considerable attention in the simulation literature. Because these facilities are poorly utilized, concerns are that better scheduling and allocation of facilities are needed. One of the most complete studies of surgical suites has been done by Kwak, Kuzdrall, and Schmitz (1975; 1976; Kuzdrall, Kwak, Schmitz 1974; Schmitz, Kwak 1972) who investigated the increased number of recovery room beds needed to handle the extra surgical patients which resulted from an increase in general hospital beds. Recognizing that length of stay in the recovery room is a random variable according to the type of surgery and that efficient surgical suite scheduling depends upon having sufficient recovery room beds, they formulated a model that determined the number of recovery room beds to handle different surgery capacities. Their model is sufficiently general to be used for many operating room/recovery room situations. Barnoon and Wolfe (1968) developed a simulation model for evaluating operating room scheduling procedures which included the interactions between admissions, bed utilization, and surgery utilization. In particular, they were interested in facilities and personnel idleness versus waiting time. Later the model was modified by Shuman, Wolfe, and Fairman (1971) to include an algorithm for generating alternative surgery schedules to insure even distribution of surgical workload. Blewett and his associates (1972) at Lancaster were concerned with modeling opthalmology surgery and were interested in studying the effect on the operating room schedule of increased surgical facilities and ward sharing. Other operating room models have considered surgical scheduling priority rules with respect to case assignments to specific rooms and/or specific days and other schemes. Avoiding surgery idle time due to patient cancellation and optimizing surgical staff assignment and responsibility delegation are other issues which have been simulated. The scheduling of surgery has also been studied by Goldman, Knappenberger, and Moore (1968b) and considered extensively in Esogbue (1971). Esogbue (1979) reflects on his experience and suggests where the results are generalizable. Finally, Ockey (1975) considers the issues of avoiding surgery idle time due to patient cancellations and optimizing surgical staff assignment and responsibility delegation.

An area related to surgery is anesthesia. Marsh and Freeman (1969) studied activities of an anesthesiologist in the operating suite. This work was extended by Esogbue (1979) and Reisman, et.al. (1977) to consider the general problems of anesthesia manpower availability as well as the design of anesthesia teams.

2.7 Material Handling and Support Services

Although hospitals have large and various requirements for support services like dietary, laundry, etc., very little attention has been given to the important area of appropriate material handling and supply services. One of the first to study these services was Kilpatrick and Freund (1967) who examined oxygen tank inventory policies and levels. Flaugh and Delporto (1971) simulated an automated material handling system as did Marsh (1977) and Swain (1978) who determined how efficiently the system met the needs of a large hospital being remodeled and expanded. Marsh (1979) reflects further on the utility of this work.

2.8 Nursing Services

The budget for nursing may approximate 40-50% of all the costs of labor within the hospital. Thus the problems of nurse staffing and allocation have great importance. Mostly these issues have been examined through optimization (Shuman, Speas, Young 1975; Warner, Holloway 1978). Hershey, Abernathy, and Baloff (1972) used simulation to study fixed and variable staffing to assess the costs of nurse staffing. Wandel (1972) combined linear programming and simulation modeling for the planning and scheduling of nurses in the hospital. Laberge-Nadeau and Feuvrier (1972) considered the utilization of nurses and explored alternative task assignments based on patient care needs for six categories of personnel. More recently, Hancock and Walter (1979) reported on their use of simulation to examine the economics of team nursing and primary care nursing. They explored the various styles of nursing care and the effects of such variables on the amount of overtime, the size of the nursing unit, the mix of staff on the nursing unit, and so forth. The general area of nursing services continues to offer excellent potential for additional study and simulation.

2.9 General Hospital Models

An early attempt at modeling the hospital as an entire system was made by Hindle (1967) in 1967 who considered the hospital as a collection of interacting queuing systems where patients and personnel queue to demand health facilities and other resources. The goal of his work was to discover the most efficient policy to manage the distribution of the limited facilities and resources.

Hearn and Bishop (1970) built a simulation model that modeled the flow of individual patients through the hospital and permitted testing the effect of capacity limits for wards and other facilities. Hardison (1968) simulated a hospital with variable departmental staffing and costs to determine how total hospital costs could be minimized by interaction among the departments to accomodate seasonal variations in patient care demand patterns. Valinsky (1975) reported on a proposal to model patient flow in the entire hospital from admission to discharge with support services, laboratory, etc. included.

Systems dynamics was used by Stearns, et.al. (1976) to help hospitals conceptualize and quantify the interrelationships of their various departments. The model helped improve patient care by allowing department chiefs to observe how their autonomous operations often had far-reaching consequences for other areas of the hospital.

3. AMBULATORY CARE

Ambulatory care has received a great deal of attention from health care modelers. The general operation of an ambulatory care unit lends itself to simulation modeling because it is easily represented as a network of queues. Patients arrive either according to schedules or walk in without an appointment. Upon arrival, patients encounter a series of queues as they wait for medical services, sometimes from several persons such as a receptionist, physician, or other health care worker. In addition, radiology, pharmacy, patient billing, and other kinds of services are often rendered during their visit. Eventually, patients complete their service and depart the system. The goal of the simulations are usually to determine where bottlenecks occur and to determine the amount and kind of resources involved. Typically the resource manipulation involves physicians, nurses, other related staff, and exam rooms. Performance is usually measured in terms of the time patients wait, the cost of patient care, and the amount of time the physicians, staff, or other resources are idle. Other less quantifiable parameters such as improved health, have also been examined.

The ambulatory care system can conveniently be subdivided into two processes, one which creates arrivals and another which responds to those arrivals. Generally, the patient arrival process is controlled by an appointment system. Response to the patient demand usually takes the form of specifying staffing, facility, and resource levels.

3.1 Outpatient Appointment Systems

The design of appointment systems was the subject of very early investigation. In 1952, Welch and Bailey (1952, 1952) examined the appointment system for the scheduling of ambulatory care patients and called for a system giving individual appointments to patients. Their work was followed up by a number of investigators. White and Pike (1964) concentrated on the lack of punctuality of patients and proposed a block appointment system where more than one patient is given the same appointment time. Fetter and Thompson (1966) constructed an outpatient simulation model that looked at a variety of design and operating policies. In particular they were interested in designing an appointment system to minimize both patient waiting time and doctor idleness. They introduced the notion of physician unpunctuality and noted the effect of interruptions during physician visits within ambulatory care settings. Williams, Covert, and Steele (1967) investigated a staggered block appointment system and its effect on manpower utilization. Katz (1969) developed an appointment system simulator with considerable flexibility so that it could be used in a variety of locations. It accommodated both individual and block appointments and allowed for physicians, radiology services, and laboratory services to be incorporated appropriately. A variety of performance measures were provided by the simulator with the intention that these could be weighted according to the criteria of the ambulatory care system manager.

Since these early works in the 1960s, the 1970s have seen greater implementation of appointment systems within computer assisted information systems. Fuller reference to appointment systems are made in Miga (1966), Berkowitz (1974), and Granot and Granot (1973).

3.2 Outpatient Clinics and Physician Offices

Studies in both outpatient clinics and physician offices, while in different environments, reflect the same operational procedures. The outpatient clinic is usually closer in operation to a large group practice than is a physician's office, and a more complicated array of patients are treated, utilizing a greater variety of staff, sometimes including residents, medical students, and other health related professionals. Private practitioner offices tend to be more homogeneous in terms of the patient care rendered and the staffs and facilities provided.

Most of the studies in outpatient clinics and medical practices deal with problems of staffing, clinic space, and patient flow. Examples are Glenn and Roberts' (1973) study of OB clinics, Naddor, Berkowitz, and Drachman's (1970) study of comprehensive child care clinics, Lees', et.al. (1974) study of a health center, and Lasdon's (1973) study of a community health center. A university health service clinic was the subject of a simulation by Rising, et.al. (1973) and Baron and Rising (1973). Their work is particularly interesting because it contains a number of useful suggestions for implementation of the simulation and acceptance of the results. Their model was later used by Stuart (1974) for evaluating outpatient clinics in the U.S. army. Aggarwal and Stafford (1976) also simulated the university health center and their work was later followed up by Stafford and Wyman (1977) who constructed a general simulation model of outpatient care.

Liebman, Reuter, and Reuter (1972) used simulation to aid in the design of a prepaid group medical practice at a medical center, evaluating staff and room assignments for various clinics. Roberts, et.al. (1976) employed simulation to evaluate several operational alternatives in an outpatient clinic based on an extensive study of outpatient care. Dill, et.al. (1976) simulated an endocrine metabolic clinic while Yen (1972) and Lasdon (1973) simulated community health centers to determine optimal resource allocation for given service patterns. Dilley and Larkins (1973) examined a family practice clinic with simulation.

Studies of private medical practice have focused on staff and exam room requirements. Freeman (1970) built one of the earliest simulation models of private practice. Since this initial study, recent simulation models of private practice have concentrated on examining manpower alternatives to physician care, in particular using nurse practitioners and physician's assistants. Questions investigated include deciding what tasks a physician should delegate, how many assistants should a physician have, how can demand be related to various manpower team combinations, and how do the costs and income to the practice vary as these new kinds of health practitioners are used (Kasanof 1973)?

Lazarus, et. al. (1974) created an interactive simulation for examining several practice issues including patient scheduling, office size, and delegation of tasks. Also the model was reported to have been used as a teaching tool for medical students. A similar model was developed by Mirabile and Anderman (1975) based on data from New York State's Appalachia region. Reid (1972) simulated the ability of a rural health care clinic staffed by nurse practitioners to provide primary medical care to a local population while Dhillon (1975) modeled the effect of using technology to enhance the services of a nurse practitioner or a physician's assistant. A simulation model by Uyeno (1974) focused on the composition of a pediatric health care team consisting of physicians, nurse practitioners, and nurses. Productivity of the practice was measured as teams of various composition were assumed. The model also considered the effects of patient load, skill level of team members, and facilities available. Schneider and Harz (1974) constructed a model of a prepaid group practice that incorporated physician's assistants. Based on an optimization of team composition via a linear program, the simulation produced a statistical interpretation of the results from which they could infer how the staff to facilities ratio should change to obtain optimal use of available health manpower.

The most recent examination of operational practices in ambulatory care is the work by Carlson, Hershey, and Kropp (1977) who used a combined linear optimization/simulation model. The optimization routine was used to determine staffing and facilities needed for a given patient population and the simulation program was then used to model the clinic operation and determine various patient waiting times. Regression was used to relate the patient waiting time to the staffing and facilities parameters and thus to form new constraints for the optimization. This recursive resolution of linear programming and simulation used together has been an important contribution by achieving the benefits of simulation and optimization simultaneously. Kropp and Hershey (1979) also describe further extensions to their work and its application.

In a more strategic study of ambulatory care, Hirsch and Bergan (1973) compared three types of ambulatory care systems; prepaid clinic, fee-for-service clinic, and solo practitioners. Their systems dynamics model produced such measures as cost, patient load per physician, physician time per patient visit, and waiting time for appointments. Extensive classification of medical needs, physician decisions, visits, outcome referrals, and other discrete categorizations of health care were tabularized and analyzed for internists, specialists, and general practitioners.

Finally, in the area of statistical analysis, Eulenstein (1974) applied control theory and antithetic random number variance reduction techniques to a simulation model of an outpatient clinic and compared the results to an ordinary Monte Carlo simulation to examine variance reduction. Work reported by Kropp and Hershey (1979) involved similar activities in an effort to refine their analysis of outpatient simulation models.

3.3 Dental Practice

Dental practice has been the subject of several excellent simulations. Unlike medicine, dentistry is more procedure oriented and consequently more amenable to identification of dental care processes and modeling of the associated resource requirements. A model by Kilpatrick and his associates (1972, Kisko 1974) at the University of Florida is a good example of dental practice simulation which includes opportunities for examining patient scheduling and resource utilization. The motivation for this model was primarily to evaluate the use of extended function auxilliaries or dental assistants. This concept, which is analogous to the nurse practitioner or physician's assistant in medicine, permits the dentist to delegate to these new dental personnel a number of tasks ordinarily performed by dentists, consequently increasing the productivity of the dental practice. A model with simular intent was developed by Dilworth, et.al. (1973).

A systems dynamics model was used by Hirsch and Kellingsworth (1975) to simulate how dental practice would respond to dental manpower and dental insurance changes. Further systems dynamics modeling in dentistry is described in the book by Levine and Roberts (1976).

3.4 Pharmacy

The operation of a pharmacy can be conceptualized as a queuing model where patients queue to wait for their perscription, and pharmacists fill perscriptions, answer the phone, do bookkeeping, and other tasks. Consequently, the objective of a pharmacy simulation is to balance patient waiting and pharmacist idle time in the same fashion as is done in dentistry and in medicine. Myers, Johnson, and Egan (1972) consequently developed a model to examine the introduction of a pharmacy assistant as a means to achieve cost reduction. Harmon and Novotny (1974) used a similar pharmacy model at a medical center.

3.5 Public Health

Simulation models in public health usually revolve around problems of disease control and are used to analyze the cost-effectiveness of medical care programs administered to groups with specific medical needs. For example, Pyecha, Voors, and Poole (1971) as well as Duce, et.al. (1968) have dealt with disaster planning to evaluate the community's ability to respond to nuclear attack or any sort of natural or manmade disaster. One of the more active areas of public health simulation modeling has been in the area of screening for the early detection of hypertension. Both Feldman, et.al (1970) and Hannan and Graham (1977) developed models to examine the economic and other benefits of establishing hypertensive screening programs. In another application, Holder, Sawyer, and Schlenger (1974) used simulation to compute the cost effectiveness of various treatment strategies for public alcoholism and Chorba and Sanders (1971) used simulation to model tuberculosis prevelance and optimize the cost of prevention. Some systems dynamics models in the area of public health have involved yellow fever (Kalgraf 1974) and community narcotics control (Levin, Hirsch, Roberts 1972). Frerichs and Prawda (1975) simulated the spread of rabies in urban Columbia while Horwitz and Montgomery (1974) simulated a rebella epidemic and Elveback, et.al. (1976) constructed an influenza simulation model. Roberts, Gross, and Maxwell (1979) simulated the costs and life expectancy of patients with end-stage renal disease.

3.6 Multiphasic Screening

Multiphasic screening was proposed in the late 1960s as an efficient means for gathering baseline data on patients initially encountering a health care facility. By a sequential set of standardized tests, it was believed the patient could be better referred for medical treatment. Such screening systems were often computerized and supported by an array of health manpower. An early simulation of one of these systems was performed by Warner and Freeman (1969). Another model was subsequently developed by Smith and Warner (1971). Since these developments, multiphasic screening seems to have lost its initial momentum.

4. OTHER HEALTH CARE INSTITUTIONS

A number of other health care institutions have been examined by simulators. We will deal primarily with blood banks, nursing homes, and health maintenance organizations because they have received the greatest study. However, the modeling approaches certainly apply to other special health care systems such as mental health and rehabilitation programs (Holder, Sawyer, Schlenger 1974).

4.1 Nursing Homes

The earliest simulation of nursing homes, performed by Colley and his associates (1967), attempted to determine resource requirements to meet certain needs and demands of nursing homes. Other models were developed for the Illinois State Department of Public Health (1975) and by McKnight and Steorts (1969). Their efforts produced user's manuals that were written to be employed by health planners, administrators, and regulatory agencies to simulate the efficiency and effectiveness of long term care facilities. An interesting example of the adaptability of health care patient flow modeling is the development of the pediatric hospital care unit model by Brayton (1976) based on modification of one of the earlier nursing home simulation programs.

4.2 Blood Banks

Blood banking has been treated conceptually like many other inventory problems with the added constraints that stock-outs should not be allowed and that the shelf life of the item is limited (normally 21 days with a possible further extension to 35 days). Other considerations include different types of blood and the allowance for the aging of blood. Finally, obtaining blood depends on many factors, and the use of the blood is an important consideration. A number of mathmatical inventory models of blood banking have been developed, but due to the unique complicating factors of the blood banking inventory problem, computer simulation has also proven quite useful. Policy issues considered by a blood bank inventory simulation model include: 1) what inventory level to maintain; 2) the possibility of substituting Rh-negative blood for Rh-positive under limited conditions; 3) double cross-matching, a policy of pooling blood units that have been reserved for individual patients; 4) variation in the number of days a unit of blood is held in reserve if the patient does not use it after cross-matching; 5) alternative uses of the blood, such as plasma fractionation or freezer storage of red blood cells and; 6) selective cross-matching of older blood to patients deemed more likely to actually use it.

Structurally, most blood bank simulation models appear to be similar, including those by Elston and Pickrel (1965), Jennings (1968), Nelson (1976), and Rabinowitz (1973). A Monte Carlo demand generator requests a certain number and type of blood units to be used or to be cross-matched each day. This demand is filled by depleting the inventory, replenishing the inventory by volunteer or call-in donors or from other blood banks, and removing outdated blood from the inventory. These models are fairly general and appear to be applicable to a variety of blood banks. In related simulations, Yen and Pierskalla (1977) simulated a centralized blood bank system which fed several smaller hospital blood banks, while Pegels, et.al. (1975) simulated a blood collection system where the dates and locations of bloodmobile collections were variable and the object was to reduce seasonal imbalances between supply and demand for blood. Cohen and Pierskalla (1979) review their most recent work in simulation of blood bank systems and offer several insights into the contribution of simulation to blood bank operations.

4.3 Health Maintenance Organizations

Health Maintenance Organizations (HMOs) are gaining acceptance and popularity in the American health care system at a rapid pace, following the enactment of PL 93-222 (the HMO Act of 1973). Due at least partially to the complexity of the economic, social, and political issues to be considered in modeling the operation of an HMO, relatively few computer simulations have been formulated to date. Some of the issues which must be considered are: 1) ownership of hospital and other facilities versus contracting for hospital care; 2) the size and composition of the patient population necessary to break even on costs; 3) marketing strategies for patient recruitment; 4) services and benefits to include in the basic health care provision package; 5) enrollment fee; 6) method of physician remuneration and; 7) potential impact of changes in the U.S. health care system such as the enactment of a national health insurance program.

An initial model for examining many HMO issues was described by Moustafa and Sears (1974). Morehart (1976) used a simulation model to affirm the feasibility of a statewide HMO system in Georgia. Perhaps the most complete examination of HMO issues is achieved by systems dynamics modeling. Hirsh and Miller (1974) constructed such a model that dealt with patient demands, marketing, medical personnel and allied resources, inpatient facilities, finances, and preventative health care programs. With their model, they studied HMO feasibility including marketing strategies, benefit packages, etc.

5. HEALTH PLANNING

Within the past 15 years there has been a growth in health planning as a process for rationalizing the health care delivery system. This growth has been spurred by growing governmental involvement at state and national levels in the regulation of health care. The need for rationalizing health planning is reflected by a significant growth in the number of simulation models oriented to planning topics. These models range from planning for institutionally based health care programs to national programs resulting from congressional action.

5.1 Health Manpower Planning and Forecasting

In the early 1970s, there was considerable concern for the availability of health manpower, particularly medical manpower. Some believed there was indeed a national shortage of doctors, while almost everyone agreed there were specific regions without adequate medical care and referred to this as a maldistribution problem. Also there was concern that too few primary care doctors were available and that the growth of specialty practice would mean less primary care. Consequently a number of models were built to examine health manpower. Vector Research (1974) reviewed some 56 health manpower models of various types developed in the period 1970 to 1973. By our definition, however, only a few of these were computer simulation models.

Standridge, et.al. (1977) constructed a simulation model of medical manpower for the State of Indiana. The model considered four elements: primary care physicians and the volume of services provided, the population and the volume of services demanded. The model projected these variables for future years based on an understanding of the processes affecting the values for the variables. Standridge (1979) further reviewed this work and discussed the importance of data acquisition, analysis, and management.

The supply, demand, and distribution of nurses was the subject of Bergan and Hirsch's systems dynamics model (1976). Four sectors, education, employment, demand, and demography, were modeled with seven possible employment settings and five levels of educational preparation to estimate the impact of changes in programs and policies on nursing personnel. The model was used to predict nursing personnel behavior under various conditions for a four year time frame. Interestingly, nurse availability continues to be a major concern and the shortage of hospital nurses is becoming a critical problem in many areas.

5.2 Planning Health Delivery Systems

Within the past decade perhaps the greatest expenditure of effort in the building of simulation models has been in the area of planning (England, Roberts 1978). Planning models have been built for individual institutions, for communities, for regions, and even for the nation as a whole. Much of this activity has been supported by large research grants which have fostered extensive projects concerned with meeting health care needs. Currently, regional agencies have been established (through the National Health Planning and Resources Act of 1974) called Health Systems Agencies which have as their primary responsibility the planning of health services. Their work involves the review of specific programs of care.

Planning for community health services by the use of simulation has been undertaken from a number of perspectives. The most ambitious simulation of a neighborhood health center ambulatory care system was accomplished by Geomet beginning in 1969 and continuing through 1974 (Milly, Pocinki 1974; Pocinki, Thomas 1973). This large simulation model was built from three submodels, one modeling the population, the second modeling a health care delivery system, and the third computing costs. The model keeps track of every patient's moves through the clinic, allowing for 74 diagnostic categories, each of which requires a specific sequence of health care resource utilization for treatment. Actual health care delivery occurs at treatment stations where patients queue to await delivery of the care elements required by their diagnostic category. Data was obtained from one neighborhood health center in Chicago and verified using three other centers in other areas of the United States. Another large community health service simulation model begun in 1969 was a project performed by the Research Triangle Institute (Gentry, Kennedy, Packer 1968; Kennedy 1968; Kennedy, Woodside 1968; Packer 1968; Weaver 1968). The model was based on data from maternal and infant care projects and provides a mechanism for designing a community health system which allocates health resources for the care of expectant mothers and infants on a regional basis. Other community health planning models have dealt with planning and operating family planning programs and include those by Urban (1974), Alessandra, et.al. (1978), Colosi (1974), and O'Conner and Urban (1972). In some of these simulations, the model includes capabilities for evaluating alternative strategies for allocation of program funds and resources.

Planning models for regional health care delivery systems include Fox's, et.al. (1974) model and Baum's (1971) model which emphasize health care delivery to the poor and the provision of health care systems within an urban environment. Moss's (1970) health services node was used as a building block in an Indian health service model. Milsum's, et.al. (1971) health submodel was built to interact with population, pollution, transportation, and energy submodels to form a microcosmic model of the greater Vancouver region. Finally, a model by Dei Rossi, et.al. (1977) used simulation to develop standards for areawide bed requirements while the model of Browning and Hogg (1979) simulated the certificate of need review process in one state.

Systems dynamics has been applied very extensively to problems of planning. Hirsch (1979) reviews the applications of systems dynamics modeling in health care. He reports on a variety of strategic and planning applications ranging from plans for individual institutions to models built for health systems agencies to large scale models built to aid in policy formulation for manpower in dentistry, nursing, and so forth. A critical component of planning has been the need to incorporate complex relationships in a data poor environment and to examine the implications of these relationships. It is for this reason that systems dynamics has had wide spread use and application. In fact, in a review of models for national planning, Deane and Litkowski (1976) found that systems dynamics was the most feasible approach for examining these very global problems.

6. EDUCATION

Simulation has been applied in both educational planning and in the education of students. The most comprehensive studies to date of applying simulation to planning health educational units have been done by the University of Toronto (Wilson, Wolfson, Centner, Walter 1969; Wilson 1971). These models were used to study the impact of changes in educational programs on resource requirements within the health unit, for example, to calculate staff teaching loads, patient exposure, facilities use, capital expenditures, etc.

More recently, simulation has often been used in an interactive mode for students to gain simulated practical experience in a laboratory setting. Historically, one of the first developments in educational simulation was the computer aided simulation of clinical encounters by Harless, et.al. (1971, 1973). This model was used by medical students to learn diagnosis and management of diseases. Johnson, Moller, and Bass (1975) developed a model for students to study congenital heart disease while Hoffer, et.al. (1972) describe a model for teaching cardiopulmonary resuscitation. To provide experience in medical practice planning, Roberts, Murray, Kronman, and Fox (1977) developed an interactive medical planning package. Baum, Bergwall, and Reeves (1975) created a model for students to examine alternative programs of care for an urban population.

Recently, gaming has become a more popular means of providing students insight into health care problems. Reisman (1979), for example, has done extensive work in developing a dental practice management game. Two hospital based simulation games, one by Meredith (1978) and the other by Silvers (1976) have experienced growing use. Warner (1980) recently described a health planning game and Highland (1979) described a game for simulation of an epidemic. Games of these kind clearly provide outstanding opportunities for those who are not simulation modelers to experience, in a laboratory setting, the problems involved in operational and strategic problem solving. We believe their use will grow.

7. DEVELOPMENT OF GENERAL APPROACHES TO MODELING HEALTH CARE SYSTEMS

A retrospective examination of health care delivery systems reveals considerable similarity among applications. Most of the models take an operational viewpoint where patient demands are quantified and processed through a health care system that utilizes various personnel, facilities, or equipment, yielding a variety of output measures that generally deal with patient measures of effectiveness and resource utilization measures of effectiveness. Because of these similarities, general approaches to solving these problems have been proposed.

Fetter (1979) drew upon his experience to develop a modeling language called CML (Mills, Fetter, Averill 1976) which is used to build various simulation (and other modeling) languages. CML not only contains a number of capabilities for modeling but also the ability for data retrieval and analysis of large files. Using CML, Fetter and Mills (1975) built HOPSIM, a specialized simulation language for planning and designing various hospital and health care systems. Using a different perspective, Roberts (1979) examined simulation language development which was based on the recognition that many operational problems, particularly in health care, could be modeled as a network of queues and other logical elements. Based on this perspective, the simulation language called INS was developed (Roberts, Schier 1979). Although INS is now a general purpose simulation language, it grew out of a health care environment. More recent work caused the creation of another simulation language particularly useful in the modeling of medical decision making problems (Roberts 1979). In a related area, Standridge (1979) reports on the development of a data base management scheme for data acquisition, analysis, and organization growing out of his involvement in health manpower planning.

These developments illustrate the maturity of simulation applications in health care. Findings from health care applications are being generalized and these are forming the base for methodological development. We anticipate continued methodological growth resulting from ever increasing applications of simulation.

8. REFLECTIONS ON HEALTH CARE SIMULATION

Over 200 simulation models of health care systems have now been identified. These models represent the experience of many investigators in a wide range of health care environments. We would like to offer some generalizations based on several consistently appearing results.

1. Health care processes are similar from site to site. Although specific models were built at specific locations, when one reviews several models, say of a radiology department, the process of care is strikingly similar. Therefore, anyone building a model of a health care system would benefit from a review of other simulation models constructed in the general area. We conjecture that even though some aspects are different, the structure of the care process examined should be quite similar. Unfortunately, not all references document their models and consequently the utility of the actual simulation model may be limited. Consequently, we believe that publication of actual models should be encouraged so that other prospective analysts can benefit from previous work.

2. Assumptions relative to the distributions seem to have universal application. Lengths of stay in the hospital have been consistently modeled by lognormal distributions. The length of surgery time has been consistently reported as Gamma. Service times in ambulatory care are found to be Erlang (Gamma). Furthermore, the Poisson arrival process has been shown to be adequate for emergency arrivals and OB deliveries. Our conjecture is that these distributional assumptions are relatively universal and can be applied almost routinely. Furthermore, by careful attention to type of environment, the specific distributional parameters may be applied universally. This is another reason why specific, well documented simulation models should be published.

3. The classification of demands and services are often similar among similar settings. Although problems of classification remain, the careful modeler can benefit from the choices of previous researchers. This is the weakest of our conjectures and we suggest care in adapting the classifications, but we believe they are useful in many cases.

There is generally much to be gained by the sharing of mutual experience in scientific research, but health care simulation is often thought to be less widely applicable or beneficial to those seeking to construct their own models. We do not share this belief and encourage those simulating health care systems to consider their generalizable findings. Such would certainly assist a similar model building activity.

9. IMPLEMENTATION OF HEALTH CARE SIMULATIONS

Several have observed that relatively few of the published health care simulation models have had widespread implementation and a number of concerns have been voiced (Shuman 1975; Stimson, Stimson 1972). Clearly, simulation has been applied to a wide perspective of health care problems and although no single dramatic event in health care has occured, a number of changes have been reported and improvements made, illustrating the utility of simulation to operational problems in a very practical way. As quantitative techniques are continually exposed to administrators and health planners through such texts as the ones by Warner and Holloway (1978) and Griffith, Hancock, and Munson (1976), simulation will become less esoteric and have greater application within the health care setting. Also, the development of simulation languages and the ability to create data bases will clearly expand the influence of simulation. However, there remains impediments to implementing simulations in health care (England, Roberts 1978).

1. Lack of Economic Incentive; The financial structure of the U.S. health care system does not require health care institutions to explicitly demonstrate cost effectiveness in their operation. Expensive tests are billed to third party payers and the public resultantly demands the best available care without regard to its cost. The solution to this implementation problem lies outside the modeler's control. Health care institutions will not earnestly become concerned with using simulation modeling to lower the cost without decreasing the quality of their care unless they are economically or politically required or heavily rewarded for doing so. This contrasts sharply to the use of simulation in production industries where lowering cost within a quality constraint is a fundamental goal.

2. No Vested Authority; Health care administrators, physicians, elected public officials and patients all exercise control in various ways over the health care system. In production industries the management heirarchy that exists insures implementation of simulation results that demonstrate potential for system improvements. The diversity of authority in health care facilities thwarts the simplicity of a single administrative decision to change the system. The solution to this implementation problem again lies mostly in the political sphere.

3. Insufficient Data; Almost all modelers complain of lack of data, but in health care, data is particularly scarce. This occurs because health care institutions are not oriented to operations management and generally do not collect data on their service processes. Thus simulation modelers must work in data poor environments, often spending more time collecting and handling data than in building and analyzing the simulation model. Therefore, analysts engaging in a simulation study of health care systems should be prepared to undertake a substantial data collection activity.

4. Inadequate Models; Health care systems are composed of people serving people. Human behavior is very difficult to quantify and describe. Thus some simulation models just do not simulate actual system behavior accurately enough to warrant use of the simulation results. Evaluating the "success" of health care delivery systems is not simple to quantify either, so when a model is developed, there is little agreement about whether the model really demonstrates a significant system improvement. Simulators are increasing their imagination and creativeness in quantifying health care systems and progress is being made in this area as models build upon each other's concepts and results. The computer languages, simulation methodologies, and hardware systems available today for health care modeling have progressed a long way from the earlier fledgling models, but there are still new ideas to be explored.

5. No Institutionalization of Simulation; Only a few of the simulation models reviewed were developed by staff from the health institution being studied. Most are developed by students and faculty at Universities, sometimes in association with a hospital or health program. This relationship means that there is little commitment to followup or implementation. However, there is a growing number of analysts situated directly within hospital and health care programs actively engaged in simulation (for example, see Marsh 1979). These persons are having outstanding success working within the health care institution, hand in hand with administrators, nurses, physicians, etc. For the most part, they work on small but well-received applied projects and are internalizing simulation. As these efforts grow, simulation will become even more highly regarded.

6. Analysts and Administrators Lack Understanding; In health care, the people who "produce" health care and the managers responsible for implementing a simulation's results are one in the same. Thus the credibility of a simulation modeler by his medical peers is a key factor in whether the model's results will have an influence on the system being modeled. Simulators and engineers must earn the respect and understanding of the nurses and medical staff they seek to model. Academic programs which place industrial engineers and prospective health care modelers in a medical "internship" so they learn the issues, professional environment, and vocabulary of their medical peers is an important step toward reducing the number of unimplemented simulation models. Furthermore, as administrators are increasingly exposed to simulation as a tool for problem solving (as in Warner and Holloway 1978 and Griffith, Hancock, and Munson 1976), their understanding will grow, and they will better be able to direct the application of simulation.

10. THE FUTURE OF SIMULATION IN HEALTH CARE

In a previous paper (England, Roberts 1978), we counted the frequency and rate of the appearance of health care simulation models. Generally, our findings were that simulation activities in health care followed the topical health care interests. In the 1960s, the concern was with institutions, specifically hospitals. The late 1960s saw a growing interest in ambulatory care systems. The early 1970s reflected a national concern with health manpower. The later 1970s have witnessed the growth of health planning. Currently, the most topical health care issue is health care cost. Therefore, we expect that this will be a topic of chief concern among simulation modelers. However, the traditional areas of simulation modeling have not been abandoned and much work remains. As health care institutions and health care programs increasingly feel the "squeeze" of economic pressure, greater emphasis will be given to the cost-efficient. This heightened emphasis on efficiency should foster a productive environment for the use of simulation as a means of examining operational problems in the health services. Consequently, we expect greater internalization of simulation and a positive record of implementation.

From our perspective, we believe the following to be apparent:

1. Simulation will become institutionalized in hospitals and used routinely as a means of operational analysis. Improved simulation languages and tools, combined with the knowledge of previous work should stimulate this development.

2. Simulation will be depended upon increasingly as a means of health planning. Future expenditures and changes in programs of care will need simulation in order to evaluate proposals before they become reality.

3. Simulation will broaden its application in health care to include regulation and medical decision making. For example, the first application of simulation in a medical journal has appeared (Roberts, Maxwell, Gross 1980; in press). By expanding and extending simulation to a broader range of problems in health care, simulation will become a more accepted methodology for problem solving.

4. Simulation in health care will follow applications elsewhere by being used more frequently with analytical methods and be examined more thoroughly by statistical analysis of its output. We have cited several instances of optimization being used in conjunction with simulation and we have also cited instances when output analysis was a major concern. We expect increased emphasis in both areas in health care applications.

Simulation has increased our understanding of health care, and health care in turn has benefited from analysis by simulation. As simulation becomes increasingly a part of the health systems analysis, its routine application can be expected. In this way, the contributions of simulation will play an important part in improving the health and well being of mankind.

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