H

HALF SPACE

See **Linear inequality**.

HAMILTONIAN TOUR

In an undirected connected graph, a Hamiltonian tour is a sequence of edges that passes through each node of the graph exactly once. See **Graph theory**; **Traveling salesman problem**.

HAZARD RATE

See **Failure-rate function**; **Probability distribution selection**; **Reliability of stochastic systems**.

HEALTH CARE SYSTEMS

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INTRODUCTION: The field of operations research applied to health care experienced its major growth in the 1960s and the 1970s. The 1980s saw refinements and/or reapplications of this earlier work except for the area of medical diagnostic and therapeutic decision-making which caught the attention of many research physicians, and which is continuing to grow substantially. With the current trend to nationally structured quasi public health care systems in the world, interest in operations research in health care delivery is again on the rise.

The different studies in operations research applied to health care cover a broad variety of subjects most of which fall into five areas: scheduling, allocation, forecasting demand, supplies/materials planning, medical-decision making. We will examine each area by describing some of the different topics they include, and the operations research techniques used to approach the problems.

For extensive reviews of operations research in health care, see Fries (1976, 1979) and Pierskalla *et al.* (1993).

SCHEDULING: Scheduling problems in the health care sector apply to situations involving patients, nurses, physicians, facilities, vehicles, and other health specific providers and settings. Many models for nurse scheduling have been constructed. Maier-Rothe and Wolfe (1973) proposed a cyclical model where the nurses would have the same schedule on a regular basis. Mathematical programming approaches were also used to solve the nurse scheduling problem (Warner, 1976; Miller *et al.*, 1976). A comprehensive nurse scheduling model should include most of the following features: the preferences of the nurses, the minimum staff requirements, frequence of weekends off, maximum number of consecutive working days, varying shift lengths, shift rotation, but few attempts were made to include all of them because of the complexity of the problem. Goal programming is also used to meet more than one objective such as desired patient care staffing requirements, nurses' preferences, nurses' special requests, and minimum costs. Heuristic algorithms taking into account the combinatorial structure of the problem were also considered. Nurse scheduling problems still continue to arouse interest because there is not yet a model that can gather all the elements of the whole problem.

Most of the work on vehicle location and scheduling in health care delivery involves dispatching EMS (emergency medical service) vehicles, blood donor mobiles, and blood delivery vehicles. The EMS scheduling solution primarily assigns the closest vehicle to best satisfy the demand (Liu and Lee, 1988; Trudeau *et al.*, 1989). The blood delivery solution is more closely related to the multiple traveling salesman problem. In both areas, however, the problem and solution are very closely connected to the vehicle locations, and also to the demands which must be forecasted. Simulation was the technique of choice to help determine solutions to these complex comprehensive problems.

The scheduling problem of patients for outpatient services consists in constructing an appointment system that will reduce the staff idle time, and the patients' waiting time. A good coordinated approach in outpatient scheduling leads to a solution that maximizes a function which trades off the satisfaction and utilization of both patients and providers (Fries and Marathe, 1981). Inpatient scheduling systems are more complicated since they have more constraints and more objectives to achieve in addition to those faced by outpatient systems. Many approaches have been used for these problems such as simulation (Dumas, 1985), mathematical programming, and heuristic methods (Hancock and Isken, 1992).

ALLOCATION: Health care resources are increasingly limited. It is thus necessary for the providers of health services to determine how to allocate the different services, rearrange the capacities of different services and/or choose the site of the services. Most service capacity planning studies are concerned with allocating beds to services within a hospital to meet demand. The factors considered are categories of patients based on disease and sex, categories of beds, type of physicians, etc. The primary objective is to maximize the utilization of available beds while being able to admit immediately the emergency patients and to reduce the length of the waiting list for elective admissions (Dumas, 1985). Simulation is the approach most often used. Service capacity planning which is closely related to allocation also deals with patient flow through a health care service. Queueing theory and simulation techniques are used in many studies to determine the patient population movement from one service care level to another in order to minimize the waiting time.

The site/location problem in health care was formerly related to constructing new hospitals. Now this construction is a much less frequent event. So location problems currently involve locating expensive facilities such as scanners, outpatient facilities and other high cost technologies to minimize the costs or involve the location of ambulances to minimize the response time and to serve a maximum number of emergency calls (Pirkul and Schilling, 1988; Trudeau *et al.*, 1989). Mathematical programming approaches such as goal programming and integer programming as well as heuristic algorithms and simulation are used for these problems.

FORECASTING DEMAND: Forecasting demand in health care is necessary to estimate the future occurrence of a disease and demands for diagnosic services and/or treatment. It has been used to make better decisions for allocating resources and also to study the progression of diseases. The forecasting models used in health care are numerous. Among them are multiple linear regression, exponential smoothing, ARIMA, Box Jenkins models and Markov processes (Kao and Pokladnik, 1978; Kao and Tung, 1980). A given model will be more appropriate for a certain type of database accuracy, time constraints and other factors. There have been many applications of forecasting in health care to forecast admissions, census and discharge from hospitals, the need and demand for emergency transportation, for services in nursing home and specialized clinics (Lane *et al.*, 1985), or for specific services in hospitals or clinics. The large volume of research studies involving forecasting models indicates how essential they are in health care. Morever, the need to reduce the costs in health care will encourage operations researchers to provide even better forecasting solutions.

SUPPLIES/MATERIALS PLANNING: The supplies in health delivery situations consist of perishable and non-perishable items many of which are very time and location dependent. In these cases, it is very important to prevent shortages. Hence, most applications of inventory models in the health care sector concentrate on preventing shortages rather than on minimizing the costs of inventories. However, some studies considered costs in determining the inventory levels for a multi-item pharmacy warehouse or determining the amount of inventory needed for sterile supplies (Ebrahimzadeh *et al.*, 1985). More work is currently underway on stockless just-in-time inventories. Because blood is a perishable and critical product, most of the articles on inventory models in health care are on managing blood bank inventories (Prastacos, 1984).

MEDICAL-DECISION MAKING: Medical-decision making in detecting and treating disease has flourished since the early introduction of artificial intelligence and expert systems for cardio-pulmonary diseases in the 1970s. Paralleling this work was work on Bayesian decision trees to detect gastrointestinal diseases. Both approaches are now used extensively for the detection, prevention and treatment of hundreds of diseases. Many medical schools have introduced decision analysis in their regular curriculum (Pauker and Kassirer, 1987).

Data envelopment analysis (DEA), first proposed by Charnes and Cooper (1978), has seen a growing interest in applications in health care. Chiligerian and Sherman (1990) used DEA to evaluate physician decision-making efficiency in the provision of hospital services. Other researchers applied DEA to compare quality of care in different hospitals, and the efficiency of similar services in teaching hospitals.

See **Emergency services; Facility location; Forecasting; Goal programming; Hospitals; Medicine and medical practice; Practice of OR/MS; Queueing theory; Scheduling and sequencing; Simulation of discrete-event stochastic systems.**

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