# CHAPTER 27

# Industrial Engineering Applications in Health Care Systems

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## 1. INTRODUCTION TO HEALTH CARE DELIVERY SYSTEMS

This section gives a brief history of health care delivery in the United States for readers who may be unfamiliar with the health care industry. It also addresses government regulations and health care financing issues that impact the delivery of health care.

### 1.1. History of Health Care Delivery Systems

Historically, most health care has been delivered in hospitals. Initially, hospitals were founded, many of them by charitable organizations, to house poor people during epidemics. As medical technology

*Handbook of Industrial Engineering: Technology and Operations Management, Third Edition.*
Edited by Gavriel Salvendy  

advanced, hospitals actually became centers for treating patients. They also became resources for community physicians, enabling them to share high-cost equipment and facilities that they could not afford by themselves.

Some hospitals are government-owned, including federal, state, county, and city hospitals. Federal hospitals include Army, Navy, Air Force, and Veterans Administration hospitals. Nongovernment hospitals are either not-for-profit or for-profit. The not-for-profit hospitals are owned by church-related groups or communities and constitute the bulk of the hospitals in the country. Investor-owned for-profit hospitals are mostly owned by chains such as Hospital Corporation of America (HCA) and Humana.

### 1.2. Government Regulations

A number of federal, state, county, and city agencies regulate hospitals. These regulations cover various elements of a hospital, including physical facilities, medical staff, personnel, medical records, and safety of patients. The Hill-Burton law of 1948 provided matching funds to towns without community hospitals. This resulted in the development of a large number of small hospitals in the 1950s and 1960s. The enactment of Medicare legislation for the elderly and the Medicaid program for the poor in 1965 resulted in rapid growth in hospitals. Because hospitals were paid on the basis of costs, much of the cost of adding beds and new expensive equipment could be recovered. Many states developed "certificate-of-need" programs that required hospitals planning to expand or build a new facility to obtain approval from a state agency (Mahon 1978). To control expansion and associated costs, the National Health Planning and Resources Development Act was enacted in 1974 to require hospitals that participated in Medicare or Medicaid to obtain planning approval for capital expenditures over $100,000. The result was a huge bureaucracy at local, state, and national levels to implement the law. Most of the states have revised or drastically reduced the scope of the law. Many states have changed the review limit to $1 million. In other states, only the construction of new hospitals or new beds is reviewed (Steinwelds and Sloan 1981).

### 1.3. Health Care Financing

Based on the method of payment for services, patients can be classified into three categories. The first category includes patients that pay from their own pocket for services. The second category includes patients covered by private insurance companies. The payment for services for patients in the last category is made by one of the government programs such as Medicare. A typical hospital receives approximately 35% of its revenue from Medicare patients, with some inner-city hospitals receiving as much as 50%. A federal agency called the Health Care Financing Administration (HCFA) manages this program. Medicare formerly paid hospitals on the basis of cost for the services rendered to Medicare patients. Under this system of payment, hospitals had no incentive to control costs and deliver the care efficiently. To control the rising costs, a variety of methods were used, including cost-increase ceilings, but without much success. In 1983, a new means of payment was introduced, known as the diagnostic related group (DRG) payment system. Under this system, hospital cases are divided into 487 different classes based on diagnosis, age, complications, and the like. When a patient receives care, one of these DRGs is assigned to the patient and the hospital receives a predetermined amount for that DRG irrespective of the actual cost incurred in delivering the services. This system of payment encouraged the hospitals to deliver care efficiently at lower cost. Many of the commercial insurance companies such as Blue Cross and Blue Shield have also adopted this method of payment for the hospitals.

### 1.4. Emerging Trends

During the past decade, a few key trends have emerged. A shift to managed health care from traditional indemnity insurance is expected to continue. This has resulted in the growth of health maintenance organizations (HMOs) and preferred provider organizations (PPOs), which now account for as much as 60–70% of the private insurance in some markets. Employers have also been changing health care benefits for their employees, increasingly going to so-called cafeteria plans, where employers allocate a fixed amount of benefit dollars to employees and allow them to allocate these dollars among premiums for various services. This has resulted in increased out of pocket costs and copayments for health care for the employees.

Medicare has reduced payments for DRGs and medical education to the hospitals. It has put many health care systems in serious financial trouble. The increase in payments is expected to stay well below the cost increases in the health care industry. These trends are expected to continue in the near future (Sahney et al. 1986.)

Since the advent of the DRG system of payment, the length of stay has continually dropped in hospitals from an average of over 10 days in the 1970s to below 5 days. Hospital admission rates have also dropped because many of the procedures done on an inpatient basis are now being performed on an ambulatory care basis. Inpatient admissions and length of stay are expected to continue to decline, and ambulatory care is expected to continue to grow over the next decade.

Medically indigent people who have neither medical insurance nor coverage by federal and/or state programs continue to place a serious financial burden on health care institutions. In the past, hospitals were able to transfer the cost of indigent care to other payers under a cost-based payment system. But under the DRG-based payment systems, hospitals are unable to do so.

Hospitals have been experiencing shortages in RN staffing, especially in inpatient units and emergency rooms. The nursing shortages can be attributed to low starting salaries for nurses and potential nursing students opting for other carriers with regular daytime work hours. Nurses also have other opportunities within health care aside from the inpatient setting that do not require night shift rotation or weekend coverage. The nursing shortage is projected to continue for positions in inpatient units.

Another trend in the health care industry has been an increase in ambulatory care clinics and ambulatory surgical centers. Hospitals have developed freestanding ambulatory care centers as a means of penetrating new markets by providing easy access to primary care services to the growing number of HMO patients.

The other major trend is consolidation within the industry. Hospitals have been facing a bleak financial future. Hospitals have been consolidating to form larger and leaner health care delivery systems to take advantage of economies of scale. Usually there is a reduction in the number of excess inpatient beds and an elimination of duplicate services in a community as a result of these mergers. Industry consolidation is expected to continue in the coming years. It is expected that in most large cities only a few large health systems will account for most of the inpatient health care services.

## 2. INTRODUCTION TO INDUSTRIAL ENGINEERING IN HEALTH CARE DELIVERY SYSTEMS

Frank Gilbreth is considered to be the first to use industrial engineering tools for methods improvement in a hospital situation. He applied his motion study techniques to surgical procedures in 1913 (Nock 1913); (Gilbreth 1916). In the 1940s, Lillian Gilbreth published articles explaining the benefits of using methods-improvement techniques in hospitals and in nursing (Gilbreth 1945, 1950). In 1952, a two-week workshop was conducted at the University of Connecticut on the application of methods improvement in hospitals (Smalley 1982). Also in 1952, the American Hospital Association (AHA) created a Committee on Methods Improvement. This committee prepared several papers on methods-improvement activities in hospitals and published them in its interim report in 1954.

In the late 1950s, the American Hospital Association started offering workshops on methods improvement around the country. Universities added courses on the application of methods improvement in hospital administration and industrial engineering programs. Gradually, other industrial engineering techniques were studied and applied to various hospital problems. The growing use of industrial engineering techniques in hospitals resulted in the foundation of the Hospital Management Systems Society (HMSS) in Atlanta in 1961, which subsequently moved to Chicago in 1964. The Institute of Industrial Engineers also recognized the expanding role of industrial engineering techniques and formed a hospital section in 1964. This section changed its name to the Health Services Division in 1977, reflecting the broader scope of the field. In 1988, the Institute of Industrial Engineers approved the formation of the Society for Health Systems (SHS) to replace the Health Services Division. In 1987, HMSS changed its name to Healthcare Information and Management Systems Society (HIMSS) to recognize the growing role of information systems in health care. Both HIMSS and SHS offer a number of seminars and workshops throughout the year related to the application of information systems and industrial engineering in health care. They also cosponsor annual HIMSS conference in February and the annual SHS conference in September/October of each year. Many of the industrial engineers working in the health care industry are members of both organizations.

Educational institutions started offering industrial engineering programs with specialization in health care systems. Many industrial engineers today work for hospitals and health systems, while others work as consultants in health care. The industrial engineers working in health care systems are usually referred as management engineers or operations analysts. Smalley (1982) gives a detailed history of the development of the use of industrial engineering in hospitals.

Industrial engineers gradually realized that many industrial engineering techniques initially applied to manufacturing/production systems were equally applicable in service systems such as health care systems. Almost all of the industrial engineering tools and techniques have been applied to health care systems. In this chapter, the application of only some of these techniques to health care systems will be discussed. From the examples presented here, readers should be able to appreciate the application of other techniques to health care systems. The application of the following techniques in health care systems is discussed here:

1. Methods improvement and work simplification
2. Staffing analysis
3. Scheduling
4. Queuing and simulation

5. Statistical analysis
6. Optimization
7. Quality improvement
8. Information systems/decision support systems

The emphasis will be on the application in health care, not on the techniques themselves, because the details of industrial engineering techniques are given in the other chapters of this Handbook. Applications will be discussed using various hospital departments as examples. For individuals not familiar with health care systems, Goldberg and Denoble (1986) describe various hospital departments.

## 3. APPLICATIONS OF METHODS IMPROVEMENT AND WORK SIMPLIFICATION

### 3.1. Introduction

The terms *methods improvement, methods engineering, operations analysis,* and *work simplification* have been used synonymously in industrial engineering literature. These techniques use a systematic procedure to study and improve methods for carrying out any set of activities to accomplish a task. In health care systems, these could be the work methods used in the actual delivery of health care to the patients or the work methods utilized in support activities. One common tool used to document an existing process or work method is a flowchart, which can also be used to document a new process as it is developed prior to implementation. A flowchart allows a critical examination of the various steps of the process and assists in the identification of unnecessary steps and inefficiencies in the process. Flowcharts show each step of the process as well as decision points and various courses of action based upon the decision.

Other tools available for methods improvement that have been used in health care systems include a flow diagram and a paperwork simplification chart. A flow diagram can be used to visualize the flow of material and patients in a facility. It can help identify areas of congestion and assist in the planning of the physical layout of facilities. Paperwork-simplification charts are used to analyze and improve paper documents to provide the needed control and communication.

### 3.2. Application of a Flowchart to Document Patient Flow in an Outpatient Clinic

Figure 1 shows the flowchart for patient flow in an outpatient clinic starting from the time when a patient arrives at the reception counter to the time the patient leaves the clinic after the visit. This chart shows all the steps a patient goes through to complete a visit with the physician. Management engineers can critically examine each step to study the possibility of eliminating, simplifying, or modifying it. For example, this flowchart indicates that patients have to stand in line till a receptionist is available to serve them. If this wait is excessive, one alternative could be to have a sign-up sheet so the patients could sign it and then take a seat. When available, the receptionists could then call the patients to the counter to serve them.

## 4. APPLICATION OF STAFFING METHODOLOGIES

### 4.1. Introduction

*Staffing* refers to the number of employees of a given skill level needed in a department to meet a given demand for services. The determination of the staffing is basically a problem of work measurement. It requires listing all the different tasks done by a certain skill level in the department. The departmental tasks are classified as constant or variable. Constant tasks are those tasks that are not directly related to the departmental output, that is, they are independent of the level of demand for services. For example, cleaning the work area and equipment every morning in a blood-testing laboratory is a constant task that does not depend upon the number of specimens tested. Variable tasks are those that are directly related to the output of the department. For example, a variable task may be the actual testing of a specimen. The total time spent during a day in testing specimens would be equal to the time taken to test one specimen multiplied by the total number of specimens tested in a day.

After the identification of constant and variable tasks, the work content associated with each task is measured. The work content could be measured using any of the traditional work-measurement techniques such as stopwatch time study, predetermined motion time systems, and work sampling. Work content could also be established using the Delphi approach in which a group of individuals familiar with a well-defined task try to reach a consensus about the time required to accomplish the task. The frequency at which each variable task occurs per day is also determined. The total number of hours of work to be performed for each skill level is then determined by adding the time taken

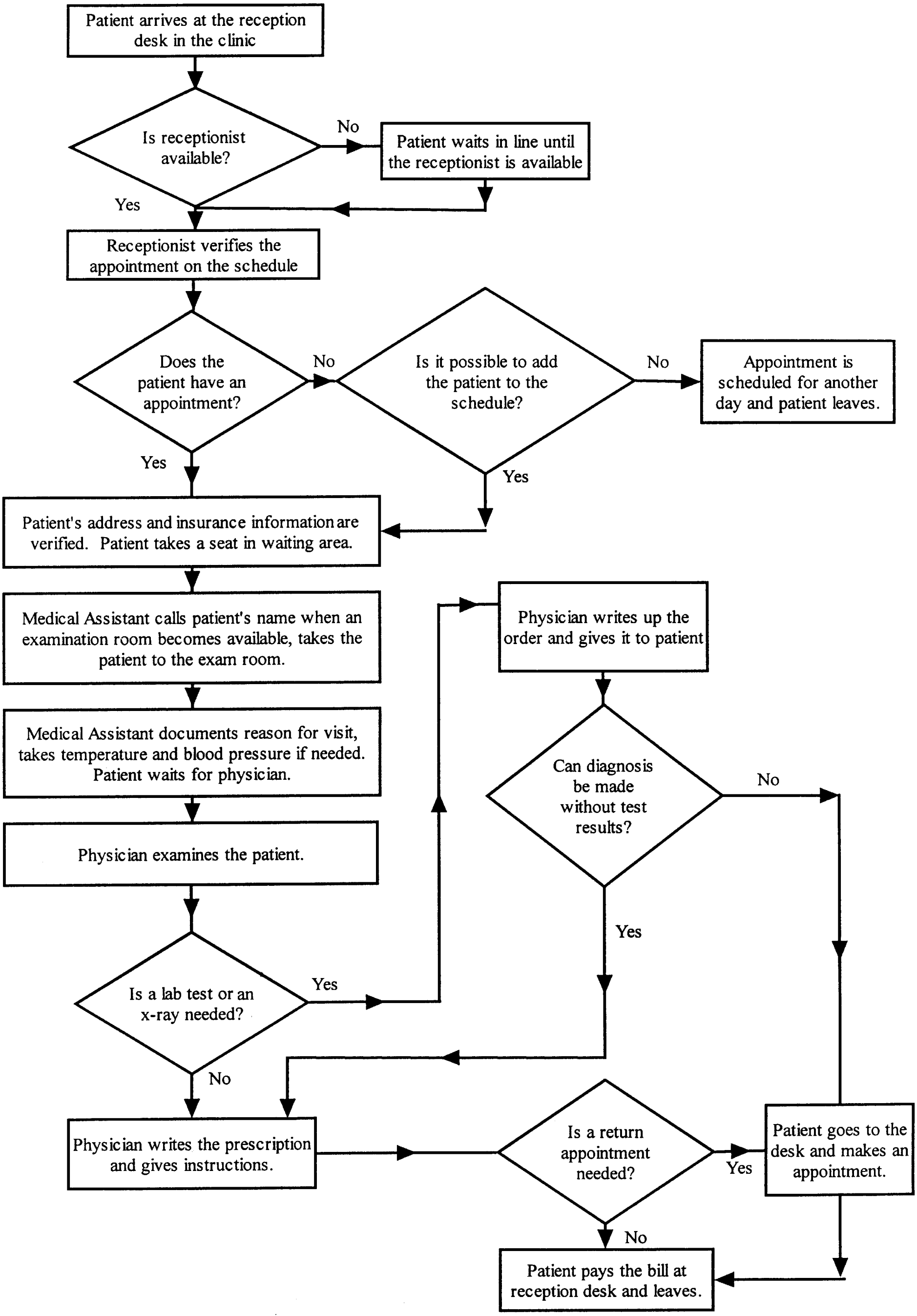


**Figure 1** Patient Flowchart in an Outpatient Clinic.

to perform the constant tasks and the variable tasks at a given frequency level associated with a given demand for services.

One disadvantage of using the common work-measurement techniques is that the process is very cumbersome and time-consuming. Moreover, any time the method changes, the work content of various tasks has to be measured again. Another alternative may be to use one of the standard-staffing methodologies available in the health care industry. These methodologies describe the typical tasks that are performed in a particular hospital department and assign a standard time to each task. Resource Monitoring System (RMS), developed by the Hospital Association of New York State, is an example of one such system.

The time available per full time equivalent (FTE) is also calculated. If the department is open 8 am to 5 pm with a one-hour lunch break and if two 15-minute breaks are allowed during the shift, the time available per FTE per day will be 7.5 hours. The actual required FTE depends on demand variability, coverage issues, scheduling constraints, skill level requirements, and similar factors. One approach is to determine the efficiency level (a number less than one) that could be expected because of these factors. Efficiency is defined as the ratio of the actual hours of work done to the actual number of hours used to do the work, including idle time, if any. The FTE needed is then determined using the following equation:

$$\text{FTE needed} = \frac{\text{total number of hours of work to be performed per day}}{\text{time available per FTE per day} \times \text{efficiency level}}$$

### 4.2. A Case Study in the Ambulatory Surgery Center

An ambulatory surgery center can be defined as a specialized facility organized to perform surgical cases in an ambulatory setting. Ambulatory surgery centers are normally staffed by registered nurses (RNs), who provide care in preoperative, operating, and recovery rooms. A staff of nurse anesthetists (CRNAs) works in the operating rooms and also performs patient assessments in the preoperative area before the patient enters surgery. Nurses' aides clean and package surgical instruments and assist with room turnover between cases. Room turnover involves cleaning and restocking the operating room between cases. The patient registration and all the initial laboratory work are done prior to the day of the surgery. On the day of surgery, the patient is asked to arrive one hour prior to the scheduled surgery time. After checking in with the receptionist, the patient is sent to preoperative area for assessment by CRNAs. After the surgery, the patient is in the recovery room until the patient is stable enough to be sent home.

The objective of the study was to determine the staffing requirement for each skill level including RNs, CRNAs, and nursing aides. As stated above, all the constant and variable tasks were identified for each skill level. The time required to perform each task was determined using a combination of approaches including direct observation and Delphi consensus-building methodology. The calculations for determining staffing requirements for nursing aides are shown in Table 1.

The actual efficiency should be computed and monitored each week. If there are definite upward or downward trends in efficiency, adjustments in staffing levels should be made. The work level at which a department is staffed is a critical parameter. One approach could be to perform a sensitivity analysis and compute the FTE requirement at various levels of case activity and then decide on the appropriate staffing level.

## 5. APPLICATION OF SCHEDULING METHODOLOGIES

### 5.1. Introduction

In health care systems, the term *scheduling* is used in a number of different ways. It can refer to the way in which appointments are scheduled for patient visits, testing procedures, surgical procedures, and the like. This form of scheduling is called work scheduling because patients represent work. In certain departments, it may be possible to move the workload from peak periods to periods of low demand to balance the workload. An example is an outpatient clinic where only a given number of appointment slots are made available. The number of appointment slots in a session determines the maximum number of patients that can be seen during that session, thereby restricting the workload to a defined level. In other departments, such as an emergency room, the patients or workload cannot be scheduled.

Another use of the this term is in the scheduling of personnel in a department based on the varying demand for services during the various hours of the day and days of the week while providing equitable scheduling for each individual over weekends and holidays. It must be noted that in the inpatient setting in health care, certain staff, such as nursing staff, need to be scheduled for work even over holidays. In the scheduling of personnel, each individual is given a schedule indicating what days of the week and what hours of the day he or she would be working over a period.

**TABLE 1 Staffing Requirements for Nursing Aides**

| | | |
|---|---|---|
| (A) Variable Activities | | |
| Room Turnover | | 10.0 min/case |
| Cleaning of Instruments | | 12.0 min/case |
| Sorting and Wrapping of Instrument Sets | | 6.0 min/case |
| Total for Variable Activities | | 28.0 min/case |
| (B) Constant Activities | | Minutes per Day |
| Testing Equipment | 5 min/day | 5 min/day |
| Morning Set-up | 10 min/day | 10 min/day |
| Cleaning of Sterilizers | 30 min × 9 sterilizers per week | 54 min/day |
| Running Spordi Test | 90 min/day | 90 min/day |
| Stocking Supply Room | 15 min/day | 15 min/day |
| Checking for Outdates | 2 hrs/week | 24 min/day |
| Operation of Sterilizers | 3 hrs/day | 180 min/day |
| Stocking Scrub Area | 20 min/day | 20 min/day |
| Prepare Suction Containers | 30 min/day | 30 min/day |
| Taking Specimens to Lab | 1 hr/day | 60 min/day |
| Taking Supplies to Station | 1 hr/day | 60 min/day |
| Prepare Wrapper/Stock | 1 hr/week | 12 min/day |
| Other Misc. Tasks | 1 hr/week | 12 min/day |
| | Total Constant Activity Time | 572 min/day |
| (C) Total Work Per Day at 100 Cases per Day | | |
| Constant Activity Time | | 572 min/day |
| Variable Activity Time | 23 min/case × 100 cases/day | 2300 min/day |
| | Total Work per Day | 2872 min/day |
| (D) Staffing Requirement at 90% Efficiency | | |
| Time Available per FTE per Day | 7.5 hr/day × 60 min/hr | 450 min/day |

Required FTE = (Work per Day in Minutes)/(Available min/day/FTE × Efficiency)
= (2872 min/day)/(450min/day/FTE × 0.9)
= 7.1 FTE

## 5.2. Work Scheduling

Some of the areas where work scheduling is possible are elective admission scheduling, case scheduling in operating rooms, appointment scheduling in outpatient clinics, and appointments for radiological procedures and other testing such as amniocentesis. These are the areas where there is not an immediate and urgent need for services. To help determine the demand for services and understand the variability in demand, the workload data are collected by day of the week and hour of the day. In certain areas, it may be possible to smooth out the peaks and valleys in demand. For example, workload at a call center, where patients call by phone to schedule an appointment, can be shifted from busy hours to slow hours by playing a message on the phone as the patients wait to be served advising them to call during specific periods for reduced wait. After the workload has been smoothed, a decision is made to meet the demand a certain percentage of the time. After the staffing requirements are determined for this demand level using the methodologies discussed in the last section, staff is scheduled. Workload will then basically be restricted by the staff schedule.

Appointment slots are created based upon the type of work to be done and the number of providers available by hour of the day and day of the week. Appointments are scheduled as patients call for appointments. Once the appointment slots are filled, no additional work is scheduled. Appointment scheduling can be done using a manual system where an appointment book is maintained and the appointments are made by filling in the available slots. A number of computerized systems are on the market that basically allow the computerization of manual appointment books. These systems have the capability to search for available appointment slots meeting the time restrictions of the patient.

### *5.2.1. Appointment Scheduling in a Primary Care Clinic*

Most people have a specific physician whom they see when they have a health-related problem. Individuals belonging to an HMO (health maintenance organization) select a primary care physician who takes care of all of their health care needs. For infants and young children, this would be a pediatrician, and for adults and teenagers, an internist or a family practitioner. Appointment scheduling or work scheduling in a primary care clinic (internal medicine) is discussed here.

An internal medicine clinic had been struggling with the appointment scheduling issue for a period of time. In particular, they wanted to determine the number of slots to be provided for physical exams, same-day appointments, and return appointments. The first step was to estimate the total demand for physical exams and for other appointments in the clinic. Data on average number of visits per person per year to the internal medicine clinic were available from past history. Multiplying this number by the total number of patients seen in the clinic yielded an estimate of total number of visits to be handled in the clinic.

The number of visits to the clinic varied by month. For example, clinic visits were higher during the flu season than in the summer months. Past data helped in the estimation of the number of visits to be handled each month. It was determined that the number of visits varied by day of the week, too. Mondays were the busiest and Fridays the least busy. The number of visits to be handled each day of the month was estimated based on this information. Staff scheduling was done to meet this demand. The total number of appointment slots was divided among physical exams, same-day visits, and return visits based on historical percentages. Other issues such as no-show rates and overbooking were also taken into account in appointment scheduling.

### 5.3. Personnel Scheduling

Once the work has been scheduled in areas where work scheduling is possible and the staffing requirements have been determined based upon the scheduled work, the next step is to determine which individuals will work which hours and on what days. This step is called personnel scheduling. In other areas of the hospital, such as the emergency room, where work cannot be scheduled, staffing requirements are determined using historical demand patterns by day of the week and hour of the day. The next step again is to determine the schedule for each staff member.

The personnel schedule assigns each staff member to a specific pattern of workdays and off days. There are two types of scheduling patterns: cyclical and noncyclical. In cyclical patterns, the work pattern for each staff is repeated after a given number of weeks. The advantage of this type of schedule is that staff members know their schedules, which are expected to continue until there is a need for change due to significant change in the workload. The disadvantage is the inflexibility of the schedule in accommodating demand fluctuations and the individual needs of workers. In noncyclical schedules, a new schedule is generated for each scheduling period (usually two to four weeks) and is based on expected demand and available staff. This approach provides flexibility to adjust the staffing levels to expected demand. It can also better accommodate requests from workers for days off during the upcoming scheduling period. But developing a new schedule every two to four weeks is very time consuming.

A department may allow working five 8-hour days, four 10-hour days, or three 12-hour shifts plus one 4-hour day. The personnel schedule has to be able to accommodate these various patterns. The schedule must also provide equitable scheduling for each individual when coverage is needed over weekends and holidays.

Personnel schedules are developed by using either a heuristic, trial-and-error approach or some optimization technique. Several computerized systems are available using both types of approaches.

Warner (1974) developed a computer-aided system for nurse scheduling that maximizes an expression representing the quality of schedule subject to a constraint that minimum coverage be met. Sitompul and Randhawa (1990) give detailed review and bibliography of the various nurse-scheduling models that have been developed.

## 6. APPLICATION OF QUEUING AND SIMULATION METHODOLOGIES

There are a number of examples of queues or waiting lines in health care systems where the customers must wait for service from one or more servers. The customers are usually the patients but could be hospital employees too. When patients arrive at the reception desk in a clinic for an appointment, they may have to wait in a queue for service. A patient calling a clinic on the phone for an appointment may be put on hold before a clinic service representative is able to answer the call. An operating room nurse may have to wait for service at the supply desk before a supply clerk is able to handle the request for some urgently needed supply. These are all examples of queuing systems where the objective may be to determine the number of servers to obtain a proper balance between the average customer waiting time and server idle time based on cost consideration. The objective may also be to ensure that only a certain percentage of customers wait more than a predetermined amount of time (for example, that no more than 5% of the patients wait in the queue for more than five minutes.)

In simple situations, queueing models can be applied to obtain preliminary results quickly. Application of queueing models to a situation requires that the assumptions of the model be met. These assumptions relate to the interarrival time and service time probability distributions. The simplest model assumes Poisson arrivals and exponential service times. These assumptions may be approximately valid for certain queues in health care systems. Incoming phone calls to a call center for scheduling appointments have been shown to follow Poisson distribution. Usually the service times are also approximately exponentially distributed. Queueing models with Poisson arrivals and exponential service times have also been applied to emergency rooms for determining proper staffing of nurses and physicians (Hale 1988). From the data collected over a period of time, he was able to verify the validity of assumptions made in the model and determine the average waiting time and average number of patients waiting for service.

In situations where a simple queueing model is not applicable or a more accurate result is desired, simulation models are used. Simulation models are also used when there are complex probabilistic systems with a number of entities interacting with each other. These models are also useful during the design stage to investigate the effect of changes in various parameters in a system.

Simulation models have been extensively used in the analysis of emergency rooms (Weissberg 1977; Saunders et al. 1989). Ortiz and Etter (1990) used general-purpose simulation system (GPSS) to simulate the emergency room. They found simulation modeling to be a better approach even for simple, less complex systems because of its flexibility and capacity to investigate various alternatives. Dawson et al. (1994) used simulation models to determine optimal staffing levels in the emergency room. McGuire (1997) used a simulation model to investigate various process changes and choose a solution that significantly reduced the length of stay for patients in the emergency room.

Simulation models have also been extensively used in other areas of health care systems. Roberts and English (1981) published a bibliography of over 400 articles in literature related to simulation in health care. The *Journal of the Society for Health Systems* (1992b, 1997) published two issues dedicated to health care applications of simulation. Bressan et al. (1988) and Mahachek (1992) discussed generic structure for simulation in health care. Dumas and Hauser (1974) developed a simulation model to study various hospital admission policies. Kachhal et al. (1981) used GPSS to simulate outpatient internal medicine clinics in order to investigate various clinic consolidation options. They used another model to determine optimal staffing for audiologists administering hearing tests ordered by ear, nose, and throat (ENT) physicians. Dumas (1984) used simulation in hospital bed planning. Hunter et al. (1987) used a model to simulate movement of surgical patients in a facility. Levy et al. (1989) developed a simulation model using SIMAN to assist in the design of a new outpatient service center. Wilt and Goddin (1989) simulated staffing needs and the flow of work in an outpatient diagnostic center. Lowery and Martin (1993) used a simulation model in a critical care environment. Cirillo and Wise (1996) used simulation models to test the impact of changes in a radiology department. Schroyer (1997) used a simulation model to plan an ambulatory surgery facility. Benneyan (1997) conducted a simulation study of a pediatric clinic to reduce patient wait during a visit to the clinic.

## 7. APPLICATION OF STATISTICAL METHODS

Several statistical methods have been used in the analysis and improvement of health care systems. Variability is the fact of life in any kind of data collected in health care, and statistical methods are the tools needed to understand this data. In this section, some common examples of the use of statistical analysis and modeling in health care will be presented.

As stated above, use of queuing and simulation models requires collection of data regarding the probability distribution of interarrival times for customers and service times. Use of a specific queuing model requires that the assumptions regarding the probability distributions in the model are valid. Industrial engineers must be able to verify that the collected data fit the assumed probability distribution. Similarly, simulation models need the data regarding various service times and other probabilistic elements of the model. Statistical methods have also been used to study and manage variability in demand for services (Sahney 1982).

### 7.1. Use of Regression Models

Regression models can be used to predict important response variables as a function of variables that could be easily measured or tracked. Kachhal and Schramm (1995) used regression modeling to predict the number of primary care visits per year for a patient based upon patient's age and sex and a measure of health status. They used ambulatory diagnostic groups (ADGs) encountered by a patient during a year as a measure of health status of the patient. All the independent variables were treated as 0–1 variables. The sex variable was 0 for males and 1 for females. The age of the patient was included in the model by creating ten 0–1 variables based on specific age groups. The model was able to explain 75% of the variability in the response variable. Similar models have been used to predict health care expenses from patient characteristics.

### 7.2. Determination of Sample Size

Industrial engineers frequently encounter situations in health care systems where they need to determine the appropriate amount of data needed to estimate the parameters of interest to a desired level of accuracy. In health care systems, work-sampling studies are frequently done to answer questions such as "What percentage of a nurse's time is spent on direct patient care?" or "What fraction of a clinic service representative's time is spent on various activities such as answering phones, checking-in the patients, looking for medical records, and the like?" In work-sampling studies, the person being studied is observed a predetermined number of times at random time intervals. For each observation, the task being performed is recorded. The estimate of the fraction of time spent on an activity is obtained by dividing the number of occurrences of that activity by the total number of observations.

The number of observations needed for a work-sampling study can be calculated from the following formula:

$$N = \frac{Z^2 \times p(1 - p)}{I^2}$$

where $N$ = number of observations
$Z$ = normal probability distribution factor, based on confidence level
$p$ = unknown fraction to be estimated
$I$ = desired margin of error in estimation

It is common to use a 95% confidence level for which the value of $Z$ in the equation is 1.96. The value of I needs to be selected based upon the situation. For example, if the fraction being estimated is in 0.4–0.6 range, a value of I as $\pm 0.02$ may be acceptable, but $\pm 0.05$ may be too high. The value of $p$ to be used in the equation poses a problem because this is the unknown fraction one is attempting to estimate from the data. If, from past experience or from literature, an approximate value of $p$ is known, it can be used in the calculation of $N$. Another approach is to use $p = 0.5$ because it results in the largest value of $N$ for fixed values of $Z$ and $I$. If the computed value of $N$ is too large to observe due to time and cost constraints, the only choice is to tolerate a larger possible error or a lower level of confidence.

A similar formula is also available for determining the sample size in situations that require determination of actual time to perform a task. For example, for a staffing study in a call center, one may need to estimate average time needed to service a phone call.

### 7.3. Use of Control Charts

Control charts have been used in health care as visual tools to observe the performance of a process over a period of time and alert the managers when an investigation may be necessary to identify an external cause that may have affected the performance. Individual (X) and moving range (MR) charts have been used for measurement data such as patient wait time, turnaround time for a test, number of times an error is made during a day, and length of stay for a particular diagnostic related group (DRG). P-charts have been used for fractions or percentages. Examples include patient satisfaction data, percentage utilization of a resource, bed occupancy expressed as % of total beds, and fraction of patient transport requests handled within 15 minutes of request. Cumulative sum charts have been used to detect small but significant changes in the mean. Kachhal and Schramm (1995) describe a bed model where auto regressive integrated moving average was used on a control chart with economic control limits to manage bed capacity at a hospital.

## 8. APPLICATION OF OPTIMIZATION MODELS

The best-known application of optimization models has been in the context of nurse scheduling. Warner (1976) formulated the problem of determining the optimal nurse schedule as a two-phase multiple-choice programming problem and solved it using a modified version of Balintfy's algorithm. In his formulation, the objective is the determination of the schedule that maximizes an expression representing the quality of the schedules, quantifying the degree to which the nurses like the schedules they would work. The solution is determined subject to the constraints that the minimum coverage requirement for each shift and for each skill level be met. The popular ANSOS nurse-scheduling software uses this model. Warner et al. (1990) discuss automated nurse scheduling software.

Trivedi (1976) studied the problem of the reallocation of nursing resources at the beginning of each shift. He developed a mathematical model that minimizes the total severity index for the hospital, which is a measure of the need for an additional staff member by skill level. The model was solved using a branch-and-bound algorithm to determine the optimal assignment of nurses by skill level to various inpatient units.

Fries and Marathe (1981) used mathematical models to determine the optimal variable-sized multiple-block appointment system. Calichman (1990) used a linear programming model to balance the bed demand among various surgical services.

## 9. APPLICATION OF QUALITY-IMPROVEMENT TOOLS

The concepts of quality control, quality improvement, and quality management in the United States largely evolved from the efforts of Dr. W. Edward Deming, Dr. Joseph Juran, and Philip Crosby. Manufacturing industries were first to apply these concepts to achieve significant improvements in the quality of manufactured goods while reducing costs. During the late 1980s, the health care industry started using some of these methods to improve quality of health care delivery and reduce costs. Many hospitals started continuous quality improvement (CQI) and total quality management (TQM) programs. Sahney et al. (1989) summarize 10 common points from the quality philosophies of Deming, Juran, and Crosby and conclude that they can be applied to any industry, including the health care industry, to improve quality.

Continuous quality improvement focuses on improvement of various processes in a health care organization. It starts with identifying the customers and their needs for each of the processes. The objective is to improve the processes to meet the needs of the customers. All the changes are data driven. Key quality characteristics are identified and measured to track improvements. The physicians and hospital employees are trained in quality concepts and tools for improvement. Some of these tools are the Pareto chart, the cause–effect (or fishbone) diagram, flowcharts, run charts, and control charts. These tools assist in the documentation, analysis, and improvement of processes. Sahney and Warden (1991), and Gaucher and Coffey (1993) give a good overview of the application of CQI approach in health care. A popular CQI methodology is FOCUS-PDCA. Griffith et al. (1995) give a description of this methodology.

Another term in the quality improvement effort that has gained popularity during the late 1990s is *process reengineering.* While the CQI approach looks at making incremental improvements in the processes, reengineering efforts look at radical redesign of systems and processes to achieve major improvements in the cost and quality of services (Hammer and Champy 1995). Kralovec (1993) provides a good introduction to applying reengineering techniques to health care. The proceedings of the Quest for Quality and Productivity in Health Services Conferences that have been held each year since 1989 provide numerous examples of the application of total quality management, CQI, and reengineering methods in health care systems.

## 10. APPLICATION OF INFORMATION SYSTEMS/DECISION SUPPORT TOOLS

Many projects conducted by industrial engineers in health care deal with the use of information systems to improve quality and performance. There is a need to take a team approach in information system-related projects. A project team is needed that has individuals from management engineering and information services as well as the user department. The role of an industrial engineer on this team is to first interview the client department to determine the user requirements. The requirements are then used in the request for proposal (RFP) process to obtain proposals from vendors of information systems. Subsequently, the evaluation of proposals is also done on the basis of meeting these requirements as well as other factors. Industrial engineers are also used in the implementation phase to redesign the manual processes in the client department because these processes usually require major changes after the implementation of an information system. Kachhal and Koch (1989) report on the development of user requirements for a management information system for an operating room and the evaluation of the systems available in the market in meeting these requirements.

Decision support systems (DSS) have become a standard component of hospital information systems. They allow managers to look at financial data on a product line basis. A product line is a collection of one or more diagnostic related groups (DRGs). DSS are able to integrate various sources of data and give managers the capability for ad hoc reporting, building models to project revenues and costs, analyzing various reimbursement scenarios, and the like. The *Journal of the Society for Health Systems* (1991) published an issue with focus on decision support systems that presents a good overview of DSS in health care.

The other type of DSS used in health care are the clinical decision support systems (CDSS), which use a set of clinical findings such as signs, symptoms, laboratory data, and past history to assist the care provider by producing a ranked list of possible diagnoses. Some CDSS act as alerting systems by triggering an alert when an abnormal condition is recognized. Another set of these systems act as critiquing systems by responding to an order for a medical intervention by a care provider. Several systems that detect drug allergies and drug interactions fall into this category. Another use of CDSS is in consulting systems that react to a request for assistance from a physician or a nurse to provide suggestions about diagnoses or concerning what steps to take next. The application of CDSS in implementing clinical practice guidelines has been a popular use of these systems. Doller (1999) provides a current status of the use of these systems as medical expert systems in health care industry. The author predicts that the major use of CDSS in future will be in implementing clinical guidelines and allowing nonphysicians to handle routine care while directing the attention of true medical experts to cases that are not routine.

While some industrial engineers may be involved in the development of home-grown DSS or CDSS, the role of other industrial engineers is still in the evaluation and cost–benefit analysis of the standard systems available in the market.

## 11. APPLICATION OF OTHER INDUSTRIAL ENGINEERING TECHNIQUES

The application of other industrial engineering techniques such as forecasting, inventory control, materials management, facilities planning, economic analysis, and cost control is also common in health care systems. Examples of many of these applications are available in the proceedings of the annual Quest for Productivity and Productivity Conferences of the Society for Health Systems and the Healthcare Information and Management Systems Society Conferences. See also *Journal of the Society for Health Systems* (1992a), and Sahney (1993) on the use of industrial engineering tools in health care.

## 12. FUTURE TRENDS

Most healthcare systems around the country are facing serious financial problems due to the reductions in Medicare and Medicaid reimbursements. Health maintenance organizations (HMOs) have also reduced payments to health systems for services due to reductions in health care premiums forced by competition from other HMOs and by employers looking for cost reductions in their own organizations. Health care institutions are looking for ways to reduce costs while maintaining or improving quality. Industrial engineers are being asked to conduct benchmarking studies to identify areas where costs are higher than the norm and need reduction.

The financial problems are also leading to mergers and takeovers of financially troubled hospitals by health care systems in better financial health. Industrial engineers are being asked to work with individuals from finance on projects related to mergers and consolidation of services to evaluate the financial impact of alternative courses of action.

Many health care systems have undertaken TQM programs that include training of managers and supervisors in quality improvement tools such as flowcharts, cause–effect diagrams, run charts, and control charts. Quality improvement teams (QITs) consisting of employees from the departments in which the process resides are now conducting many of the studies previously conducted by industrial engineers. Industrial engineers are being asked to serve on these teams as facilitators or in staff capacity to conduct quantitative analysis of the alternatives.

Although simulation tools have been available to health care systems for decades, it is only recently that simulation models have been increasingly used as tools to model real systems to predict the impact of various policies and resource levels. Administrators and department managers are aware of the capabilities of these models and are requesting the use of simulation models to make sound decisions. The availability of reasonably priced, user-friendly simulation packages has increased the use of simulation modeling. The same is true for advance statistical tools. With the availability of user-friendly statistical software, more sophisticated statistical models are being built to guide in decision making.

Another area gaining attention is supply chain management. As health care systems are looking for ways to reduce costs without impacting the quality of patient care, procurement of supplies has stood out as an area where substantial reductions can be achieved through supply chain management. Some hospitals are having some of their supplies shipped directly from manufacturers to the user departments, bypassing all the intermediate suppliers and distributors. Other hospitals have eliminated their warehouses and distribution centers, giving the responsibility for daily deliveries and restocking of departments to external vendors. Industrial engineers are evaluating the alternative courses of action in supply chain management.

Industrial engineers are also working for consulting companies contracted by health care systems to assist them out of financial problems. The use of sophisticated industrial engineering tools in health care still lags behind the use in manufacturing industry. Over the next decade, it is expected that the use of these tools will become more prevalent in health care.

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