Review Article

Computers in Hospital Management and Improvements in Patient Care—New Trends in the United States

William P. Pierskalla and Deirdre Woods

This article discusses the current state of informations systems in hospital management. Decision Support Systems (DSS) for the management, administrative and patient care units of the hospital are described. These DSS's include market planning, nurse scheduling and blood screening systems. Trends for future uses of information systems in the hospital environment are addressed.

INTRODUCTION

The purpose of any health care delivery system is to prevent or cure disease or, if that is not possible at the time, to ameliorate its development or its symptoms. This purpose is achieved through the efforts of a well-structured system of patients, providers, institutions, facilities, equipment, and payers cast in the context of its environment. But the prevention, cure, or amelioration of disease is expensive, has varying quality, is frequently not easily accessible, and often is not the same level of intensity for all. Consequently this system must function in an environment of cost control, quality assurance, open access, and equity of delivery. To do this it must have *information*.

The entire health care delivery system, and more particularly the hospital care delivery system, is built on the appropriate *people* having the appropriate *information* at the right time in order to deliver the *optimal care* to the patient. This information is critical

and comes in many forms—oral, written, images, and most important for modern times, computer screens and copy. It is ubiquitous and as our health care systems become more and more complex, the demand for decision-aiding and decision-making uses of information grow exponentially.

Information systems (IS) have a key role in the delivery of health care in the United States. In combination with decision and model based support systems IS contributes to improved decision making, improved quality of patient care, improved productivity, and reduced costs. In the area of improved decision making, managers can now conduct extensive strategic planning, market analyses, technology assessment, and demand forecasting to appropriately direct the institution. They can also assess the level of risk incurred as the institution adds new services, new technologies, and new facilities; or modifies or eliminates old. Clinicians, nurses, and other providers can call on protocols, algorithms, expert systems, and other models to aid in prognoses, diagnoses, and treatment. In the area of improved quality of patient care, the correct diagnosis and treatment are critical. But also IS contributes to improved quality by reduced waiting time for orders, information, and results, to the elimination of unnecessary services and orders, to reduced errors, and to increased satisfaction by the providers and the patients. In the area of improved productivity, IS leads to better staffing patterns, improved scheduling, appropriate supplies, equipment, and materials, and elimination of duplication and redundant systems and actions. Finally, all of the above benefits affect costs—the installation of IS and support systems to achieve these benefits raise costs whereas the improvements in management, administration, and patient care delivery lower costs. In some cases the costs saved exceed the costs incurred. In others they don't but the benefits received are worth the expense. In most cases it is not actually known whether benefits exceed costs or vice versa.[1]

As stated above information always has, is, and will be vital to optimal care delivery. But the role of computers in fulfilling a portion of this information need has only emerged in the past three decades and is still greatly evolving. Before 1960 there was very little use of computers in health care delivery. Most information needs were met by oral, written, manual, and largely local self-contained activities of the providers and administrators. From 1960 to 1969 all large health care institutions had large batch data processing capabilities. These facilities were almost entirely used for administrative systems processing—payroll, billing, registration, admissions, etc. There was some interest in their use for clinical purposes but no software, appropriate hardware, or trained programmers and users were available to do the job effectively. Furthermore, equipment costs were so high that purchases could not be justified for the presumed benefits.

The decade of the 1970s saw not only the overwhelming success of information processing but also the development of on-line systems at many large medical centers. IS also diffused to small to medium-sized hospitals and health care delivery settings such as HMOs, physician practices, health agencies and long-term care institutions. A few of the large health care chains and other multiple systems began to tie their operations and planning activities together. With the continuing sharp rise in hardware power and its significant drop in price, it became obvious that the greatest cost and the greatest constraint to further use of computing was software development. The clinically oriented software which was developed in this period tended to complement the skills of the users by handling large amounts of data more effectively. Some examples of this are the display

of CAT images, complete ECG images, ICU monitoring, and lab test and other protocols. Except for a few research sites, knowledge-based systems such as MYCIN and similar software did not replace any of the decision activities of the clinical users. On the other hand managers and administrators were beginning to use decision support systems that not only aided in making decisions but also made decisions. Examples in this arena are nurse staffing and scheduling, ADT programs, and surgery and recovery suite scheduling.

By the beginning of the 1980s the PC technology was well ensconced in the computer world and was making its way into the health care delivery system. Figure 1 demonstrates this growth in PC usage. To utilize this technology most effectively reliable multivendor multicomputer networks were being built and installed. At the same time computing power and electronic storage capacity exploded at the desk top site. We could now talk confidently about the development of large decision support systems, large integrated hospital IS and the construction of knowledge-based systems for general use. By this time also we had built a very large base of knowledgeable computer scientists, programmers, and sophisticated users. These users are still primarily in the management and administration ranks but there is a large and growing group of clinicians, nurses, and other providers who are not only less threatened by the computer and feel comfortable with it but also are actively pursuing the development and purchase of new software. Much of the development of clinical knowledge-based systems is still at the research level and is not available commercially. In the first place it is still too expensive to create and implement and second the clinicians are still reluctant to adopt it. However, there is now a large and growing group of software firms which market clinical DSS and IS and also market some knowledge-based management and administrative systems. They have long marketed DSS and large IS to these latter groups.[2]

What we are also seeing in this decade of the 1980s in the United States is the growth
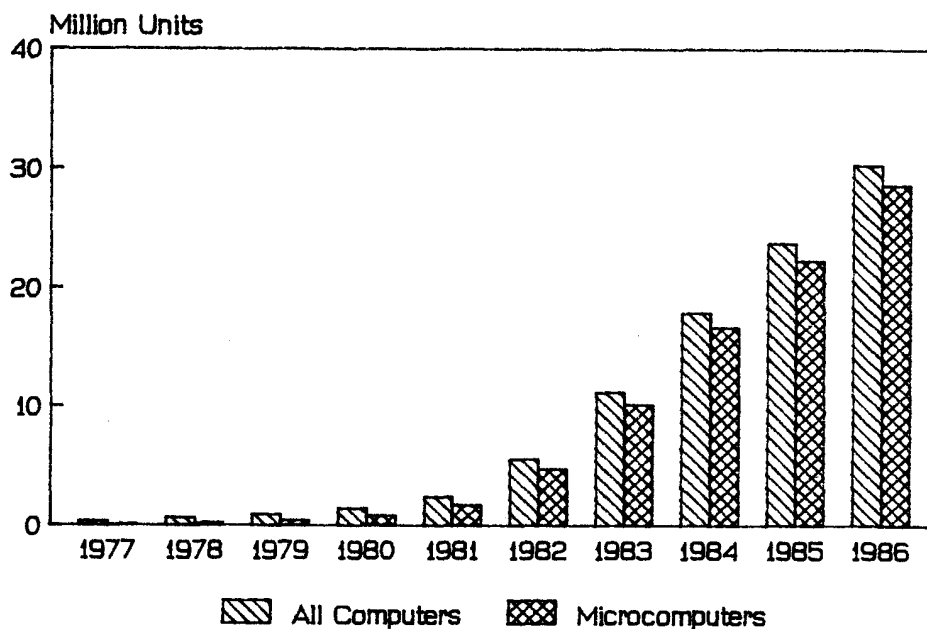
Figure 1. Computers in use (manufactured and sold in the United States).

of the PC environment in all of the small hospitals in rural and suburban areas.[3] The large mainframes were too costly for these hospitals and the skilled personnel to operate them were unavailable in the past so they often turned to time sharing systems. It is now possible to buy a system for approximately $1300 which would have cost $1 million in 1956. With turnkey systems from many vendors and large computing power at low prices, largely unskilled users can and do benefit from their adoption. Furthermore, more and more of these small hospitals are linking clinically to large medical centers via telecomputer networks to retrieve information on library sources, laboratory reports, clinical protocols, and electronic mail.[4] These networks and information links are also being extended to physician offices, home health agencies, and long-term care settings.

The U.S. Health Care System Today

Possibly the greatest factor pushing new managerial and administrative computing endeavors in the United States today has been the emergence of the prospective payment system (PPS) largely in the form of Medicare diagnosis-related groups (DRG) reimbursement. Although originally conceived as a productivity enhancing tool by its authors, the DRG has become the leading factor in the federal government's efforts to control Medicare costs. Other payers such as Blue Cross and insurance companies also view DRGs in this manner. With the old retrospective reimbursement systems in the past, DSS and IS were designed to maximize reimbursement with little or no concern for costs. Now there is the real possibility that a hospital or other health care center could lose money consistently and go out of business or be forced to merge or otherwise change its way of delivering care. For this reason a hospital must now also minimize its costs and deliver quality care and insofar as possible maximize revenue. Consequently the hospital must now know who its customers are, where its markets are and will be, and what it *actually costs* to treat each patient. Most hospitals are now subject to the same forces and pressures as a business and must be run like a business. The executives are now businessmen and women. To understand this business, they must know all about its products and services from a product-line perspective. To do so means installing extensive case-mix based IS and DSS which can be used in all phases and areas of strategic planning and operations.[5]

Today's health care customers are becoming "prudent buyers." For their payments they want to know that they are receiving the highest quality care at the lowest prices. They are asking for detailed data, by case-mix, on morbidity, mortality, and clinical outcomes.[6] They are beginning to use this data in ISs or DSSs of their own to compare quality-price relationships among institutions and change their payments, insurance coverages and preferred institutions for diagnoses and treatments. Entrepreneurial providers recognize this opportunity by creating new forms of health care organizations such as ambulatory health centers, HMO chains, preferred provider organizations, home care and managed care organizations, long-term care chains and many other forms of vertically and horizontally integrated care delivery institutions. The United States today presents a very pluralistic system of payers (individuals, companies, and governments), providers (public and private for and not-for profit) and care delivery settings (ambulatory, acute and long term). The information needs to understand, manage and deliver care in this system are enormous.

The U.S. population is undergoing major demographic change. Not only is the

population aging significantly relative to births but also the elderly are living longer. The consequences for health care delivery are not well understood or even being seriously addressed. The amount of money spent on nursing care in 1987 was 38.1 billion dollars. With the growth of the elderly population and new life extending procedures and technologies, this amount is expected to be $129 billion by the year 2000 unless we change the nature of care delivery.

Another demographic change in the U.S. is the large amount of immigration and the correspondingly high birth rate in many segments of the immigrant populations. Many of these people have inadequate or no access to quality care and no funds to pay for care. The treatment of these and other indigents and other uninsured persons is a major problem facing U.S. health care institutions today. Funding and treatment systems must be built for their care.

The phenomenal change in technology procedures, methods and equipment occurring in the U.S. today is the fundamental engine driving health care costs higher. Even after controlling for population growth and aging and for higher liability costs and after all of the cost containing measures instituted in the past five years, health care costs have risen at a 5 to 6% annual real rate every year.[7] This rise can only be attributed to new technologies and their adoption throughout the health care system. These technologies not only cost more because of newer more expensive tests and equipment but also in the many needed new skill levels and types of health care workers including physicians, other clinicians and equipment and computer specialists.

A final set of major issues facing the U.S. health care system today can be classified as legal and ethical issues. These include such areas as malpractice and liability claims and risks, data, and information security, standardization of data and input and output measures, right-to-life and right-to-die, complex organ transplants, and licensing and certification. Each of these areas and others present complicated legal, moral and/or ethical issues facing patients, providers and payers. At the core of them is who gets what kind of care, who is responsible, who pays, and who decides. In all areas the information needs are significant.

Overview of Current Computation Efforts in U.S. Health Care

The issues and forces shaping U.S. health care delivery today have profound effects on many of the current computation efforts. In Management Systems the emphasis is now on planning and strategy in a highly competitive environment. In Administrative Systems it is on systems to cut costs and errors, improve productivity, and improve the timeliness and usefulness of the information and decision support. In Clinical or Patient Care Systems it is on decision support and knowledge support to provide correct and appropriate diagnoses and treatments in an error-free, timely, and possibly less costly manner. In several large research-oriented medical centers and a few large hospital chains, it is on highly Integrated Systems which combine the Management, Administrative, and Patient Care Systems in a distributed largely decentralized network of databases, IS, DSS, and knowledge systems (KS).

Figure 2 illustrates an Integrated System on a network for a hospital. The core of this integrated system is the patient identification (PID) and patient medical record (MR). Almost every service or unit of the hospital must have access to this information and key

HOSPITAL INFORMATION SYSTEM

PID/MR

Centralized Database
- network
- census data
- medical records
- DRG data

Patient Care

Nursing
- order/entry

Labs
- microbiology
- hematology
- pathology
- chemistry

Imaging
- scheduling
- NMR
- XRAY
- EKG, EEG

Pharmacy
- distribution
- allergic reactions
- dosages

Surgery
- anesthesiology
- protocols/
  algorithms

Emergency
- triage
- primary

Outpatient
- scheduling tests
- triage

Inpatient
- ICU/CCU
- dietary
- treatment
  protocols/
  algorithms
- diagnostic systems

Ancillary Services
- rehab medicine
- resp therapy

Administrative Systems

Scheduling
- ADT
- census
- registration
- surgery/OR
- outpatient

Financial
- payroll
- accounts rec/pay
- billing
- gen'l ledger
- op budget
- case mix

Facilities
- purchasing
- inventory
- maintenance
- housekeeping

Personnel
- employee records
- skill inventory
- labor analysis
- nurse scheduling

Quality Control
- drug plans
- dietary

Management Systems

Strategic Planning
- budget
- facilities
- technology
- competitive
- product mix

Marketing
- demographics
- utilization
- research
- case mix

Risk Management
- malpractice
- informed consent
- incentives

Quality Control
- utilization
  review/PSRO
- organizational
  structure
- organizational
  processes

Figure 2.

its activities to work revolving around the PID and MR.[8] This record receives inputs from the clinical departments, the administrative departments and support services. Consequently it is used for decision analytic models to conduct utilization review, productivity studies, cost assessment studies, tracking of the patient diagnoses and therapy and location, and billing and other purposes. It is central to all patient care and most administrative activities. It is also used in aggregation in strategic planning and market research.

The integrated system is also capable with the present and forthcoming computer network systems to have centrally available database management tools, productivity tools, reports/graphics generating tools and free text entry capabilities. This effectively means each department will have many work stations to support multiwindow, multiterminal emulation, large storage capacity, integrated telecommunication capability, and extremely high speed computing and data access power.

Another point to note from Fig. 2 is that although PID and MR are the core of the hospital IS, every service and unit of the hospital will also have its own databases, IS, DSS, and KS. Later we will illustrate this decentralized integrated system with an example from each area: management, administration and patient care. Before doing that it will be convenient to discuss each area in turn and its integration needs.[9]

MANAGEMENT SYSTEMS

As mentioned previously the health care system in the U.S. has become very complex, very competitive and very dynamic. To cope with this system, strategic planning is not only useful but also essential to success and survival. This planning must be based on a thorough knowledge of the hospital's product lines as manifested in its case mix and services. For its role in the community it must know its particular mission and goals clearly, know its strengths and weaknesses, know its competition and assess its present and future environment accurately. IS supports many DSS and a few KS to do market research analysis and forecasting, risk management assessment, performance measurement and analysis, resource acquisition, and capital and budget planning. Some of the elements of this IS are the hospital's own patient case mix by severity and resources consumed, competitor's case mixes and resources, present and future regional demographics, incomes and resource cost patterns, market surveys of patient attitudes and preferences, physician specialties, locations and practice in the region, and any known competitor's plans for the future. Using this information, different units at the management level construct models based in statistics, operations research, management science, expert systems and, perhaps in the future, artificial intelligence to support and make strategic decisions concerning the directions of the hospital. These decisions involve expansion, contraction, new technologies, mergers and acquisitions and diversification.

ADMINISTRATIVE SYSTEMS

Administrative systems were the first to be instituted in the hospital. Although the current generation of these systems are more complicated and sophisticated than their earlier versions, some still provide only an IS function while others have incorporated

DSS and KS activities. Payroll systems now easily incorporate the newest changes in the taxcodes and benefit packages. Accounts receivable and payable have some DSS capability for stimulating or slowing payments respectively. Billing systems are very sophisticated to handle the great variety of rules and requirements from the various payers. Budget planning and analysis is highly integrated into strategic planning systems so that the operating departments activities are coordinated with the directions of the institution. General ledger accounts now contain a vast array of new accounts which grow daily. But the biggest change is in the Cost Accounting systems being implemented. Prior to prospective payment's introduction, cost accounting was merely "charge accounting" and had little to do with actual product costs. Total cost allocation schemes had been devised and agreed to by the payers to reimburse the hospital for each case. Any errors in these allocation schemes were adjusted the next year to recover losses or return surpluses. Surpluses were rare because hospitals were always trying to increase their costs in order to increase their reimbursements. Now under prospective payment the hospital receives a fixed fee for each case. Losses and surpluses are *not* readjusted. Consequently the hospital manager's new incentive for maximizing surpluses is to make certain the actual cost of a case is below its reimbursement fee. To do so, sophisticated cost accounting for costs in each DRG is required. Actual nursing time and costs by skill level for each patient is needed. Actual costs of radiographic plates, time and patient movement are needed. Similar cost needs must be measured in the laboratories, pharmacy, dietary, and all other variable cost categories that comprise the effort going into the diagnosis and treatment of each DRG.

The cost accounting system is closely integrated with many of the other information systems in the hospital. These other systems are in turn linked to still other systems. The Admissions, Discharge, and Transfer (ADT) system is the first entry of the patient into the system and through the patient identifier starts or renews the medical record for the other information systems to use. After registration the inpatient is assigned to a nursing unit, may later be transferred and is eventually discharged. In between, the patient id has keyed work via orders from many clinical and supporting departments.

Other administrative scheduling systems occur in administrative and in clinical departments. For example, surgery and recovery room scheduling and nurse staffing and scheduling are complex DSS which often occur outside the ADT system. These systems have strong interfaces with other systems again via the patient id. Finally most large hospitals have outpatient scheduling and appointment systems for handling the large numbers-of outpatients and their interaction with the inpatient systems of the hospital.

For many years administrative systems have been operating in purchasing, inventory control and maintenance. Recently many inventory items have been put on automatic order and others on clinical line order direct to the supplier via dedicated computer networks. The purchasing department buyers receive computer updates to their standing orders but do not have direct or indirect human interface with the order or the supplier. Maintenance of machines and equipment is also DSS controlled in order to perform optimal cost minimizing prevention and repair.

Administrative personnel systems were early to be installed in the 1960s but have recently been greatly expanded in data and scope. The employee records as a concept have not changed much but new data has been added as required under changing laws, regulations, and societal trends. However, as mentioned above, new systems to capture labor

analysis for each cost center have been added. These systems capture the various skill inventories of the hospital and also have led to the construction of DSS for productivity and quality control by employee as well as unit and department.

CLINICAL/PATIENT CARE SYSTEMS

Perhaps the area of greatest all-around information systems and DSS growth in the 1970s and 1980s has been in patient care systems.[10] Clearly it has had the greatest variety and complexity of software development. Computers are ubiquitous in the clinical departments. Almost any new machine or piece of equipment purchased in recent years contains one or many computers. Although most are digitized, many are still analog devices. They occur in such areas as ECG and EEG to support analysis, interpretation and point out exceptions and patterns and perform similar and further tasks in MRI, CAT, PET, and X-ray imaging. These systems have become so useful to the clinician that they are in widespread use and are constantly being enhanced in scope and depth of analysis. Similar uses for and dispersion of computers occur in the emergency, operating, and recovery rooms and the ICU and CCU to monitor, control, and alert for changes in patients' vital signs and activities.

From a systems perspective, some of the most exciting efforts presently occurring are in the areas of medical decision making. Decision analytic systems have been built to aid in diagnosis of diseases. This work started in the early 1970s for gastrointestinal illnesses and has now been extended to many other diseases. Indeed, the model at Harvard-Massachusetts General Hospital covers over 75% of internal medicine diseases. Most of these models are still in research development but a few have migrated to other research institutions and are used in some clinical areas and for medical student teaching. Some less sophisticated decision analytic models in the form of protocols and algorithms have long been in use for nonclinician personnel in the emergency room and more particularly on ambulances. Often these DSS are coordinated to a hospital ER via mobile telephone. Similar protocols and algorithms are found on the nursing units and other clinical departments.

Starting in the 1970s several Stanford University computer scientists and clinicians built what has since become the most extensive set of expert systems for diagnosis and therapy selection for specific diseases. Perhaps the best known are MYCIN, PUFF and ONCOCIN. Most of their expert systems and developmental tools are in the research and development mode and have not been widely adopted. PUFF for use in interpreting measurements from respiratory tests for pulmonary function is in use but has not seen wide dispersion. One of the best uses of these and other expert systems and other diagnostic models is their ability to rule out diseases so the clinician may concentrate on the more likely possibilities.

In general, there is still a great hesitancy by clinicians to use expert systems or other DSS models in their diagnosis or treatment activities. Of course there are many reasons why some innovations diffuse and others only stay in the research mode. It is a goal of present and future research to study this clinician-system process to understand the adoption and diffusion processes themselves. As this knowledge grows then knowledge systems will become more useful to the practicing physician.

A clinical area which has received a great amount of IS and more recently DSS support is the nursing unit. In the 1960s a few nursing units experimented with patient classification and workload measurement schemes. In the 1970s systems for these two activities became wide-spread. In the 1980s they are now being integrated into case-mix labor and workload measurement models and are being used to do micro and mini-computer based nurse staffing and scheduling. The staffing and scheduling models incorporate expert system and AI rules as well as operations research algorithms to compute optimally the number, skills, and work times and shifts of all of the nursing levels on the unit.[11] An example of this DSS will be given later.

Other nursing unit IS and DSS in wide use are order entry, unit dose systems and result reporting. To make the bedside result reporting even easier and more accurate, some hospitals are experimenting with the installation of bedside terminals. These terminals would also be used for nurse and physician order entry. Other clinical departments making significant use of DSS models are the medical and radiation laboratories, pharmacy, infectious disease control, and respiratory and physical/occupational therapies. These departments have systems to automate the scheduling, testing, reporting, and recording of sessions and/or results. The systems do error checking, test duplication checking, wrong test/treatment timing, allergic reaction checking, incompatible drugs protocols checking, and often state the correct actions to be taken or procedures to be followed or suggest alternatives to the decision maker. These systems enable the hospital personnel to reduce errors, increase timeliness, reduce costs, and make appropriate diagnostic and treatment decisions thereby reducing risk and increasing satisfaction and successful outcomes.

EXAMPLES OF DSS FOR MANAGEMENT, ADMINISTRATIVE, AND PATIENT CARE SYSTEMS

Management System—Market Planning

A strategic issue facing all hospitals in the United States today is the spacial distribution of patient utilization of hospital facilities. Knowledge of who the patients are, where they are coming from, what physicians they use, and what services they need are critical for a hospital to plan its own services and mixes of care delivery. They need plan their types of ambulatory care facilities to determine whether they should diversify or consolidate activities so that new services and locations may be made available for patients and older services may be terminated or sold to other health care delivery institutions. It is also important in order to understand what physicians and staff skills are needed at present and in the future. Finally, it is important that the hospital know which markets its competitors are most capable in and where they have the most market share and their reactions to any new ventures the hospital may take.[12]

The underlying information needed to know these markets and to do this market planning center around the patient, the physician, and the hospital. In general, the patient will go to a physician when he/she has an acute or chronic illness. Sometimes this physician will be one which the patient has seen before, other times it will be an entirely new physician, depending upon the illness, the patient's knowledge of physicians in the

area and the physical location of the patient and the physician's offices. The choice of then going to a hospital for treatment depends upon the physician's affiliation with that hospital, the patient's knowledge and interest in attending that hospital and the characteristics and services available at that hospital. In particular, the decision then to enter a hospital and be treated for a particular illness is a function of many pieces of data frequently obtained from many different sources. Table 1 indicates some of the data which is useful in this regional market planning analysis. It is necessary to have this data in great detail, for the hospital doing its own patient analysis, but also the hospital must know in considerable detail similar data for its competitor's hospitals. In many cases this latter data is more difficult to obtain, but there frequently are sources for much of the information. Some information which is not available may replaced by proxy or surrogate data which are available. This information is integrated into a decision support system to do market planning and forecasting. The decision support system, designed for use in a health care system in Rhode Island is a multi-hospital probabilistic, disaggregate decision choice model using a multinominal logit approach to predict utilization by service and patient types. It is disaggregate because it works at the patient level rather than at total demand for the service. It is probabilistic because it computes probabilities that patients and doctor combinations will choose a particular hospital for that service. An example is shown in Fig. 3 which is a special illustration of three hospitals, one physician office and one patient. The patient goes to the physician and, based on attributes of the hospital, the patient and the physician, a decision is made to be treated in hospital one, two or three. It is frequently a joint decision with the physician acting, in many respects, as an agent for the patient with regard to this choice. But, because of prior knowledge or past

Table 1. Data and Sources for Market Planning

| Source	Subject	Data
PAS hospital discharge data	Patient	Census tract of residence
		Hospital attended
		Socioeconomic class
		Sex
		Age
		Race
		Admission date
		Hospital service
Physician information survey	Physician	Office location
		Principal specialties at office location
		Hospitals with full admitting privileges
Facilities data base	Hospital	Licensed bed capacity
		Number of admissions
		Inpatient days
		Occupancy rate
		Census tract of location
		Facilities and services offered
		Number of full-time equivalent employees
		Teaching/nonteaching
		Urban/small town/rural
Statewide planning agency	Census tracts	Travel time between census tracts
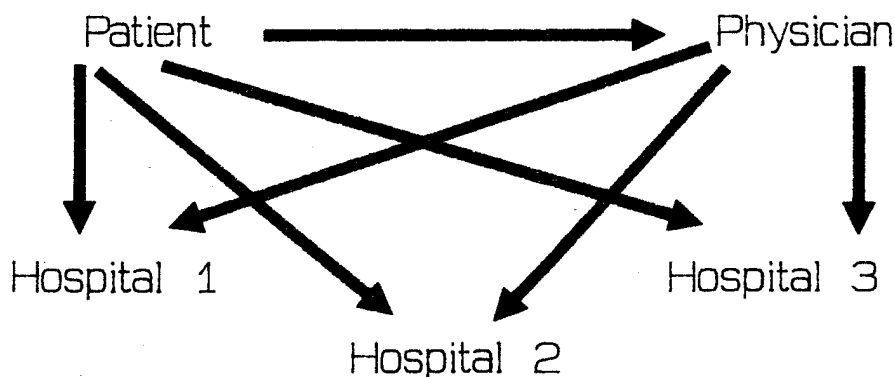
Figure 3. Market planning system: patient/physician choices.

familiarity or other characteristics, the patient also may have a significant input into the choice of hospital. Of course, the physician could not put the patient into a hospital at which he/she did not have attending privileges to perform medical care delivery at that institution.

This decision support system then predicts the case mix demands for each hospital in the region. If the hospital wished to change services, add different physician mixes to its staff, or open new facilities in different parts of the region, e.g., establishing an ambulatory care facility, the DSS would recompute and predict the service utilization for each facility by case mix. Similarly, if a competitor made any of these changes, the DSS would also predict the resulting change in mix of patients in the region. Models such as this are in use by the large investor owned chains of hospitals in the United States and by some of the large not-for-profit chains. A few of the large medical centers and teaching hospitals also may have similar sophisticated models. Smaller hospitals, on the other hand, tend to use more primitive models to predict their patient utilization or rely on those DSS furnished by hospital management consulting firms.

The particular model discussed above has been used in Rhode Island to predict utilization patterns for different subgroups of the population based upon sex, race, socioeconomic status, and age. This modelling has been broken down by various types of physician services, such as general medicine, obstetrics, pediatrics, psychiatry, general surgery, and could even be broken down for other services if sufficient data were available. In this application it is the case that the different population types of different service needs, different physician attributes and characteristics indeed determine the pattern of utilization of the hospitals in the region. As hospitals change services and/or physician relationships these demand patterns shift. Under the new case mix method of reimbursement, it is important that when the demand patterns shift, a hospital be well aware of this effect on its revenues and performance for long term survival.[13]

Administrative System—Nurse Planning and Scheduling

In the United States, nursing payroll accounts for 45%–50% of the total cost in a hospital. Nursing in this sense includes all registered nurses, licensed practical nurses, nursing aids and nursing ward clerks. Indeed, in most U.S. hospitals there are more nurses than beds. This is true not only because nursing must staff 24 hours a day, 7 days a week,

and therefore needs many personnel, but also much of the technology and growth of technology has been nursing intensive rather than nurse cost saving. Consequently, for reasons of productivity and effective utilization of this very large human resource, it is important to do optimal staffing and scheduling of the nursing units in the hospital to minimize cost and deliver patient care most appropriately. Nurse staffing and scheduling is an area that has been looked at extensively. However, it is only in the last decade, and more particularly, the last two years, that it has been effectively handled using computers and decision support systems. The nurse staffing and scheduling information base includes many *categories* of variables from the hospital and the nursing unit. In each category, there are very many individual variables. Because a typical medium to large hospital will have from 500 to 1500 nurses, these variables comprise a significantly large data base which is constantly changing. Furthermore, this database links very closely to a patient classification data base which measures each patient's acuity every day and to a workload measuring system which classifies the patients by work loads and other resource needs. The work load measurement categories for each patient classification are related to standard workload levels to determine nurse staffing and other health care personnel needs.

In scheduling nurses it is important to find the optimal set of schedules to meet all of the patient care needs on the unit and to meet each nurse's desires and needs for work stretches, time off, classes and many other activities which affect a particular work schedule of a nurse. The schedule is usually developed during a four or six week period of time wherein each nurse will know what days he/she works and has off over that period. Because the hospital works 24 hours a day, 7 days a week, these schedules must be computed for all shifts; day, evening, and night and all nursing units of the hospital.

The problem of nurse staffing, on the other hand, is to make sure on a day to day basis that each nursing unit has the appropriate types of nurses to handle the particular nursing needs on the unit in a most cost effective and appropriate care manner. Thus, nurse staffing utilizes the information from nurse scheduling to see which nurses might be available that day then adjusts that information for sick calls and other reasons why certain nurses may be out, combines that information with the daily acuity information on the patients and calculates what units may or may not be over or under staffed. The staffing DSS then makes appropriate adjustments by transferring nurses among units, by calling in other nurses who are off that day, or paying overtime to other nurses.

The decision support systems for these two activities, scheduling and staffing, are quite complex and vary from very simple systems which only furnish information and rosters of people to systems for actual decision making. These latter decision support systems specifically assign all of the nurses to all of the units on every particular day. In some cases, the nursing administrator may override the computer decision. In most cases the nurse administrator does not need to make adjustments since the schedules are optimally determined.

The type of nurse staffing and scheduling system which is frequently available is shown in Fig. 4. The schedules are usually run every four weeks. The staffing DSS is usually run daily. These two large decision support systems interact with other DSS concerning personnel hiring and training, budget planning, cost accounting, patient billing, and nurse payroll. These two systems are usually run by nursing administrators who

General
Set Generator

Schedule
Producer

Feasible Set
Generator

Nurse Schedule
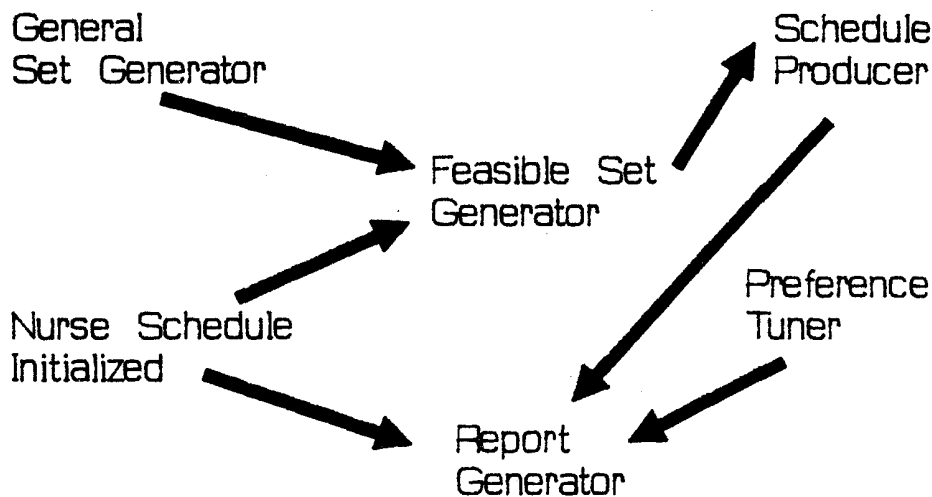Initialized

Preference
Tuner

Report
Generator

Figure 4. Nurse scheduling/staffing system.

have been taught to handle them. Most of the commercial systems are turn-key type systems so there is not a great deal of knowledge needed for their operation. This explains their rapid diffusion into the large hospitals in the United States. Also, these systems operate on a nursing information system network where each nursing unit has a micro-computer networked to a mini computer in the nursing administration office. The data inputs come from the nursing work stations and the actual scheduling and staffing systems are operated on a centralized nursing administration mini or large micro computer. Results are then down loaded to each of the microcomputers at the work stations on each nursing unit.[14]

Because the cost of computing has dropped dramatically, even quite small hospitals are now beginning to install these systems. Most commercial systems now run on large micro computer work stations which are cost effective for these small hospitals.

Clinical System—HIV Testing in the Blood Bank

The prevalence of HIV in blood donors and its transmission via blood and blood products require that blood donors be screened for markers of HIV infection. The blood center of the hospital is the obvious point of screening when the blood is collected from the donor and the decision must be made whether to keep the donated blood for use for transfusion or discard the unit. If the unit is accepted, there is the possibility that the unit will be infected and that infection could then be transmitted to the patients receiving the blood in the hospital. If the blood is discarded, there is the cost of recruiting and drawing the donors and processing the blood. Thus, the development of an optimal efficient screening program is a complex function of the biology, epidemiology, natural history, and manifestation of the HIV infection, the performance of available diagnostic tests and the effectiveness of donor registries and counseling programs in removing test positive people from the donor population. Information needed for this decision support system involves the prevalence and incidence rates of HIV infection among various donor sub-populations such as general population, gays, drug abusers and other groups. It is also

known that screening effectiveness of the various antibody tests varies by sex and by time since disease incidence, so this information must also be available. Finally, each of the various tests has its own set of specificities and sensitivities and when sequential tests are used of the same or similar type, there are high correlations between the test outcomes. Any DSS for screening must consider all of these and other factors.

In testing for HIV, there are various decision points which occur at the various stages in the process. The donor pool decision is made whether to accept a person from the particular donor subgroup population. A testing phase decision must be made whether to have one, two, three or more tests and which tests they should be. Given the outcome of the tests, a decision must be made for transfusing, discarding, or retesting the blood again. Finally, a decision must be made whether notification should be given to the donor and/or whether the donor is to be placed on a registry. Each of these decisions affects their reentry into the donor pool. The system is depicted in Fig. 5.

A decision support system was built to aid in decisions. The model was used at the national level for determining a general policy for blood donor testing and is used specifically in the blood centers to determine risks of HIV infection following different testing and donor pool strategies.

As a result of the testing and different strategies involved, the rate of HIV infections of transfusions has dropped significantly in the United States. However, HIV is a rapidly changing virus. New information must be incorporated into the decision support system to model the series of states the virus can go through. As these states change, different probabilities of being detected from these tests must be computed from the decision support system.

The data for the information system used in this decision support system were collected from various sources over the United States concerning prevalence and incidence of the disease and sensitivity and specificity of the test at different disease states. This data is continually being upgraded and modified for the various regions and locals in the country so that the blood testing may be most appropriately accomplished.[15]
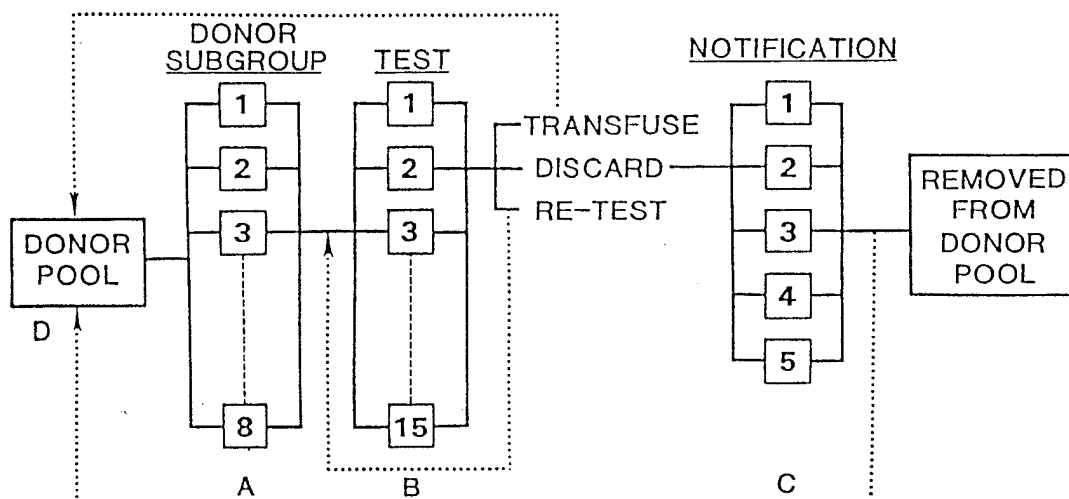

Figure 5. HIV antibody testing of blood and plasma donors.

TRENDS FOR FUTURE USES OF COMPUTING IN HOSPITAL MANAGEMENT AND PATIENT CARE

Future uses of computing in hospital management, administration, and patient care will depend on many forces external and internal to the hospital. The major trends in the United States in aging of the population, new technologies in bioengineering, genetics, and medicine, alternative health care delivery systems, new forms of competition, new regulations, much more informed consumers, rights to live or to die, access for the indigent and uninsured, massive numbers of AIDS patients, and increase in liabilities for care delivered or not delivered will all greatly affect the delivery of care and hence the gathering and uses of information. In spite of all these trends and changes in the industry, we can prognosticate on computing trends.

In the first place, the amazing drop in computing costs and rise in computing power, storage and network capabilities enables hospitals to move to integrated information systems. Although this move is just beginning in a few of the large research medical centers and a few of the large hospital chains, it will rapidly move to large teaching hospitals. As commercial software is developed for smaller hospitals, integrated systems will be installed there also. The timing is now right for such decentralized networked systems based on powerful work stations and sharing centralized PID and MR systems as well as powerful software tools. The promise but not the centralized structure of the early Technicon system will be realized in many hospitals.[16]

Networking will also enable the linked utilization of information systems between and among the hospital's departments. For example, order and/or result reporting inputs from the nursing unit will immediately flow to the order filling department, to MR, to billing, to transportation, to scheduling, and other appropriate parts of the hospital without delays and piles of paperwork. These orders will be checked by DSS and expert systems for correctness, therapeutic problems, bottle-neck difficulties, unnecessary costs, and delays.

Networking will also link the physician offices, ambulatory care centers (including the hospital's own ER and OPD as well as HMOs and surgi-centers), and home care, hospice, and long-term care centers to the PID and MR. In this way managed care will start to be performed at least in vertically integrated and linked institutions and is expected to reach 15% by the year 2000. At present some medical school centers are already linked to their teaching hospitals and attending physician and other physician offices for electronic mail and on-line literature searches and consultative advice.[17]

In order for most of the above integrations to be accomplished, there will need to be standardization or linking of data and software within and between the hospital functions and between institutions. In some cases there will need to be agreements on protocols, algorithms, and cost sharing before implementation will be successful. For this latter to occur there will have to be strong top medical and management support for implementation.

Many of the applications in the Administrative Systems area are mature. They will continue to be developed in performance and scope. Perhaps the greatest advances for these systems will be DSS and protocols to reduce processing errors, improve performance and link to other departments and functions. Also more use of management science models, as used in business in general, will be integrated into these systems.

The Management Systems area will continue to import more models for strategic and financial planning from business. Because of the continuation of strong pressures to contain costs, decision support models for performance measurement, risk management, forecasting markets and demands, and service and product evaluation will also be needed from business. All of these will be based on a product-line analysis. These models draw heavily from the MR databases and the other databases on regional and competitive demographics.

It is in the area of Clinical/Patient Care Systems that most of the research will continue. As mentioned earlier, more and more clinicians are becoming conversant with computing, DSS, and decision analytic models. Many of the leading medical schools have courses on these topics. The Society for Medical Decision Making is only about 6 years old and already has many hundreds of physician members. However, we still do not know enough about what clinicians want, need, and will use in the way of decision support or expert system software. So far there are only a few notable successes in the use of diagnostic and/or treatment systems for clinical practice. In the general literature on computer software innovation, adoption and diffusion, there are some clues for successful systems. However, in diagnostic and therapeutic DSS, the physician is to some extent being replaced by computer software which not only presents some psychological problems but also may place the physician at legal and financial risk for decisions made based on computer code. It will be some time before these issues are well understood, so it is not likely that there will be rapid adoptions of software for these decisions. Those expert systems that are able to be integrated directly into new equipment and machines will continue to find rapid adoption if the equipment and facilities contribute to the ease or accuracy of the diagnosis or therapy. The examples of imaging devices, blood cell and products analyses, and genetic materials analyses stand out in this regard. DSS will also find more rapid adoption for rare disease treatment or for diseases which have rapidly changing treatment protocols.

For patient care on the unit there will be more integration of all relevant patient data on a single workstation (charts, tests, images, insurer coverage, etc.). This workstation will be tied into bedside information entry and monitoring even on nonintensive care units as this technology becomes cheaper and more versatile.

At some point in the future it is quite likely that patients will be carrying their own medical records on a laser card in their wallets/purses or have national access to their records via their primary care physician or HMO. The technology is already here; it is not yet cost effective for issuing and maintaining the information. Furthermore, most MRs in the U.S. are not computerized except in parts of the records. It will still be some time before clinician friendly software will be available for broad general use.

On a national scale there already are registries for body organs, rare bloods, tumors, arthritis, and other diseases. These information systems will continue to grow in number and scope. Furthermore, they will develop DSS software to determine who receives the organs or bloods and software to study the epidemiology of the diseases. When the entire pathological process of a disease is understood, it should be possible to build complete protocols and algorithms to diagnose and treat it.

Finally on an even longer time scale there will be regional information networks and databases for resource planning and control. As costs continue to rise with the growth in technology and an aging population, there will be again an increased clamor for federal

and state control and rationalization of resource usage. The United States now expends over 10% of its GNP on health care delivery and disease prevention. At present there are doubts in many quarters whether we can afford a higher rate. But with a politically active aging population asking for government payment for quality long-term care and catastrophic coverage, there will be new federal programs being brought forth for these coverages. Some versions of these programs will be adopted. Shortly thereafter regional planning will be in vogue and information systems will be constructed to handle regionalization decisions.

In summary computing has matured from its early days of data processing to the construction of extensive information systems supporting large decision support systems. We are now at the beginning stages of building and implementing useful knowledge systems in health care delivery. Paralleling this computing growth has been major institutional and patient care growth, mergers and vertical and horizontal integrations which have been demanding more information for clinical, administrative and management decisions. The health care industry in the USA is in an unprecedented period of change in biological, medical and institutional knowledge. Only through new methods of handling, analyzing and synthesizing the vast amount of data being generated will it be able to accomplish its primary purpose: prevention, amelioration, and cure of disease.

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