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TECHNOLOGICAL IMPACTS ON HEALTH FACILITIES:

ANALYSIS AND PLANNING

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CHAPTER I

INTRODUCTION

Objectives

The general objectives of this study were to investigate the types of impacts which technology has made on health facilities and the delivery of health care through the systems approach, and to investigate the applicability of management science principles, approaches, and techniques in planning and evaluating potential applications of technologically advanced systems in the health field.

As used herein the term "systems approach" means an approach which involves identifying and describing each stage of a process or system and determining the relationships among the stages, including the inputs and outputs for each stage. This is accomplished so that functioning of the total process relative to its environment can be understood. The term "management science" refers to the body of scientifically verifiable knowledge related to management, and to the application of scientific techniques and approaches in the study of managerial decision situations, the execution of the managerial function, and the solution of managerial problems. In this study special emphasis was placed upon modern industrial engineering and operations research as representing the field of management science.

The author's interest in this subject stemmed initially from involvement in determining equipment planning programs for health facilities while working with the Health Systems Research Center at Georgia Institute of Technology in Atlanta, Georgia. Experience in these projects revealed a need and significant potential for the application of management principles in planning and evaluating new technology based systems for use in the health field. It also made clear the many difficulties and complexities involved in bringing these principles, approaches, and techniques to bear in the planning and evaluating process. Furthermore, a review of the literature revealed that planning and evaluating the uses of technology in health facilities to date has been essentially devoid of the use of management science except for certain limited operational aspects of the facilities design. The conventional planning approaches involve primarily intuition, judgment, rules of thumb, and trials and errors in planning at other locations.

Interest in this general subject was further strengthened by working in the central national office of the Health Care Facilities Service, U.S. Public Health Service, which administers the Hospital and Medical Facilities Construction Program (Hill-Burton Program). Facts about the Hill-Burton Program are included in the Appendix. Participation in this Service was with the Office of Equipment Consultation. The overall responsibilities of this Office were to provide professional consultation to health institutions, manufacturers, and individuals on problems relating to equipment planning in health facilities and to develop guides for programming more effective utilization of necessary medical services equipment. This experience brought into focus the many impacts which technology had on health facilities and revealed the need for planning and evaluation of the many factors which affect equipment planning decisions. An objective, analytical analysis of potential technological impacts, was recognized as essential to insure the effectiveness of future applications of technology in health facilities.

The need for management scientists to devote more attention to the application of their discipline in various fields of planning and evaluation has also been recognized. It has been pointed out that management science has not begun to meet the challenge of planning and the development of planning models. Its achievements were primarily in the areas of policy and control involving short-range and repetitive operations (90).

Background

The delivery of health care is faced with rising expectations and increasing demands; for many people the promises of medical science have been unfulfilled and the delivery of health care has been inadequate. Manpower, facilities, and organization are major considerations in evolving more appropriate delivery systems. However, capabilities must also be directed toward elaborating and applying the technologies called for by the changing patterns of medical care. The issue of technology and health care has become of mounting importance. Attention must be paid to the reasons for technology's successes and failures to date and evaluation made of its current application and planning conducted to insure future effective applications to health care delivery.

Galbraith (36) has defined technology as "the systematic application of scientific or other organized knowledge to practical tasks." The term is used here to denote both the substance of that knowledge and the process of developing and diffusing its influence in the social system of health care. It is not only the machine but the system of men and machines serving a task or seeking a goal.

There are several reasons why health facilities have become involved in the unavoidable demands and costs of technology and the disruptive effect of automation on human organization. One reason was that technology can increase productivity. For example, physicians in the field of ambulatory care may double the number of cases seen through the application of technology. In addition, the productivity of some other health workers may be raised by even higher factors, as in automation in the clinical laboratory. In the face of the national commitment to extend and improve health care with already scarce resources of skilled personnel, the potential contribution of technology should not be overlooked. Another reason was economy; the possibility technology offers for reducing unit costs of many ancillary service operations through trade-offs between capital cost and labor cost.

Other motivations may precede economic ones in product development. Technology serves as an extension of the senses to accomplish what was once beyond man's powers (X-ray, radioisotope diagnosis, the electron microscope, lasers). Moreover, mechanization and automation can in some instances produce a better product or service, thereby improving the delivery of medical care. Some tasks can be performed better through automation than by manual skills alone. Historically, another reason for mechanization and automation has been to relieve human beings of repetitive tasks. Certainly this notion was present in the efforts to automate paperwork in medical care, permitting physicians and nurses to spend more time in direct patient care.

The first two attributes of technology - lowered costs and expansion of capacity - although dominant motivations in competitive industries, have been formally lacking in the health services. In the field of health services there appear to be gaps between the promises of technology and the fulfillment of those promises.

Health care facilities in the United States represent an impressive resource. In 1970, there were 7,123 hospitals registered by the American Hospital Association. These institutions had 1,615,771 beds and represent capital assets of over $26 billion (2). In addition, there were 12,260 skilled nursing homes with 723,000 beds, 4,840 diagnostic and treatment centers, 3,234 public health centers, 4,300 medical group practice clinics, and thousands of physicians' and dentists' offices (44).

National health expenditures have been increasing extremely rapidly. The health "industry" is now the third largest in the country. It employs more than three million people, and in 1972 accounted for more than $83 billion, over seven per cent of the gross national product (52). This is compared with a proportion of the gross national product of six per cent in 1967, five per cent in 1955, and four per cent in 1930. This fact has encouraged industry to find a new market, applying technology to the health care industry.

Hospital care was the single most expensive component of national health expenditures in 1972. The U.S. Department of Health, Education, and Welfare reported that 39 per cent of health expenditures in 1972 were for hospital inpatient and outpatient care, over $32 billion (85). Figure 1 shows how the total health care dollar was spent in 1972. Since hospital costs have been rising at an annual rate of sixteen per cent, hospital administrators and consultants have shown great enthusiasm for applying technology in modern management (2).

The large aerospace corporations, big electronic firms, and smaller, more specialized companies have produced systems and equipment designed to reduce costs and improve service in every medical field from diagnosis to eye surgery. In 1967, the value of medical related items totaled more than $6 billion at the time of shipment by the manufacturers. Since then the market has been growing at a compound rate of ten and fifteen per cent a year (73). Not long ago an X-ray machine was likely to be a hospital's single most complex piece of equipment. But today the range of electronic equipment required by a fully equipped hospital covers a broad spectrum, from patient monitoring to kidney machine and blood analysis—with computers doing the paper work. The electronic equipment being offered to hospitals is expensive and is subject to rapid obsolescence. Another extremely important factor is the influence equipment has on the day-to-day operating expense of the hospital. The operating costs of using and maintaining automated equipment, including such expenses as personnel, materials, and back-up equipment, usually more than match the initial capital expense in three years.

The interest in automation and applied technology is clearly

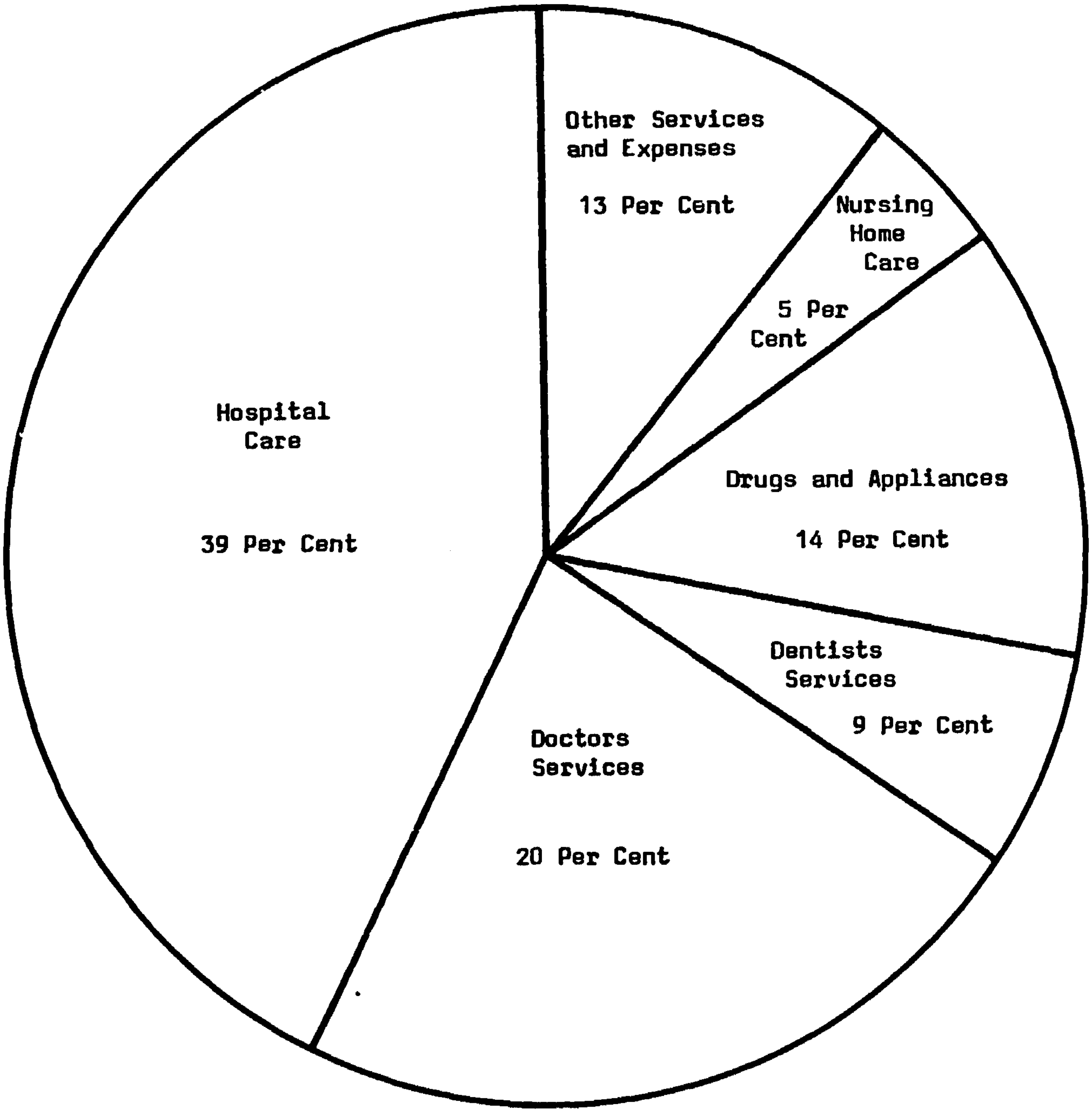


Figure 1—Total Health Care Dollar in 1972.

justifiable; however, it is frequently misguided. Too often the attraction of individual capabilities clouds the need for organizational and systems analysis necessary to make specific equipment operate effectively.

To date, technology in health facilities has not succeeded in proving itself as a means of reducing costs, although its advantages for improving the quality of medical care and increasing speed in all kinds of hospital operations have been shown (69). However, with the exception of fiscal and laboratory operation, the major technological advances by which personnel, materials, communications, and transportation tasks have been automated have not yet been utilized in benefit of most medical operations. Health facility mechanization and automation have not gained a strong position in any organized, rational manner.

It may be that for any single institution, the installation of complex equipment is too expensive. Frequently, personnel budgets indicate that long run costs could be reduced with large capital expenditures. However, it is far easier and more convenient to hire additional personnel than to finance a large sum for equipment. In addition, medical and political structures may obstruct technological application.

This tremendous advance in the complexities and technical capacity of equipment in recent years has affected health facility operation in many ways. It has resulted in a rapid rise of the initial cost, day-to-day operating cost, maintenance cost and substantial upgrading of the skill required to operate, maintain, and maximize the use of much of the new equipment. As initial investment rises rapidly, the productive use of the equipment takes on even more important considerations, for equipment which is under-utilized may be the cause of high medical costs and poor service.

Empire building also stimulates needless expenses. Elaborate laboratory equipment is too often bought by hospitals that will use the equipment very little. A recent U.S. Public Health Service study reported that 30 per cent of the 777 U.S. hospitals equipped to do closed-heart surgery had no such cases in 1969. Of the 548 hospitals that had cases, 87 per cent did fewer than one operation per week. Of all hospitals equipped to do open-heart surgery, 77 per cent did not average even one operation per week, and 41 per cent averaged under one per month. Little of this work was of an emergency nature, and the mortality rate for both procedures is "far higher. . . than in institutions with a full work load" (86).

The following excerpt describes many of the problems involved in applying technology in the health field:

> The Panel on the Impact of New Technologies was asked by the National Advisory Commission on Health Manpower to suggest specific area of technological innovations that could improve the efficiency and effectiveness of health manpower. Early in our studies, it became apparent that the problem is as much one of bringing existing technology into working support of physicians as it is one of developing new technology; it appeared that much of the technology that is needed already exists. The problem is to learn how to put it to work in that institution which we call simply the health care system. . . . We have reached a firm conclusion that the problem of harnessing new technology is paced at least as much by non-technical matters as it is by the institutions of science and technology (77).

It is apparent that the need exists to evaluate the impact of technology in health facilities and to plan future technological applications in an organized, rational manner.

CHAPTER II

LITERATURE REVIEW

Health Facility Equipment Planning

A survey of the literature in this field indicates that there was no organized effort in the study and improvement of the planning of health facilities prior to the mid-1940's (22). Following the signing of the Hospital Survey and Construction Act (Hill-Burton) in 1946, guide materials for planning, designing, and equipping hospitals were published. Harald M. Graning, M.D. (38), Assistant Surgeon General and Director, Health Care Facilities Service, U.S. Public Health Service, Department of Health, Education, and Welfare stated:

> Hill-Burton is the precursor of both health facility construction and planning programs. The original legislation not only made provision for construction grants, but also gave impetus to the first National effort directed toward coordinated planning of hospitals and other health facilities.

The initial guideline publications dealt primarily with planning the floor space and layouts for specific elements of the hospital (27). Equipment was included in the detailed schematics presented.

Beginning in 1949, suggested equipment and supply lists were published, listing the items shown on the layouts for elements of the general hospital. Equipment was listed for each room specified for the hospital and quantities were suggested for 50, 100, and 200 bed hospitals (46). This format was followed through seventeen revisions of the equipment publication until it was discontinued in 1968. However, these guidelines provided little information concerning the development of an equipment planning program.

Another indication of the methods used in equipment planning are the steps outlined in these publications for the preparation of equipment lists. This methodology was used in Public Health Service as well as American Hospital Association literature. Hospital equipment planning was defined as "the development of a method to assure the availability of equipment to provide adequate medical care to the patient" (45).

The steps are summarized as follows:

a) Assignment of Room Numbers

b) Preparation of Room Legend Sheet

c) Fixed Equipment Check

d) Listing Major-Moveable Equipment

e) Listing Minor Equipment

f) Pricing Major-Moveable and Minor Equipment

g) Totaling room costs

h) Recapitulating costs by services

This order for equipment planning and selection would indicate that equipment planning follows architectural program and layout; fixed equipment is selected separately from moveable equipment; and equipment costs are compared by item only, not systems involving different combinations of items.

Other planning guides were also prepared by the Public Health Service. In addition to check lists of fixed equipment items, other publications included questions concerning programming and equipping hospital departments and planning documents on specific services within health institutions (1, 74). Most of these studies and planning guides are based upon an accumulation of expert judgment and experience, rather than research or analytical investigation.

Numerous articles and books by hospital planners, including administrators and architects, regarding special aspects of planning and equipping health facilities have been published in recent years (48, 62, 80, 101, 102). These publications contain facts, descriptions, and discussion related primarily to functional, operational, and technical considerations in the planning and operation of health facilities. They do not represent or describe a methodology for planning or making decisions concerning technology in health facilities, nor do they discuss possible techniques for planning such as those of management science. In general, they provide information from the current body of knowledge relative to the functional aspects of health facilities which should be helpful in making the estimates and decisions required in facilities planning and design.

One publication devoted primarily to the process of planning hospital facilities is the Manual of Hospital Planning Procedures (3). This manual contains a general discussion of planning procedures and identifies some of the major steps involved, as well as the primary participants in each step, based upon traditional practice in hospital facilities planning. Equipment planning, described in the same manner as previously outlined in Hill-Burton Program publications, is discussed in terms of the purchasing agents' responsibilities.

Since 1967, five special commissions have reviewed the use of health facilities and have offered recommendations for improving the delivery of health care. The National Conference on Medical Costs, convened at the direction of President Lyndon B. Johnson on June 27-28, 1967, brought together both providers and consumers of health services to discuss "how the costs of medical services could be lowered without impairing the quality." In terms of health institutions, the need for study on increased productivity and better utilization was described:

> Productivity is an economic concept and word which has only in the past year or two been used in connection with hospitals. . . . This is not to say that there has been no concern for cost, for effectiveness or for efficiency but only that the emphasis in service industries has been more on availability rather than on productivity. Now, however, because of an increasing demand and need for a wider extension of health services, because of an increasing variety and quality of health services, because of disproportionate increases in the costs of health services, because of disproportionate increases in the costs of health services as measured conventionally, because of increasing competition for available resources, especially manpower, there is not a concern for the productivity of health services, especially the productivity of hospitals which are a very large and growing portion of health service costs (70).

Another conference was convened by the National Academy of Engineering, December 5-6, 1967, on Costs of Health Care Facilities. Papers presented here described the need for research and study in health facilities planning. "This need spans the entire process from the determination of facility needs and evaluating technological alternatives to meet those needs through contracting and construction" (65). A major report emphasizing the planning and financing of health institutions, was prepared in 1967 by the Advisory Committee on Hospital Effectiveness to the Secretary of Health, Education, and Welfare.

Examples of automation in hospitals were discussed with the idea that their application might improve hospital operation and management. The Advisory Committee (81) stated that detailed evaluation by the governing board and management of individual institutions was necessary before introducing new technology.

Another comprehensive report was issued in December, 1968, by the National Advisory Commission on Health Facilities established by President Lyndon B. Johnson. This report further emphasized the need for planning and the development of systems for the delivery of health care. The report stated:

> The cost of services within health care facilities is affected significantly by the planning and design of the facilities and the systems they employ to deliver health care. . . . Planning must consider future developments in medicine and technology and the delivery of health care (78).

The National Advisory Commission on Health Manpower, also established by President Johnson in 1968, discussed some of these issues. One major consideration of the report was improving hospital efficiency and applying new technologies to the delivery of health care. The Commission stated:

> Because labor costs are 60-70 per cent of hospital operating expenses, there is great potential for conserving resources by upgrading facilities through capital investments. . . . To build facilities that are able to take full advantage of the great changes which have occurred in the technology of communications, transportation, and medical care itself will require greatly improved design (67).

These five special commissions reported on the problems of organizations, planning, and cost in delivering medical care. They recognized the need for research on the development of a planning decision process for applying technology in these institutions.

Robert M. Sigmond (83), Executor Director, Hospital Planning Association of Allegheny County, Pittsburgh, Pennsylvania, has written several articles on planning health facilities. He gives two distinct definitions for the word "plan": "(a) a scheme of arrangement such as a floor plan or street layout and (b) a scheme of action such as a plan of a trip or a plan for your life."

The first definition emphasizes the relationship among the parts of a whole in a relatively static situation. This type of planning is very important to individual hospitals, especially when the hospital has reached the stage of designing a new wing or renovation of an existing building.

The second definition is more dynamic, emphasizing change over a period of time. In hospital planning, this second definition is most appropriate. The hospital is a product of rapidly changing forces, medical and scientific, as well as demographic, social and economic. "Planning involves three distinct processes: (a) the process of setting goals for the future; (b) the process of developing programs for achieving these goals; and (c) the process of continuously re-evaluating both the goals and the programs of implementation" (84).

Hospital planning is often thought to be synonymous with the design of facilities. In fact, a most common approach to planning at individual hospital is to ask each service chief and each department head to indicate specific needs of his unit. These are then converted into common units of space and dollars, summed up, found to exceed potential funds, and cut back by a rugged process of compromise.

> This restrictive viewpoint can only lead to buildings that are ill-adapted to the future. Programs to achieve goals involve

> much more than new buildings. Hospital plans also include programs to promote proper utilization - efficient utilization by the people being served and efficient utilization of the facilities by health personnel (84).

The importance of evaluating hospital activities has been emphasized in several articles (100). In once such article important factors in evaluation were explained:

> Proposed automation demands a careful review and analysis of hospital functions as a basis for determining the areas requiring consideration. Attention to volume and work-unit activities is essential to an understanding of need and extent of automation required in a given function. Automation has the potential to improve the level of patient care, conserve operational monies and skilled personnel, and allow us to operate our health facilities more efficiently, effectively, and economically. On the other hand, automation not properly understood or planned for can restrict function and limit flexibility. As design follows function, automation must follow function (56).

Many authors discussed the need for health facilities to look beyond their own walls to the needs of the community and the services provided by other facilities. Wasteful duplication of advanced technology was shown to exist in health facilities (75). This occurs when several facilities unnecessarily duplicate services for which demand does not justify expenditures for specialized equipment, staff, supplies, and other expenses. There are too many examples of institutions installing advanced technology for purposes of prestige, when other less glamourous services are needed by the community. Hospital activities which have been duplicated include technology for megavoltage therapy, open-heart surgery, artificial kidneys, and hyperbaric or compression chambers. Alternative to this wasteful duplication are: (a) referred service - when only one member of a group of institutions maintains a service and other institutions refer any of their patients who are in need of the service, (b) purchased service - when an institution pays directly for a service, (c) multiple sponsored service - when a group of institutions jointly control and operate a service, and (d) regional association service - when an association of institutions sponsors a service (10, 12, 20).

Technology in Health Facilities

The previously mentioned books and articles discuss equipment planning and the potential of technology from the point of view of the health institution. This approach recognizes health needs and attempts to plan solutions to meet those needs, including the application of technology. On the other hand, there is literature discussing the value of technological applications and the effect of automation and medical instrumentation on the operation of health institutions.

One important research study on hospital automation was conducted by Mark S. Blumberg, M. D. (11), at the Sanford Research Institute. This work conducted in 1960 was supported by both a U.S. Public Health Service grant and a grant from the California Hospital Association. The aim was to determine those hospital tasks where new equipment would have the greatest impact by either reducing costs or improving quality of care. Various hospital departments were discussed - laboratory, administration, and patient care areas, including the operating room, delivery room and nursery. In conducting the research studies, several criteria were developed to divide the many activities in hospitals into those which most needed study from those which were less pressing. One criterion used was whether a particular area or activity of the hospital constituted a major labor cost. A second related criterion was whether the cost for this activity had been increasing rapidly in recent years. A third, recognizing the importance of facilities other than hospitals, reflected whether the activity related closely to care of bed patients. The fourth criterion was whether the activity was primarily of a medical or related nature. Finally, tasks which were important, judged by the above criteria, were also examined to see whether they required human judgment or skill, or if they could be done by machine.

The most comprehensive report to date on technology in health services was published in the November, 1969, issue of the Proceedings of the Institute of Electrical and Electronics Engineers (89). This special issue contained 28 articles on current advances in technology which are being implemented in the health field. Material was developed in four problem categories:

a) Expansion of population served. These articles discuss the utilization of computer-communication technology to bring both routine and emergency medical care to individuals who can not be reached by doctors and use of automated multiphasic health testing to generate a profile of a patient's physical condition.

b) Medical instrumentation needs. These articles discuss these needs recognizing factors of costs, operator training, equipment maintenance, requirements for reliability and dependability, psychological problems in using technology, equipment industry's uncertain market, and the role of the Federal Government.

c) Cost control. Articles related that the role of technology involves primarily the most economical realization of changes effected in hospital organization and planning, and in health systems design; emphasis was placed on realization of the economics of scale inherent in centralized facilities.

d) Specific health system problems. Articles discuss potential technological contributions in ambulance systems and design, modeling of health problems, nursing homes, and hospital information (89).

The concern was expressed that the full impact of engineering has not made itself felt on finding solutions to the hospital's problems. Included in the reasons for this failure were: (a) innappropriate approaches to the problems, particularly failure to recognize that many of the problems are of a discrete, project-oriented type; (b) the interaction between individual engineers and medical personnel has often been ineffective; (c) the hospitals are not economically motivated to avail themselves of technological advances; (d) the resources brought to bear on these problems have been inadequate (49).

Other books and articles have discussed the application of technology in the delivery of health services (16, 95, 99). The role that instrumentation has played in the development of more adequate methods for health care includes: automation of clinical laboratories, patient monitoring, hospital information systems, multiphasic testing, artificial organs, medical photography, ultrasound techniques, atomic energy, and lasers.

Much of the literature discusses the opportunities which exist in the development of computer technology (57, 58, 87, 94). To date, computer efforts in the hospital field have been largely directed toward business applications. Now, however, equipment manufacturers are developing systems for patient care purposes. The computer has had a great impact on hospital operation; hospitals have discovered that:

> No other single item of capital goods has changed the basic terms of so many human activities in so short a time. . . . It has forced men to think about what they are doing with clarity and precision. A man cannot instruct the computer to perform usefully until he has arduously thought through what he is up to in the first place, and where he wants to go from there (18).

A few biomedical applications of computers used in hospitals include patient monitoring, permanent automated patient clinical records, automated pharmacy-current hospital records, clinical chemistry systems, population multi-phasic health screening, patient interview and pattern recognition.

Medical electronics has also received much attention in the hospital literature. The main topic of discussion is the balance between improved care and harm presented by the use of electronic instrumentation in the hospital (26, 42, 69, 88). Instruments can improve diagnosis by providing physicians with information measuring change, predicting change and recording status. Instrument-assisted treatment of pathological conditions enables the physician to stimulate, remove, repair, or destroy various body parts. Instruments can supplement or replace the action of deficient physiologic functions either temporarily or for long periods of time. However, hazards arise from the use of these instruments. The hazards include electrical shock and burns, radiation dangers, and wrong diagnosis due to improper equipment calibration and maintenance. In addition, special staff training is necessary to insure safe and effective use of instrumentation.

The potential danger of medical devices improperly manufactured, operated, or maintained is shown in the following 1970 data. A Food and Drug Administration, U.S. Public Health Service, tally of several hundred articles published since 1963 shows a reported 676 deaths and more than 10,000 injuries from medical devices (33). Of this total, over twenty per cent were associated with anesthesia machines, radiation equipment, orthopedic devices, dental equipment, and other specialized equipment. Dr. Seymour Ben-Zvi, Director of Scientific and Medical Instrumentation at the Downtown Medical Center in Brooklyn, New York, has stated in an interview for Medical World News that forty per cent of the medical devices which come into his institution are defective (59). Other authors have described electrical, as well as other hazards of electronic equipment (17, 39, 43).

Dr. Joel J. Nobel (51), Director of Research, Emergency Care Research Institute, Philadelphia, Pennsylvania, adds another dimension to use of medical devices: "More patients are hurt because of failure of equipment to perform effectively, like ECG's (electrocardiograms) that do not spot myocardial infraction. The device as it operates is not hazardous but its results are a hazard to a patient." Dr. Nobel was Scientific Director of Health Devices; this journal includes information which rated devices for safety, ease of use, and reliability, and suggested the best buy. In addition, it presented exact procedures used for testing the instruments and organizing a hospital equipment control program (29).

In 1966, the Division of Hospital and Medical Facilities, U.S. Public Health Service, Department of Health, Education, and Welfare, conducted a study on the extent of use of electronic equipment in hospitals (40). From the survey comes the general impression that there are at least thirty different patient situations in which treatment through some means of electronics seems desirable. Essential, however, was electronic equipment for use in seven areas of the hospitals including anesthesia recovery, cardiac care, medical recovery, respiratory care, trauma care, premature infant care, and specialized intensive care.

Hospitals over 100 beds have much more biomedical equipment than hospitals under this size. In terms of one list of 41 common categories of medical equipment used in hospitals, institutions over 100 beds had about 75 per cent of the equipment, whereas the smaller hospitals had only one-third to one-half of this equipment. In addition, "this equipment is sophisticated enough that calibration and maintenance must be performed by personnel with some knowledge of electronics" (98).

Additional information on patient use of electronic equipment was revealed in another study. It showed 12.3 per cent of patients having used electronic equipment during their hospitalization (37). In addition, 3.8 per cent of the total census were exposed to the use of some medical electronic equipment each day. The use of electronic equipment such as X-ray, ECG, and radiotherapy, not included in the survey, were used to a much broader extent.

Many individuals have attempted to classify medical devices. One such classification was developed during a National Conference on Medical Devices sponsored by the Association for the Advancement of Medical Instrumentation and the Department of Health, Education, and Welfare in September, 1969. "Classification of devices which involve the patient-device relationship appear to be most applicable to cost/benefit and benefit/hazard relationships." Some of these classifications are:

I) Proximity of device to body - (a) remote, (b) in contact with the skin, (c) inside body passages, (d) inside closed body cavities, (e) in direct contact with tissues and organs.

II) Energy-transfer relationship - (a) extrinsic, from the patient to the device, (b) intrinsic, from the device to the patient.

III) Time in contact with the body.

IV) Type of hazard associated with the device - (a) inherent, such as X-rays, (b) secondary, preventable (such as possibility of electrocution).

V) Degree of acceptance by professionals - (a) generally regarded as safe and effective, (b) wide disagreement.

VI) Importance to patient survival - (a) critical, such as pacemakers, (b) not critical, such as an artificial limb.

VII) Intended use - (a) research), (b) limited clinical use, (c) broad distribution and widespread clinical use (4).

With respect to hospital equipment expenses, one study revealed an average of $4,273 book value of equipment capital per bed in a survey of ten New York City hospitals. In addition, it was discovered that (a) the ratio of purchases to depreciation expense is higher for medical and related departments than for business and housekeeping departments, and (b) the medical departments have younger equipment. However, "Equipment capital has been given limited attention in social policy in the health field. Facilities' standards usually include a list of necessary equipment, the concern being with technical adequacy as a condition of approval. Equipment allowances as a customary percentage of capital budgets are said to be overly modest and, to the extent that this is so, such a method of financing may work against adequate capital support for staff responsibilities" (64).

The need for estimating the influence of technological changes on health facility requirements has been recognized (50). Howath (47) has stated that one relatively untouched problem is "the development of some simple methods to enable planners to take into effect discoveries on future requirements." The relationship between technology and manpower is extremely important (6, 40) Other factors, such as purchasing and capital budgeting for hospitals are also important when considering the application of technology. Alternatives such as direct purchase, and leasing, have been recognized in addition to the need for cost-benefit analysis measuring non-monetary benefits (7, 34, 93, 97).

The concept of economies of scale has also been analyzed (8). It has been shown that certain specialized items and systems of equipment require a high volume of usage in order to be economically feasible. "Although better equipment and personnel make possible a higher quality of health service, such equipment and personnel must be utilized to a degree that enables them to operate effectively. Moreover, greater investment and payroll result in higher unit costs unless they generate proportionately large numbers of procedures." Other factors are also important for the "cost per patient day tends to be higher in a large hospital than in a smaller institution. Large hospitals offer more professional services and more programs of research and education than do smaller institutions. They also contain more expensive types of apparatus and equipment" (79).

Medicine and engineering have moved into an era of technological revolution. Change is essential because the social demand for health is beginning to seriously outpace the traditional use of available economic and manpower resources. However, an important feature of many modern developments has been tho disturbing fact of ever increasing operating costs, although the services provided are of a higher level. This indicates a failure of the technology and the organization used for its implementation, because it means that the new facilities have only been made possible through a significant growth in the organization needed to provide them. The benefit that medical progress can provide will be weakened if the total interaction between the social, economic, and technical factors involved are not realized.

Management Science and Planning for Technology

The investigation is directed toward the potential application of management science principles and techniques in the planning-decision process for applying technology in health facilities. Although these decisions on technology are only part of the process of managerial planning, they are dependent upon the entire managerial planning process.

Planning is one of the primary functions of management. It has been defined as follows: "Planning is an intellectual process, the conscious determination of courses of action, the basing of decisions on purpose, facts, and considered estimates" (31). Planning involves the setting of goals and objectives, the identification and development of alternative courses of action, and, at the appropriate time, the selection of one of the alternatives. It provides guidance for necessary and desirable change. It is the conscious and purposeful act of attempting to link present actions with desired future results.

The increasing need for formal planning has been discussed by two leading authors in management and economics, Galbraith (36) and Drucker (25). Rapidly advancing technology is one of the primary factors contributing to the increasing need. With the advancing technology comes the lengthening time span of many managerial decisions, the time between the initiation and the completion of the task resulting from a decision, and the time span of continuing effects of a decision. In addition, more capital is required for special equipment. With increasing technology, the large amounts of money and time are more inflexibly committed to the particular task decided upon.

The large commitments of time and money and the high degree of inflexibility bring a higher level of uncertainty and risk into the decision process. The decision maker must look further into the future and make systematic efforts to evaluate the pending decision in the light of these uncertainties and risks. Therefore, the fundamental purpose of planning is to influence decisions and actions.

Planning may be classified as to its purpose - operational or strategic. Operational planning has as its purpose the development of specific operational methods and approaches for accomplishing a given objective. This type of planning assumes a definite goal and future, and is directed toward the accomplishment of a definite and specific sub-objective. Examples of operational planning include production planning, developing a schedule and detail of moving a plant or department, and the layout of specific areas in facilities design.

Strategic planning is for the purpose of setting goals and objectives, anticipating the future and its implications for the organization, and selecting the general means of accomplishing these goals and objectives, under anticipated conditions. This type of planning demands an intimate knowledge and understanding of the organization, the industry in which it operates, its resources, its capabilities, and its limitations.

Planning may also be classified as short-range or long-range. Short-range planning involves decisions which are to be implemented in the near future and for which the anticipated results are not necessarily long-lasting; the decisions could be altered without major costs or serious effects on the organization. Long-range planning involves a planning horizon of many years, versus one year for short-range planning. It has been defined as "the continuous process of making present entrepreneurial decisions systematically and with the best possible knowledge of their futurity, organizing systematically the efforts needed to carry out these decisions, and measuring the results of these decisions against the expectations through organized, systematic feedback" (25). The major ideas in this definition are the continuous nature of the process, the risk-taking aspect of decisions, and knowledge of the futurity of present decisions. It should not be assumed that planning eliminates or minimizes uncertainty and risk. Hopefully it will lead decision makers to take the right risks through recognition of the nature of the risk involved in each alternative.

Although planning presupposes the use of reason, many decisions require a high degree of intuition and judgment because of lack of time or resources for thorough study, incomplete information, and the inappropriateness of analytical and quantitative methods. Many aspects of the process involve matters of human behavior and value judgments (14).

The following list of general steps in planning is representative of most such outlines in the literature:

a) Setting goals and objectives

b) Making assumptions and establishing premises

c) Developing alternative means for achieving goals and objectives

d) Making "forecasts" (anticipating possible futures) and projecting results

e) Deciding among alternative means

f) Implementation

g) Evaluation and feedback

In general, the terms "goals" and "objectives" refer to the ends which the institution is trying to achieve. Setting objectives is the first and one of the most critical elements in planning. Objectives determine the direction of all other efforts. However, very few managers have well-defined overall objectives to guide their operations (63). It has been said that the real problem is not determining objectives but rather, is in setting them so that management knows what variables indicate progress and how to measure them. Without measurement it is dificult to plan and feedback and control are impossible. These variables must be selected with care, since what is measured and how it is measured tend to determine what is considered to be relevant (25).

Assumptions represent what the decision makers believe to be true about the institutions internal and external environment. The making of good assumptions demands a great deal of knowledge and understanding relevant to the particular institution involved, its industry, and its environment.

The next step is the identification and description of alternative courses of action for achieving the objectives. This involves the specification of programs, resources, and methods. After the determination of alternative means, possible states of the future must be anticipated and the results of the various alternative means under each anticipated state must be projected. Because of the inaccuracies of long-term forecasts, one of the primary functions of planning should be to provide the flexibility to meet the requirements of the inevitable and unpredictable changes.

After the projection of expected results, a decision must be made among the various alternatives. The decision should be based upon a comparison of the expected results of the alternatives measured against the criteria derived from the institution's objectives. Usually this comparison will call for some technical analysis and will offer opportunity for the application of decision-analysis models. The ultimate responsibility for selecting the course of action must rest with top management in order for the planning effort to be successful.

Following the decision is the implementation of the course of action chosen. In this phase it is decided who is to do what, and when and how they are to do it. Finally, there is the evaluation of results. Evaluation is a comparison between "results obtained" and "desirable results", as against valid criteria; it is a comparison of objectives and results. Measurement is essential. Evaluation and feedback permit managerial control and provide for the continuous updating and revision of plans. Planning is a continuous process of change, updating, and recycling.

Galbraith (36) defined technology as "the systematic application of scientific or other organized knowledge to practical tasks. Its most important consequence is in forcing the division and subdivision of any such task into its component parts. Thus can organized knowledge be brought to bear on performance."

Nearly all of the planning considerations of technology derive from this need to divide and subdivide tasks and from the final need to combine the finished elements of the task into the finished product as a whole. These planning considerations are as follows:

a) An increasing span of time separates the beginning from the completion of any task.

b) There is an increase in the capital that is committed to production aside from that occasioned by increased output.

c) In terms of the performance of a particular task, increasing technology makes the commitment of time and money more inflexible.

d) Technology requires specialized manpower.

e) The inevitable counterpart of specialization is organization. This is what brings the work of specialists to a coherent result.

f) From the time and capital that must be committed, the inflexibility of this commitment and needs of organization and the problems of market performance under conditions of advanced technology, comes the necessity for planning.

Galbraith (36) adds:

> Tasks must be performed so that they are right, not for the present but for the time in the future when, companion and related work having also been done, the whole job is completed. So conditions at the time of completion of the whole task must be foreseen as must developments along the way. And steps must be taken to prevent, offset, or otherwise neutralize the effects of adverse developments, and to insure that what is ultimately foreseen eventuates in fact.

Technological progress may be viewed as an ever increasing series of episodes. However, there is a tendency to assume that progress is the exclusive result of scientific discoveries - technological breakthroughs. Certainly, such discoveries are important, but in many cases the advances simply represent a growing awareness and application of available technology.

When considering the application of technology, one must understand all of the consequences of its implementation. Dr. Eugene Fubini (35) has defined the order of technology in four stages:

> 1st Stage) How can I use this new technology or scientific discovery to improve what I am now doing? Improvement of Existing Devices.
>
> 2nd Stage) What else can I do with this new technology that I have been unable to do before? Creative Utilization of the New Technology.
>
> 3rd Stage) What changes do I make (or does society make) to match this new technology? Accommodation for the New Technology.
>
> 4th Stage) What are the social consequences of the changes in life which this new development will make? Consequences of Using the New Technology.

The role of planning and management is to insure that the institution is responsive to these four consequences of technology. Technology is too often applied when it does not meet even the first order of consequences - improvement. Novelty in everything is prized, perhaps too much, as an end in itself.

To alleviate problems, all individuals affected should participate in the planning of technology implementation. The term "participatory technology" describes a process of interaction. It refers to the inclusion of people in the social and technical process of developing, implementing, and regulating a technology, directly and through agents under their control. It occurs when the people included assert that their interests will be substantially affected by the technology and when they advance a claim to a legitimate and substantial participatory role in its development or redevelopment and implementation (21).

An interdisciplinary approach in planning the implementation technology is essential. This is necessary to understand even the economic significance of automation. Utilization of individuals with different skills and experience enables the planning team to analyze all important factors. One factor is the consequence of automation on the form and amounts of capital and labor required. This may include: potential savings due to the use of capital and labor involved with the technology represented in the change of total output; alterations in the ratio of labor and capital; time changes in production; and changes in the degree of substitutability of labor and capital involved with the technology.

The previous economic evaluations of technology indicate the importance of changes in productivity. One objective of applying technology is to improve the productivity of the institution. This involves either producing the same output with fewer inputs or producing a greater output with the same inputs. These inputs are combinations of resources, including labor, money, equipment, materials, and methods. The total interaction of these inputs is essential in completing any product or service. This can not succeed, however, unless the importance of cybernetics is understood.

The central element in cybernetics is the recognition that systems include feedback mechanisms and that the existance of appropriate feedback mechanisms is a requirement for the survival of any system. This occurs in human, mechanical, economic, social, and other systems. Feedback means that "when an action takes place, the initiator of the action receives information as to what has followed his action so that he can be sure that the desired effect is being achieved" (92). Emphasis must be placed on the performance of a system of components, rather than on the components themselves. Figure 2 expresses decision-making in terms of its function in the entire system.

The relationship between technological capability available to an organization and effectiveness is important. This is best described as shown in Figure 3. Overall performance is dependent upon the techniques or tools used. If the tools are too deficient, optimum performance will not be achieved. On the other hand, using tools that are too powerful, and thus wasteful, will also be inappropriate. For example, digging the Panama Canal with spades and wheelbarrows involves deficient tools; however, doing gardening with a bulldozer involves the use of too powerful equipment. "Middle managers can often make do with the tools they are given, but their leaders should not be misled by these heroic underlings. Such leaders have condemned their organizations to suboptimal performance - which usually means at higher costs than need be" (13).

In any large scale planning effort there are numerous elements which must be considered. Many of these elements will be interdependent, and many will involve time or precedence relationships. One of the primary decisions in developing an approach to planning is which of the elements are to be developed simultaneously or in parallel and

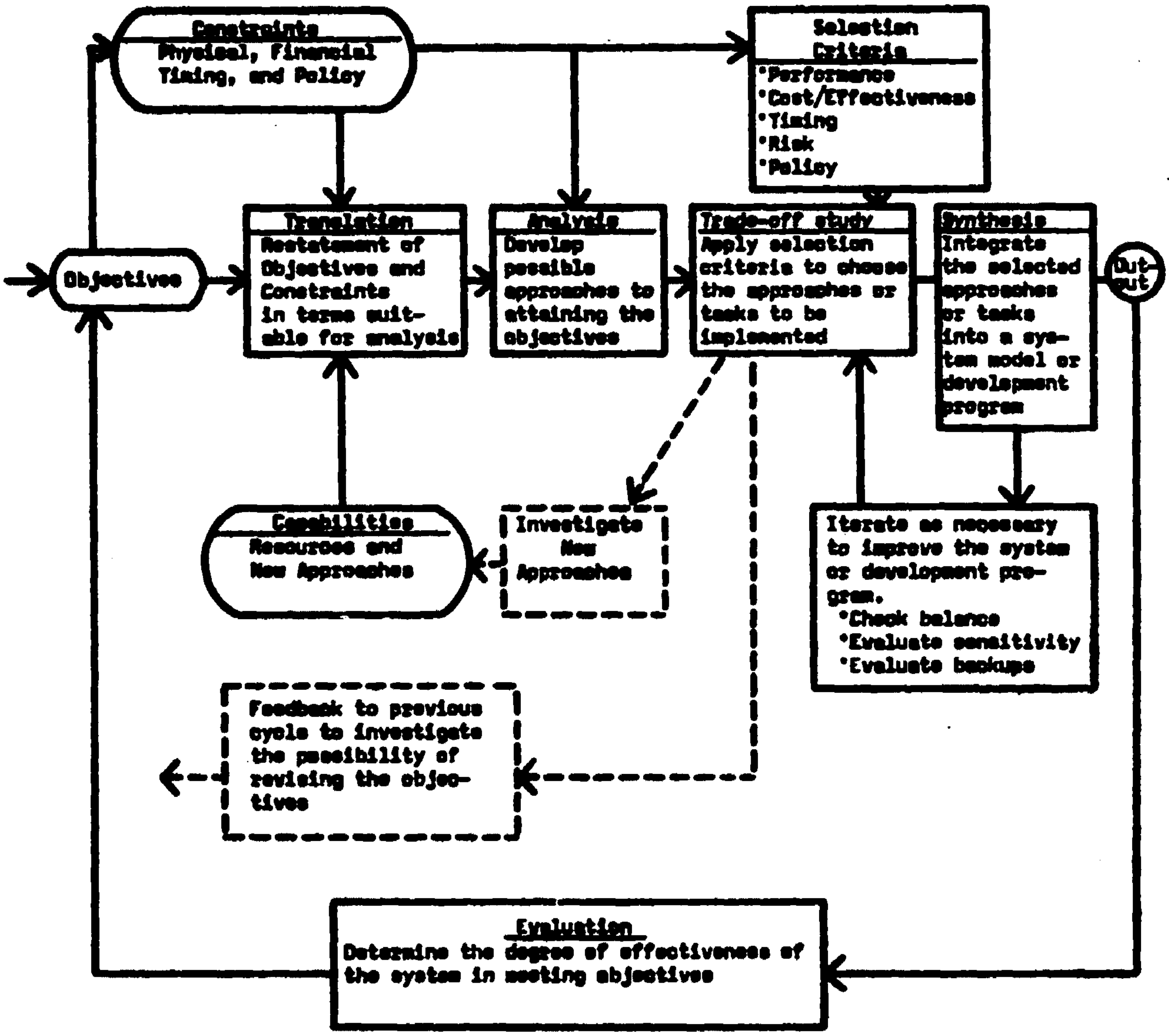


Figure 2--Steps within Systems Approach.

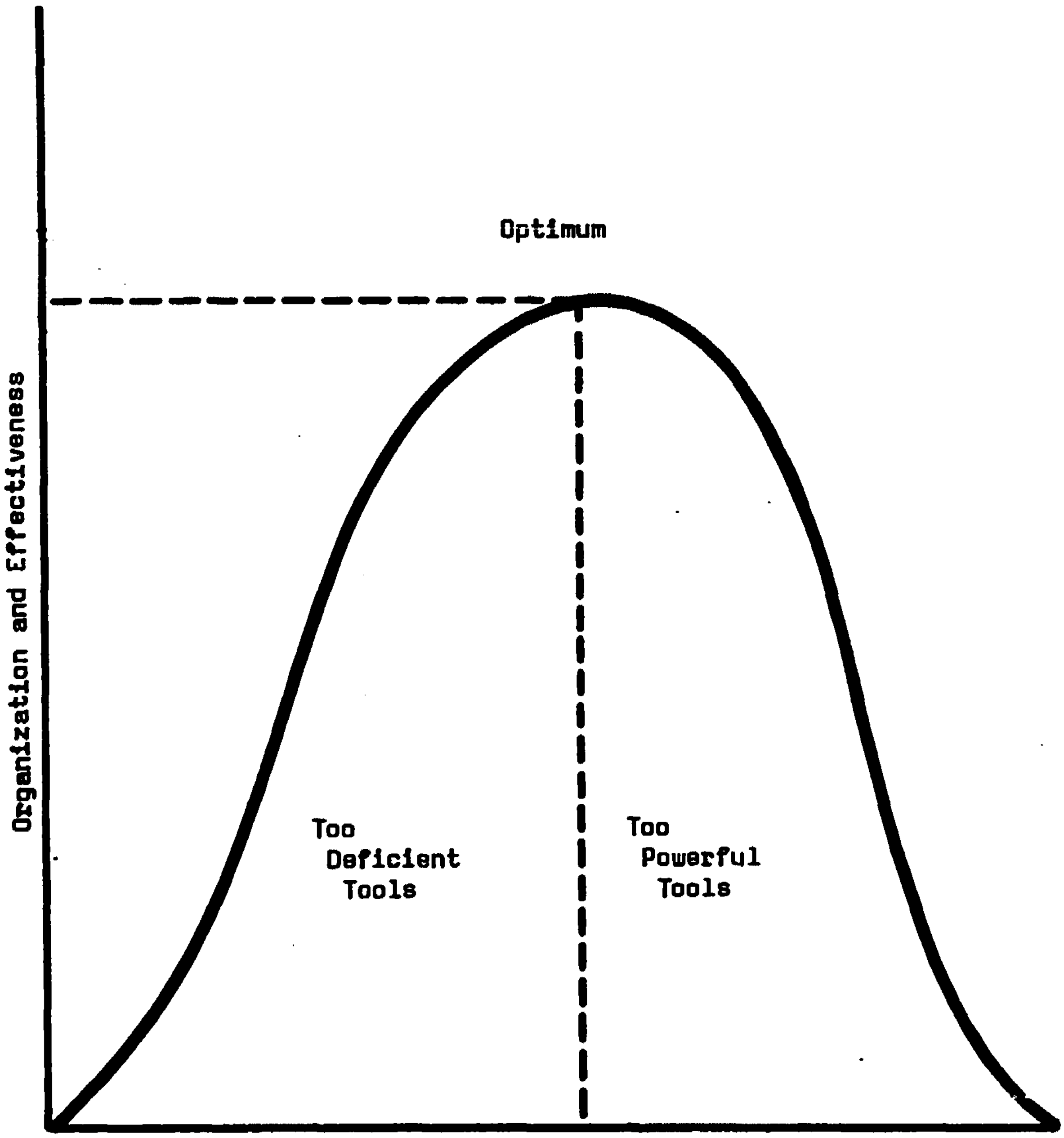


Figure 3—Technological Capability

which are to be developed sequentially. Because of the difficulty of handling numerous elements at once, there may be a tendency to handle most of them sequentially. However, because of the interaction and interdependence of many of the elements, parallel development may be necessary. Parallel development is usually recommended, even though it requires more extensive coordination and control (14).

Another apparent dichotomy in the selection of a planning approach is the outside-in versus the inside-out approach (30). With the outside-in approach an institution would determine its strategy based upon forecasts and a study of the market within which it operates. The opportunities, challenges, and demands of the market are weighed against the strength and resources of the institution. Under this approach, primary emphasis is on the market forecast. There is difficulty in using the outside-in approach, for long-range market forecasts are notoriously inaccurate. Among the many reasons for erroneous forecasts are changes in the economy and advances in technology.

With the inside-out approach, the decision objective in planning is the exploitation of the institution's strength and resources. Market forecasts and managerial judgment are used as a check or constraint on strategies developed on the basis of strengths and resources.

It is important that the uncertainty inherent in decisions regarding the future be specifically recognized in the planning process. In many cases, decision analysis models and other formal planning models are helpful to the planner as methods for dealing with uncertainty. These usually demonstrate the sensitivity of the decision to the elements of uncertainty involved.

Perhaps the most general characteristic of management problems is that some kinds of resources are always being used as inputs to produce some kind of outputs. The resources generally have alternative uses. Also a cost must be sustained in using the resource. Similarly, the output, or benefit, from using the resources generally has value. Efficient management may try to minimize the costs associated with a given use of resources. These opportunities invariably generate management interest in some kind of cost-benefit analysis (61).

When complex planning problems involve the consideration of numerous elements and various values for variables, more than verbal discussion and internalized mental effort may be required in order to structure and visualize the problem in a manner simple enough to lead to solutions or decisions (14). Visual and graphical exposition can help to identify the important elements, gain insights, and improve judgments. In many cases, however, there may be a tendency to avoid these techniques since few people have developed the ability to structure problems in this way.

Many other technical and analytical methods are useful in the planning-decision process. However, planning is not a science and scientific and analytical approaches may play only minor roles. Decision analysis models are of value in the planning process, but their role is limited by several factors including the number of immeasurables involved in most planning efforts and the lack of available and adequate information. Decision analysis models and other approaches included in management science are useful in furnishing partial answers and in helping to structure a systematic approach to the decision process. This is true because one of the primary methodological objectives of planning is the maximum use of reason in decision-making regarding the future.

The techniques of management science are especially useful in the comparison of alternative courses of action in situations involving criteria susceptible to quantitative measurement. Certain mathematical techniques may be useful for seeking optimal solutions in problem situations which can be described quantitatively. Also, the theory of games may help gain some insight into an understanding of strategy decisions.

Systems engineering is concerned with the analysis, improvement, and design of man-made systems for producing items or services of value to mankind. It has been defined as "a process for establishing significant objectives, for allocating resources, for organizing information so all aspects of a problem may be known as exactly as possible, and for providing the coordination between processes, people, and tools to achieve stated goals according to a predetermined schedule" (55). Its emphasis is upon the analysis of component interactions and their integration in a manner to achieve the system's purpose effectively and efficiently as shown in Figure 2 (see Chapter II, page 34). One statement of the systems engineering approach is as follows (41):

a) Define the problem

b) Select objectives

c) Synthesize systems for accomplishing objectives

d) Analyze systems

e) Select the best alternative

f) Plan for action.

The parallel and similarity between systems engineering and planning are apparent from the above description. The primary differences seem to stem from the fields of application, the emphasis, and the key participants. For example, one of the main differences is the heavy emphasis on quantitative and mathematical methods in systems engineering.

One example of a technique from the general field of management science which offers significant value in planning is computer simulation models. These models can be used to help predict the consequences of assumptions, alternative methods or designs, and changes in the values of various parameters. They can be used to investigate the sensitivity of outcomes to the uncertainties believed to exist. Other types of models that may be of value in planning are mathematical models such as those of engineering economy, linear programming, and inventory control. One of the primary difficulties with these models is the lack of adequate data relative to future operations.

Managers of all institutions must make decisions with long range output. An effective planning-decision process will enable the manager to have a clearer understanding of likely future impacts on present decisions, to anticipate areas requiring future decisions, to increase the speed of relevant information flow, and to provide for faster and less disruptive implementation of future decisions.

Conclusion

In general, the results of this literature survey indicate the need for a general investigation of the applicability of management science principles and techniques in planning technological applications in health facilities. As Charles D. Flagle stated in the Special Issue of the IEEE Proceedings on Technology and Health Services: "Management must have the mechanism to recognize a desirable technological alternative to manual methods--essentially an industrial engineering or systems analysis capability" (89).

CHAPTER III

METHOD OF PROCEDURE

Purpose

The following specific objectives were established as the primary elements in pursuing the general purpose of the present investigation:

a) The development of a description and conceptualization of the process of planning for and evaluating technological applications in health care institutions.

b) An investigation of the applicability and practicability of management science principles and techniques through an analysis of the planning decision process, and the development of examples of the application of management science techniques. An area of special importance concerns cost-effectiveness considerations of proposed technological applications.

c) The identification of promising and important areas of the planning and evaluating process which require further research and development regarding the application of management science.

Scope and Limitations

This investigation was aimed at the process of planning technological applications for health facilities and evaluating their potential impact on facility manpower, cost, and overall operations.

Technology was analyzed in the form of medical devices or equipment, acquisition of specialized equipment being one of the important ways in which hospitals incorporate current technology. Other principal aspects of technology not discussed were new materials, procedures, and plant design.

The health institution of primary emphasis was the hospital, although reference was made where similarities exist in other health facilities such as health centers, or long-term care facilities. One of the major premises of this work was that one needs a comprehensive understanding of the managerial environment and of the modus operandi of the institution in order to evaluate the applicability of management science. Further, plans for health facilities must be based upon relatively comprehensive and well-developed managerial long-range and functional program plans.

It was assumed at the outset of this investigation that the nature and requirements of the planning and evaluating process under study have much in common with, and are similar in many basic structural ways to, other fields of planning and decision making, such as business managerial planning. In the absence of adequate literature regarding the particular process being studied, insights and principles were sought in the literature of these other fields of planning and decision making.

This study was directed primarily toward planning decisions and problems in which the impact of technology had direct implications for major managerial and operational features of facility design and operating plans. The primary consideration was to investigate methodologies which evaluate the present and future costs versus the benefits and effectiveness of technological applications. Other important factors in the planning design process such as quality, safety, and acceptance were not emphasized.

Method of Procedure

The planning decision process for determining technological applications in health care facilities was investigated first hand by participating in planning for several health institutions. This experience revealed much about the nature and characteristics of this type of planning process which is relevant to the subject of this study.

Decisions on the allocation of scarce resources between competing services and new medical technologies tend to be made on the basis of "novelty", "medical exotics", or the politics of physician-hospital relationships, rather than a sound analysis of the benefits to the system. Dr. Frederick N. Elliott (28), Assistant Director, American Hospital Association, and General Director, Mt. Sinai Medical Center of Chicago stated: "Hospitals have seized upon the potential of technology without realizing the burden for decision-making that was placed in the human area before such utilization was to be made." Intuition and experience can be invaluable to the administrator as he makes decisions. But they cannot be depended on as the sole guides to decisions about the management of complex decisions. Today's complex systems and organizations require the well-planned application of quantitative methods. Management science involves the systematic application of such methods to the decision-making process; it supplements intuitive judgment with quantitative analysis.

Observations of these projects were augmented by accounts of other planning for similar projects reported in the literature and by discussions with professional people working in this field, including hospital administrators, manufacturers, and consultants. Another primary source of information and insight was corporate and managerial planning and decision making literature. Additional information on the impact of technology on health facilities was obtained from the medical and scientific literature.

Based upon the information obtained from the sources cited above, the planning decision process for technological applications in health facilities and the managerial environment in which it is performed were conceptualized and described. This step was performed in a manner which identified the major planning decisions and indicated the major characteristics of the planning decision process relevant to the potential application of management science.

Using the conceptual description as a base, the potential applicability of management science principles and techniques are reviewed. This review included a discussion of such factors as the nature of the decisions involved and availability of data. Several examples were constructed to illustrate the potential application of management science techniques to various decisions involved in the planning process. Special emphasis was given to the desired outcomes to technological applications, evaluation of alternative systems, and cost-effectiveness considerations.

Finally, all of the above surveys, descriptions, and analyses were used to identify promising and important areas of this planning decision process which require further research and development regarding the application of management science.

It will be noted that the investigation reported herein is not experimental research and is not a classical application of the scientific method. It is essentially based upon the exploration of a new field of application using the methods of survey, observation, description, and intellectual inquiry. This dissertation attempts to establish a clarification regarding the application of management science in planning technological applications for health care institutions through a systematic discussion of this subject.

This type of investigation appeared to be the most needed type for the general subject area under consideration. With the present state of knowledge in this field, there is no appreciable base of available research of relevant theories. There is a need for enough insight and understanding to form hypotheses for the more specialized and scientifically structured forms of research. At this time, priority should be on realism rather than on formalism. This view is supported by writers on similar subjects in the fields of management science and planning; as well as by individuals working to apply technology in the health field (5, 15, 24, 78).

Nature of the Results

As indicated above, the results of this investigation are a description and analysis of the planning decision process and its managerial environment; a review of the applicability and practicability of management science principles and techniques including several examples; and the identification of area for further investigation. These results should provide a significant contribution to the knowledge and understanding required for improved practice and research by industrial engineers, management scientists, and administrators in this and closely related fields.

CHAPTER IV

OBSERVATIONS ON HEALTH FACILITY TECHNOLOGICAL IMPACTS

None of the 32 million patients who enter United States hospitals annually, regardless of how simple or complex their disease process, escape direct contact with medical devices (2). Approximately 5,000 different types of patient related devices may be found in a hospital's equipment inventory (53). Table 1 lists some of the commonly used medical instruments (82).

Technology has a large impact on the delivery of medical care. For example, a typical adult patient with a mycardial infraction is exposed to an average of 80 different medical devices during a three week hospitalization (72). In addition, diagnostic and clinical equipment used in his care may total an additional 300 items. The typical pediatric tonsillectomy case is exposed to almost 200 separate and distinct types of devices used for his direct care and an adult undergoing gall bladder surgery has direct contact with over 600 medical devices.

Patients' lives are becoming more and more dependent upon electronic devices. Patients with kidney failures and those whose diseased kidneys are removed in anticipation of a kidney transplant are being kept alive by dialysis devices. Patients with acute heart failure are being saved with defibrillators, respirators, and pacemakers. The

TABLE 1

DIAGNOSTIC AND THERAPEUTIC INSTRUMENTATION

Medical Specialty	Medical Instrumentation
Cardiovascular System	Electrocardiograph, Phonocardiograph, Vectorcardiograph, Ballistocardiograph, Echocardiograph, Cardiac output recorders, Cardiotachograph, Injection Synchronizers, Cine Radiograph, Plethymograph, Catheters, Transducers, Flowmeters, Pacemakers, Defibrillators, Prosthetic valves, Artificial heart, Blood vessel prostheses, High-speed recording techniques.
Respiratory System	Oxygen consumption recorders, Inhaled gas analyzers, Respiratory rate gauges, Hyperbaric chambers, Resuscitators, Diaphragm-nerve stimulators.
Central Nervous System	Echoencephalograph, Electroencephalograph, Spectral distribution analyzers, Acoustic stimulators, Brain and nerve stimulators, Implanted electrode techniques, Microelectrodes, Integrators, Nerve impulse recorders, Cauterization and blood coagulation equipment, Cryosurgery, Stereotactic techniques.
Neuromuscular System	Electromyograph, Nerve muscle stimulators, Nerve impulse recorders.
Eye, Ear, Nose, and Throat	Audiometers, Acoustic stimulators, Hearing prostheses, Voice analyzers, Larynx (artificial), Tonometers, Electroretinograph, Optometry equipment, Eye movement gauges, Nystagmus recorders, Lasers, Microminiaturization, Prostheses for the blind.
Gastrointestinal System	Telemetry to measure temperature, pH, and pressure, Endoscope, Thermograph, Surgery (Cryosurgery), Lasers, Suturing instruments, Electrocauterization, Ultrasonic dental surgery, Surgical instruments in dentistry.

TABLE 1—Continued

Medical Specialty	Medical Instrumentation
Physical Therapy	Diathermy, Bone and joint prostheses, Rehabilitation equipment.
Radiology	X-ray apparatus, Radiation detectors, Spectrometers, Scintillation counters, Image intensifiers, TV systems, Synchronizers, Radiotherapy equipment, Particle accelerators, High energy isotope therapy, Gamma ray camera, Whole-body scanners.
Clinical Laboratory Specialties	Blood and other cell counters, Differentiators, Blood color analyzers, Flame photometer, Liquid-gas phase chromatograph, Sample collectors, Microchemistry apparatus, Colloidal system testing.
Anesthesiology	Gas analyzers, Oxygen tents, Equipment, Monitoring systems, Oxygen saturation photoelectric meters, Breathing apparatus, Pump oxygenators, Dialyzers, Servoanesthesia systems.
Psychiatry	Behavior monitor systems, Electronarcosis equipment, Electro-convulsive treatment equipment.
Computers	Control system theory, Information and communication theory, Adaptive system analysis, Operations research, Mathematical models, Analogue computer simulation, Data analysis, Automation theories.

impact of these scientific advances has become so great that the public has come to expect them to be offered at virtually every hospital.

Technological obsolescence is also a problem for health facilities. Many hospitals are "obsolescent" because of swift advances in medicine and its allied disciplines. The adequacy of any structure is evaluated in terms of the functions carried out in it. While the functions of some buildings have remained almost unchanged for centuries, those of hospitals have changed radically. These changed demands require responsive and commensurate changes in the space and equipment of the hospital. Unfortunately most hospitals are extremely slow to change. This may be because the installation of new technology will also force changes in organization and patterns of operation.

Hospitals built early in the Twentieth Century were still able to carry out their programs satisfactorily as late as 1940. Since then, however, the dependence of hospital based medicine on sophisticated equipment has increased enormously. This increased dependence on technology and on specialized facilities involves every department of the hospital. For example, developments in radiology have multiplied its diagnostic usefulness. Radiographic studies are being done with greater accuracy. New techniques permit the visualization of the physiology of areas previously considered inaccessible to radiological investigation, such as the blood vessels of the brain and the heart. As the value of X-ray studies has increased, so, too, has the demand. The new procedures often are more time consuming than the older ones, and require more personnel. The combination of these more complex procedures and equipment with greater volume creates a need for more diagnostic units, as well as more space for many of the units.

These examples typify the numerous considerations which must be analyzed in understanding the impact of technology on health facilities. In order to explore the possible consequences of technology, it must be thought of as more than hardware. Technology should be "perceived as a system of interrelated innovations, which comprise a coherent link pertaining to the systematic manipulation of the environment" (66).

The four orders of consequence will be used to discuss the technological impacts on health facilities. These include: (a) Improvement of Existing Devices, (b) Creative Utilization of the New Technology, (c) Accommodation for the New Technology, and (d) Consequences of Using the New Technology.

Improvement of Existing Devices

The U.S. market for biomedical electronics in 1970 was estimated at about $1.5 billion, 2 per cent of total national health outlay. This market, which was expected to double by 1975, was as follows (9):

X-ray tubes and accessories	$150 million
Diagnostic equipment	200 million
Patient monitoring equipment	25 million
Therapeutic devices	90 million
Surgical instruments and apparatus	830 million
Medical electronic data processing	215 million

These figures indicate that new technology is currently being incorporated into health facilities at an extremely high rate. However, the true value to the institution for this new equipment is rarely understood. Too often this newly developed technology is not being used to improve the delivery of health care by producing a better service or making health care available to more people. Devices are purchased which merely substitute equipment and supplies for personnel or other equipment. Unfortunately, hospitals have not been able to reach the potential of technology. The estimate that "integrated technology and sound management can reduce the cost of health services by a 'third' has not been achieved" (19).

A new device should be utilized if it enables the medical community to provide a new service through scientific discovery. However, other technological devices should not be incorporated into the delivery of health care unless one of the following criteria is met: (a) reduction in cost per unit of service, (b) increase in productivity resulting in greater capacity in providing a service, (c) improvement in the quality of delivering medical services, (d) substitute for scare manpower, or (e) allow service to be available to more people. There are many examples in which technology has been utilized to improve existing devices and health care services.

<u>Computer applications</u>

Through the use of computers, analysis is available to more people, and the cost per test is reduced more than in other methods (89). The electrocardigram, detailing electrical impulses from a patient's heart, can be analyzed by computer in thirty seconds, whereas manual analysis might require 2 man-hours. Furthermore, EKG analysis can be done remote from the patient through the use of telephone transmission. This enables a specialist to be available for consultation on cases miles away. In addition, quality is assured through a standardized EKG interpretation. This fact also assures a lower unit cost utilizing a standard machine format. This example typifies the manner in which new technology can improve the use of existing devices and enable health services to be available to a greater number of individuals (60).

Laboratory applications

In the clinical laboratory the development and spread of automatic equipment for chemical and other tests of body fluids and tissues has proceeded rapidly. So much of the work previously done by manual methods is now handled routinely by mechanical devices and instruments that automation of the laboratory is widely considered to be well-advanced. With the volume of tests demanded of clinical laboratories increasing at about 15 per cent per year, the supply of trained medical technologists has been inadequate and laboratories have increasingly turned tc automation as a means of performing their function (68).

The development of the automatic chemical analyzer represents the greatest single contribution thus far toward automation of the laboratory. Most of the work in a typical clinical laboratory consists of repeated performance of a small number of routine tests, many of which can now be done on a few automated devices. Two analyses (for glucose and urea nitrogen) account for approximately 30 per cent of all tests in the average lab; ten types of tests can account for 70 to 80 per cent of the entire workload (76).

In many small hospitals automatic devices are generally absent, but in most medium-size or large hospitals it has been estimated that in

1970 perhaps 50 per cent of the laboratory workoad had been turned over to automatic instruments (76).

The early automatic chemical analyzer permitted substantial reductions in time and costs to carry out tests (the cost of a glucose test was reduced from a range of 50 to 75 cents by manual methods, to 20 to 30 cents on the autoanalyzer). An eight channel autoanalyzer, which measures eight different chemical components at once on the same specimen, does in an 8-hour day the equivalent of what an average technician is expected to do in three weeks.

X-ray applications

Important advances are being made in X-ray and fluoroscopic equipment. In most hospitals and offices of physicians and dentists, X-ray and fluoroscopic equipment represents a substantial investment and is constantly in use as a basic tool in the diagnostic process. Fundamentally, the same type of X-ray equipment has been used for diagnosis by radiologists and other physicians over many years, but developments now under way are likely to result in adoption of a much broader range of advanced equipment.

Recent technical innovations may make standard fluoroscopy equipment obsolete. New electronic devices now being installed in hospitals magnify very small radiations and achieve brighter images without increasing radiation risk to the patient or fluoroscopist. Some types of presently available new equipment routinely record fluoroscopy on moving picture film. Such images can be transmitted over wires, and make it possible for rural or other remote hospitals to have the advantage of interpretation by expert roentgenologists located in distant cities (91).

Other extensions of X-ray techniques include various adaptations of television, and production of three dimensional images. One technique involves the application of television techniques to medical thermography, allowing doctors to get an immediate look at heat patterns in the body to speed diagnosis.

These developments will enable technicians to work more quickly and surely, and will help physicians to arrive at better diagnoses more rapidly.

<u>Instrumentation applications</u>

Existing technology is often merely utilized in new ways, thereby improving the delivery of medical care. Recently physicians have standardized a technique of measuring the size of the heart, using an instrument that has been present in hospitals for two decades. The ultrasonascope, previously used in detecting brain damage, is now the key instrument in a process known as echocardiography (71).

The ultrasonascope sends sound impulses toward the walls of the heart, which in turn bounce the sounds back. The patterns produced are graphically displayed on a flourescent screen for interpretation. The depth of the heart wall, the movement patterns of the heart, and the amount of blood being pumped can be determined from this data and compared to normal heart measurements. From this information the technician can give the physicians valuable information needed for diagnosis. Echocardiagraphy is less expensive than other techniques such as angrocardiography and features a "non-invasive" technique. With an angiocardiograph, technicians have to inject X-ray traceable substances in the heart and forearm, a procedure which an extremely skilled technician must handle (71).

Creative Utilization of New Technology

Society is enjoying the benefits from the first order of consequences - the use of new technology to improve what is being done. In addition, it is evident that society is utilizing our new technology creatively - to provide society with what it has not had before. However, these dramatic developments, such as artificial organs, computer analysis, and specialized intensive care, affect a limited segment of the patient population at exceedingly high cost. The impact of new technology presently spreads slowly to hospitals. Findings in a recent survey in a major New York City hospital, revealed that only 12.3 per cent of the patient census at sometime during hospitalization were exposed to electronic equipment (37). A few creative uses of new technology in health care include are presented below.

Laser applications

The laser produces bursts of light millions of times brighter than sunlight. To date, lasers have been used most successfully in medicine to repair small tears and defects in the retina of the eye. Other potential applications include the treatment of malignant and non-malignant tumors, dentistry, where lasers may be used in the prevention and repairing of cavities, microsurgery, destruction of pathological tissue without surgery using a flexible fiber handle, bloodless surgery, bone fusion, grafting living blood vessels together without interrupting blood flow, and cauterization of bleeding organs and vessels (60).

Automated equipment applications

Automated cardiac catheterization programs have been operational on a clinical basis for over six years. In general, those programs assist in obtaining specific dynamic pressures, inter-chamber pressure gradients, cardiac output by the dye-dilution method, and oxygen saturation levels in the various heart compartments. In addition, the relatively complex and time consuming calculations are performed by the system processor (82).

The Automated Cardiac Catheterization Programs represent a successful application of technology to the delivery of health care. Although use of this technology does not appreciably reduce the patient time of the catheterization procedure, the physician can see the calculated results while the patient is in a position to be retested. Also, the hours of calculations normally required following a procedure have been essentially eliminated. The main problem with these systems has been in introducing the technology to uninitiated medical personnel.

Monitoring applications

Telemetric monitoring systems developed for space flight research are now increasingly used in medical practice. Using miniature sensors and transmitters, the devices add a new dimension to electrocardiogram and electroencephalogram findings, respiration, blood pressure, and skin response (60).

Telemetric monitoring frees the patient of cumbersome apparatus, eliminates the examination room environment and permits responses to be observed under the normal conditions of daily life. Button-sized ECG sensors can be affixed to the patient's chest and attached to a tape recorder carried on his person; the method yields data over a ten hour period of work and recreation, stress, and repose. An electrocardioscanner surveys the entire record in ten minutes, prints any portion desired; when correlated with a diary of the patient's activity it provides data of a type never possible before.

Other electronic aids extend the range of established techniques. A vectorcardiographic mechanism sharply distinguishes the separate electric impulses in the heart, permits the accurate measurement of individual wave forms. A high-fidelity electronic stethoscope amplifies sound several hundred times; it can be tuned up or down as desired and is capable of detecting the heartbeat in a month-old fetus.

Fiber optics applications

Medical photography has been advanced by fiber optics, a technologic field developed in the last decade. The method employs bundles of fibers to transmit light, much as wires conduct electricity. Advantages are several: accident hazards of bulbs and wiring are eliminated, cold light can be conducted to internal cavities when desired, light can be transmitted with minimum distortion. Fiber optics have been employed for high speed motion pictures of the heart's interior. Using catheters physicians are able to film most major chambers and valves. Other researchers have used fiber optics in diagnosis, particularly for gastric ulcer and malfunctions of the female reproductive organs (82).

X-ray applications

A medical team recently developed three-dimension motion picture X-rays. The feat was accomplished by synchronizing a television camera and intensified screen with X-ray tubes which are turned on and off for one millisecond, 60 times a second. The high speed keeps radiation exposure down to five milliroentgens a frame, or about one per cent of the standard X-ray dosage. The films are used to study the effects of vibration and impact; they may prove valuable also for angiography, orthopedic procedures, clinical research involving dynamic motions.

Another innovation is the thermograph, which photographs internal processes in terms of infrared heat emissions. The mechanism consists of a scanning mirror, a thermistor heat detector, and a special camera; in the resulting photograph hot areas show up as white, cool areas as dark. Thermography began during World War II as a military means of "seeing in the dark"; it is now used a diagnostic aid in several conditions including cancer (60).

Nuclear applications

More than 4,000 United States physicians now use atomic techniques, and more than 10,000 hospitals, clinics, and medical centers maintain facilities for radioisotope procedures. The explosive growth is illustrated by the fact that hospital participation has increased more than five-fold in the last three to four years; the number of physicians involved has quadrupled over the same period.

Radioisotopes are used today in some 75 diagnostic tests and 25 forms of therapy; the figures are more than double those of a few years ago. Scientists estimate that medical use will eventually extend to at least 300 of the 1,500 isotopes thus far identified (60).

Radioisotopes have contributed to deciphering the genetic code, and have proved invaluable aids in innumerable studies of organ function, hormone action, metabolism, kidney circulation, cardiac output. One radioisotope alone (iodine 131) is used more than half a million times a year as an "atomic cocktail" to trace and control thyroid function.

Diagnosis improvement

Well trained physicians utilizing their own physiological sensors have demonstrated ability to identify disease processes and evaluate the severity of illness so effectively that many new diagnostic instruments cannot effectively compete. In recent years, certain clinical specialties have become equipped with many objective and quantitative diagnostic devices. For example, pulmonary function can be tested accurately and reliably in terms of respiratory volumes, flow rates, and gas composition. The advent of cardiac surgery, cardiac catheterization, and angiocardiography during the last thirty years have provided precise and detailed diagnosis of many pure and complex cardiac lesions in terms of the site, structure, severity, and functional disturbance to a degree undreamed of before that time. Biochemical techniques and discoveries regarding metabolic and deficiency diseases are providing specific diagnostic criteria and techniques are evaluating therapy. The diagnostic process can be improved by presenting to the physician relevant objective data regarding the location, size, movements, and other functional signs from internal organs. Measurements of bodily function can not become general and routine until their data can be collected by techniques which involve no hazard or discomfort (i.e., energy beams of safe intensities directed through the skin without mechanical penetration). The diagnostic process can be improved by presenting to the physician additional objective data regarding the location, size, movements, and other functional signs from internal organs. Such data should become routinely available through the use of instruments which can probe the inside of the body without hazard or discomfort. Valuable and objective information about internal organs can be obtained by probing the body with beams of wave energy. The diagnostic contributions of radiography and fluoroscopy are familiar examples. Utilizing other forms of wave energy, new families of diagnostic instruments are appearing over the horizon, the most immediate utilizing ultrasound and various wave-lengths of light.

Accommodation for the New Technology

There have been tremendous advances in the complexities and technical capacity of equipment in recent years. The accompanying result, of course, has been a rapid rise in the sophistication of the equipment, the initial cost, maintenance costs, and substantial upgrading of the skill requirements to operate, maintain, and maximize the use of much of modern day equipment. As initial investment rises rapidly the productive time of the equipment takes on ever more important considerations. Relatively it was of little consequence if the $150 typewriter had high levels of downtime and its use rate proved to be highly inefficient. But the $5,000 per month lease charge for computer hardware takes on vastly different dimensions. In this instance the maintenance of maximum programming and use rates, with the minimum downtime possible becomes of critical importance. Although many of the more sophisticated kinds of equipment are increasingly recognized as essential parts of modern hospital programming, the magnitude of the original investment and maintenance costs demands an ever more broadened base in order to achieve maximum cost benefit ratio's.

There are critical decisions which affect the use of new technology. Over the past few years there has been a growing national concern that much of this new technology has not been built to sufficient standards of safety, reliability, accuracy or utility, and that it is not always maintained or operated in a manner that assures its ultimate effectiveness and safety. An examination of these problems with regard to medical devices was the topic of a recent national conference (32). Many articles have appeared in the literature regarding increased electrical and mechanical hazards due to the greatly expanded use of complex devices, instrumentation and procedures in health care applications. One such article quotes a claim that "about 1,200 hospital patients are accidentally electrocuted annually while receiving 'routine diagnostic tests' or treatment because of faulty equipment" (96). There are also reports of a growing concern over fire hazards due to an ever-increasing use of oxygen-enriched atmospheres in the hospital.

Equipment malfunctions

In many documented cases, equipment malfunctions are identified as the cause of serious injuries or death to patients. Less fully understood and documented are the causes behind malfunctions. That is, equipment failures are usually symptomatic of such things as intrinsic deficiencies of the equipment, improper maintenance or calibration, misapplication or incorrect operation. Incorrect operation or maintenance may, in turn, be the result of inadequate or incorrect instructions from the manufacturer, poor design for proper operation or maintenance, or due to negligence on the part of the operator or health-case institution. At the present time, the equipment user has little alternative but to absorb the burden of legal and financial defense for such incidents, with the cost of such protection in turn contributing significantly to the spiraling costs of health services. It is impossible to measure the human suffering that results from such incidents.

Other equipment malfunctions or failures also occur that affect hospital operations in less serious ways. For example, malfunctions can cause erroneous readings which impair proper care, but do not necessarily lead to any injury. The repeated failure of critical devices can cause delays in scheduled hospital operations, excessive maintenance or unnecessary redundancy of equipment. Equipment malfunctions and downtime of this type also contribute to the high cost of hospital services, but are seldom the subject of any meaningful documentation upon which to base estimates of the extent and nature of the problem.

Any machine that supplements or replaces some function of the nurse, doctor, or technician must be reliable - in fact, as nearly as possible absolutely reliable in performance. Even the simplest machine is subject to deterioration from use and to either mechanical or electronic failure. As machines become more complex and more deeply involved in patient care, the characteristics of any man-made device make it increasingly vital that, above all else, the "fail-safe" feature become an ultimate design requirement. Failure cannot be prevented always, but safety must be assured when failure happens.

It is an unfortunate fact that equipment in use in hospitals now does not in many instances meet the test of being fail-safe.

For example, one of the most common forms of equipment failure occurs in heat therapy devices, and such failures too often result in major burn injuries. Thermostats in these devices are constructed to many specifications, in most instances those of the manufacturer. If the thermostat malfunctions, the resulting burn may include not only damage to soft skin tissue and muscles but also permanent disability.

Electrical hazards

Electrical hazards have always been present in hospitals; the hospital is a hostile environment containing corrosive and explosive materials which subject the equipment to wear and tear not normally found in other types of installations. But the chance of electrocution has risen rapidly in the past decade. One of the main reasons for this is an advance in the state of the art of intensive care patient monitoring equipment which, in turn, requires the insertion into the body of catheters to transmit physiological data. Before the appearance of the cardiac catheter, dangerous currents were measured in milliamps. But when there is open road to the heart, as few as twenty microamps can be lethal (17).

The instrument makers have come into their share of criticism for this situation for their failure to provide equipment with reliable, foolproof, and fail-safe grounding equipment. However, the following is accepted:

> The blame cannot be placed entirely on the manufacturer or entirely on any one condition. The situation as it exists today is a result of a dombination of factors that involve the newness and subtlety of the hazard, the complacency and apathy of hospitals, an almost total lack of standards relating to specific devices

specific hospital applications, confusion in some codes, and the unfortunate fact that connection devices that will work on light-duty, generally nonhazardous items such as electric clocks will also work on critical medical instrumentation (54).

Equipment interrelationships

The evolution of coronary and intensive care units and the need for complex supporting equipment in operating rooms, newborn nurseries, radiology departments and clinical laboratories generate many new problems. Multiple equipment usage increases danger in an exponential fashion. While a single device may be inherently safe; when used in conjunction with a second device, the combination may be injurious or lethal. The most common example is that of grounding the patient through the lead cable of an electrocardiographic monitoring system. Leakage current from a second ungrounded device can be transmitted through the patient to ground via the monitoring system. In the intensive care unit, surrounding the patient's bed with equipment frequently results in rather intricate and subtle electrical relationships. Unless the interrelationships are fully defined, antagonistic effects related to multiple equipment usage will undoubtedly continue to cause deaths or injuries without apparent cause. The almost infinite number of multiple equipment bedside configurations will disguise the problems as well as the answers for some time.

The problem of patient safety from electrical hazards is becoming of increasing concern to industry, legislators, professional societies, safety organizations, and hospital administrators.

Some specific problems facing hospital management as a result of automation are:

a) The greater technical complexity introduced into the hospital environment. Such factors as maintenance of the automated equipment and the need for precise scheduling of activities will become more important as this complexity increases.

b) Integration of processes. An automatic medical data acquisition examination is a case in point. "Material", patients, drugs, and information will flow automatically from one process to another, possibly leading to reduced flexibility.

c) The recruitment, training, and development of qualified technical staff. This staff can range from skilled maintenance people to operations research specialists, including paramedicals, who must understand and appreciate the systems approach necessary in making effective use of automation.

d) The increase in the amount of planning necessary in automation. This planning must go on at all levels, from long-range goal setting by top management to day-to-day scheduling in a radiology facility.

Cost-benefit analysis

Cost-benefit ratios for medical devices cannot be quantitated in a precise fashion because it is impossible to place a price tag on human discomfort and death. The costs of acquiring, maintaining, and operating medical devices are often difficult to ascertain. Many hospitals do not know how many electrocardiographs, for example, they own or how much has been spent to maintain and repair them.

For many medical devices a conventional life cycle cost analysis may be developed. Critical cost parameters may include: (a) acquisition cost, (b) equipment life span, (c) installation costs, (d), training investment, (e) utilization rate, (f) manning costs, (g) mean time between failures, (h) mean time to repair, (i) preventive maintenance cycle, (j) preventive maintenance downtown, (k) parts cost, (l) supplies cost, and (m) input power cost.

Depending on the type of device, critical cost parameters can be added or deleted. Significant data emerge from this approach. In one hospital with an unusually high number of electrocradiographs, machine maintenance costs and utilization by heart station technicians were reviewed. Total annual maintenance costs for all electrocardiographs within the heart station equalled the cost of replacing the entire inventory of machines at nine to ten month intervals. Poor training resulted in frequent breakage. This, in turn, reduced the number of machines available and created exorbitant maintenance costs. Because the number of machines available to meet demands was inadequate, more were purchased. Purchasing more machines created greater economic penalties, but did not increase machine availability proportionately. A relatively simple training program to teach technicians to use machines properly and not abuse them promptly reduced breakage. Maintenance costs decreased and the number of available machines increased without purchasing new ones (72).

Life cycle cost analysis of hospital radio page systems indicated that the traditionally favored vendor in the United States provides a receiver with a twenty-three dollar annual battery cost. A competitive and technically superior system has an annual battery cost of less than three dollars per receiver. While the initial acquisition costs of the two competitive systems are comparable, installation and operating costs for one system are much higher (72).

It is also important with low cost disposable and expandable items to distinguish between unit costs and total unit-mission costs.

One brand of disposable glove, intravenous administration set or scalp vein needle may be considerably cheaper than another, but the more expensive unit may demonstrate better design characteristics, quality control, and ease of use. Fewer will be needed to meet clinical goals. The device with the higher unit cost is often less expensive when total consumption is considered.

One 350-bed hospital changed vendors for scalp vein sets because of a reduction of of unit cost from 55 cents to 45 cents. The less expensive scalp vein set, however, was significantly harder to manipulate. Interns found that multiple attempts at venipuncture were required. This not only increased patient discomfort but increased the consumption of scalp vein needles by a factor of 2.4. The actual cost to the hospital for each successful insertion of a scalp vein needle had doubled, exclusive of increased labor costs. Similar experience with surgical gloves occurs when lower priced gloves tear more frequently (72).

Consequences of Using the New Technology

The incorporation of new technology in health facilities has forced a careful analysis of all factors which are affected by a new piece of equipment. This involves: (a) education and experience requirements for employment in a health facility, (b) special maintenance requirements to avoid excessive downtime, (c) compatability with existing equipment affecting container size, equipment interface, and changes in method and procedure of performing services, (d) safety considerations preventing equipment from dangerous malfunctions, and (e) modernization potential to avoid technological obsolescence.

The health service industry is expected to provide expanding work opportunities during the next decade. A constantly increasing proportion of jobs in the health field will require years of initial training. Technological changes in hospitals and other health facilities will have the effect of reducing or eliminating needs for workers with limited skills.

Since the general effect of innovations in the health field is primarily to raise the quality of health care, they tend on the whole to increase the demand for manpower trained in new skills rather than reduce the demand for labor. They not only create new kinds of jobs, but broaden existing jobs by requiring them to incorporate new skills. The computer is an example of an innovation that will have several effects: broadening the jobs of laboratory workers, nurses and others; bringing a new category of electronic data specialists into hospitals; and eventually also effecting substantial laborsavings among clerical and related other groups, which may reduce their proportions among the hospital labor force.

It is conceivable that new health technologies could spread at a pace faster than the trained people needed to man them could be developed. There are also instances where instrumentation has been developed but the spread of its application is awaiting wider development of professional skills in its use. An example is the cryosurgical probe. This device has reached a high state of development but the market potential obviously depends on the number of doctors possessing the necessary skills to use it.

Equipment space requirement

The burgeoning of equipment and its space requirements has been great. Historically the hospital was composed of little except large wards and support areas for food preparation and storage. However, major scientific discoveries have changed the method for delivering medical care. Space has been added throughout the hospital to accommodate the laboratory, radiology, surgery, obstetrics, and processing areas all with their respective equipment. Thus, space needed for non-patient occupied areas has grown at a much faster rate than the bed space. In a recent 8-year period the square footage required per bed practically doubled. The number of laboratory tests is increasing by almost 10 per cent a year so that within ten years space requirements may be much greater than they now are.

An institution such as a hospital, school, or hotel consists of a structure, building services, and equipment. But a hospital is more complex than a school or hotel because of the much higher ratio of support space to service space and because of the intricate relationship between many components that is necessary to assure efficient patient care. Hospital service is expensive in part because medical technology begets equipment which requires space both for itself and for people to operate it. The following is an excerpt from an article on "Instrumentation in Hospitals":

> "When I came here in 1962," said James F. Bray, administrator, "the hospital had only sixty beds and one piece of electronic equipment, a defibrillator worth $750." Today, Doctors Hospital has 219 beds and 308 pieces of electronic instrumentation with a purchase value of $749,439. By 1973, the hospital will

need 103 additional devices; by 1976, 414 more.

> Doctors Hospital of San Diego has thrived on management by instrumentation by following two rules: new instrumentation must either save money, save time, or cut inefficiency; and it must not duplicate patient services available elsewhere in the community.
>
> Flexibility and the ability to upgrade instrumentation both in terms of volume of use and capability are two maxims which guide the technology-oriented staff in equipment selection (23).

The high ratio of support requirements to patient space is now accepted. The support areas can be considered synonymous with technical areas; they require a great amount of technical equipment and many people to operate the equipment. The once popular theory that "one-time" construction cost could be tolerated if operating costs were substantially reduced is weakened when medical technology can cause, not only the equipment, but the structure itself to become obsolete. Adaptability and inter-changeability have become highly desirable objectives.

Centralization of functions

As recently as twenty-five years ago, the nursing unit was served by a floor utility room. In it might be found a pressure and a boiling instrument "sterilizer"; a solution/blanket warming cabinet, and a water sterilizer with a still attached. All items were sterilized in this room and in many cases intravenous and surgical fluids were prepared. As hospitals copied successful methods of industry (such as the tool crib), certain processes were centralized. But while centralization reduced the number of units required for processing, the necessity of purchasing additional larger units did not decrease capital outlay. Automatic controls and other labor saving devices cost much more than the multitude of manual units they replaced.

Consolidation of space did not necessarily reduce space either. Larger equipment and personnel work areas, more people and the need for transport pathways actually increased space requirements. Labor costs were reduced by the releasing of nursing personnel for nursing. On the other hand, centralization increased the costs of distribution within the hospital. Still, the end result was better processing with equipment being operated by special personnel. Centralized kitchens, storage, and laundries produced similar results.

The non-equipment approach

Disposables are popular today in hospitals. It is recognized that equipment can be eliminated through the extensive use of disposables. However, it is a maxim that as process costs decrease, distribution costs increase.

As an example, the use of disposable linens and packs in the OR may eliminate one or more sterilizers but it will require more carts and storage space, and will add to waste retrieval costs.

Equipment obsolescence

Medical technology creates more technology. But the development or the availability of the equipment always lags behind technology. It follows that the space to house the equipment, the personnel and the patient that can use the new technology also lags. As equipment is developed (see Table 2), it is almost always more expensive than what it has replaced.

Technical equipment often suffers rapid obsolescence (see

TABLE 2

EXAMPLES OF TECHNOLOGICAL CHANGE/GROWTH

Equipment	Replaces	Cost Factor[a/]	Advantage
Electric Bed	Manual Bed	3:1	Convenience
Autoanalyzer	Manual Method	6:1	Reduce Operating Cost
Cobalt Therapy	No Existing Method	-	New Technique
Cardiac Monitor	Personal Observation	-	Improved Technique
Portable Storage	Fixed Storage	3:1	Flexibility

a/ The ratio of the new method to the old where cost could be compared.

Figure 4). A piece of equipment may be usable for twenty years, but it also may become obsolete in as little as five years. There have been some instances of equipment being obsolete when the hospital opened its doors.

If the equipment is fixed, this conflict is all the more glaring. For example, a central service department was to be rebuilt in a new location. Much of the existing equipment was stainless steel casework in perfectly good condition but much of it, because of its design, would necessarily be destroyed in the removal. The irony is that it had been sold as a lifetime product; however, it had been in use for only twelve years. Other equipment, such as the sterilizer was also obsolete technologically, not structurally. The value of this equipment in the current market was approximately $160,000 and little could be salvaged.

Technological obsolescence suggests this definition of function: it is what someone has <u>provisionally</u> decided that a device may reasonably be expected to do at the time of purchase. In other words, function is transient and may be altered dramatically at any given time. When this happens the equipment should be capable of responding. Under the worse conditions, the equipment should be capable of being replaced with a minimum of disruption; at best, equipment should be designed so that it can be modernized.

<u>Fixed versus moveable equipment</u>

It appears to be impossible to have the two factors of physical structure, durability of equipment and medical technology, in constant alignment. The answer appears to be to assure that the space and

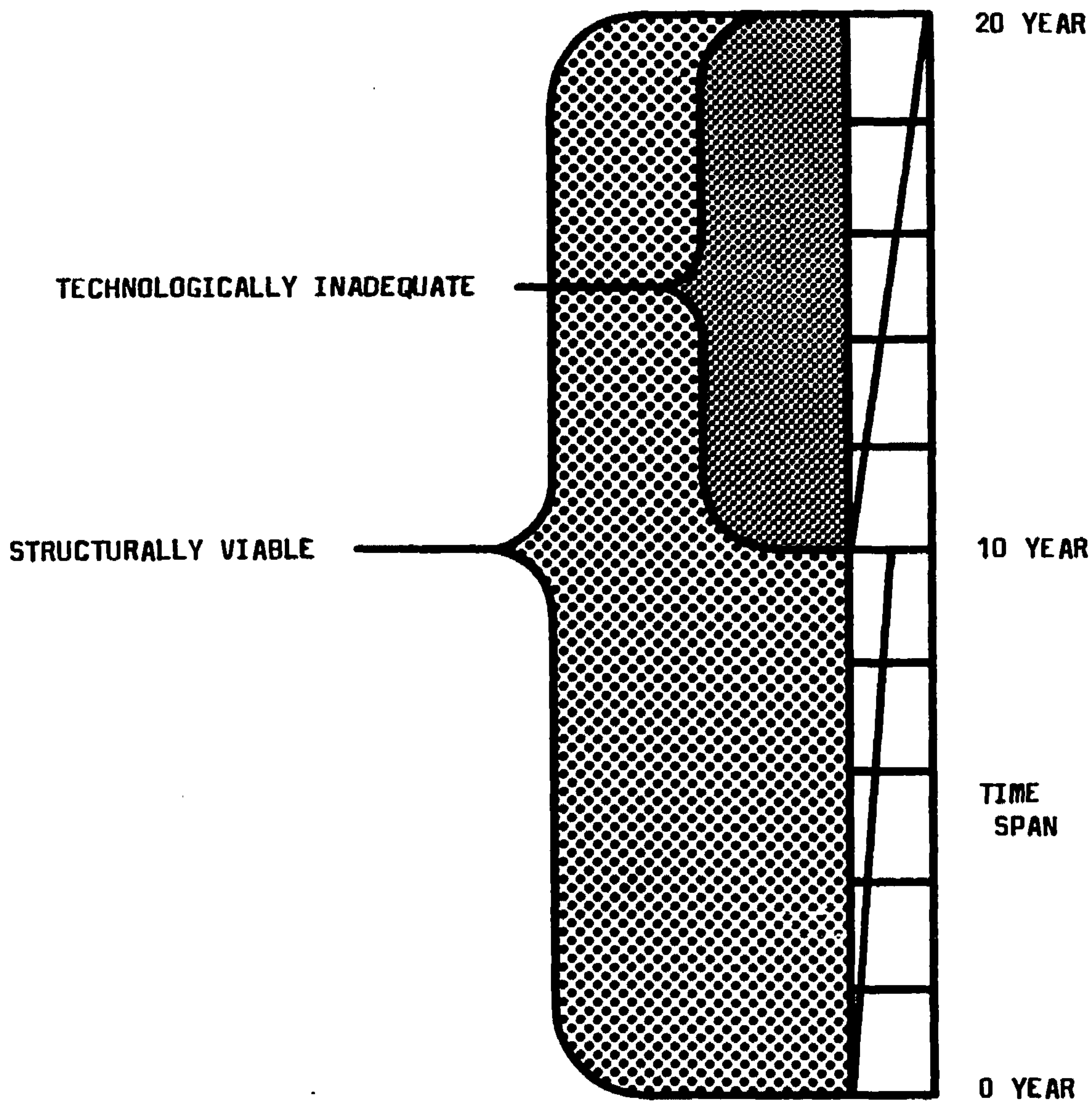


Figure 4—Structural Versus Technological Obsolescence.

equipment to the extent possible be as dynamic as the technology, equally capable of change and growth.

The shift from fixed (static) equipment to major movable equipment has slowly been taking place. Figure 5 shows the value of major movable equipment is now close to 15 per cent of construction costs. In 1953, it was slightly over 10 per cent. In the same period of time, the value of fixed equipment has decreased from 10 per cent to 8 per cent.

It can be argued that construction costs have increased at a greater rate than equipment costs. However, the equipment in some departments has increased in number of units as well as in sophistication.

In Figure 6 the costs of fixed and major movable equipment are plotted prior to 1947 through 1970 and related to cost per bed. Again the gain of major movable equipment over fixed equipment is dramatically apparent. The trends suggest that planners and administrations are seeking to avoid static situations with the hope that adaptability and interchangeability will retard the technological obsolescence of equipment.

Statistics available from Hill-Burton records have been utilized to approximate costs of major movable equipment per bed for hospitals. The costs per bed for all major departments were:

1947	1954	1961	1970
$890	$1,840	$2,550	$4,170

Equipment is necessary for accomplishing specific functions and saving labor. But it requires much space both for itself and for the people who will use it. Medical technology creates additional problems

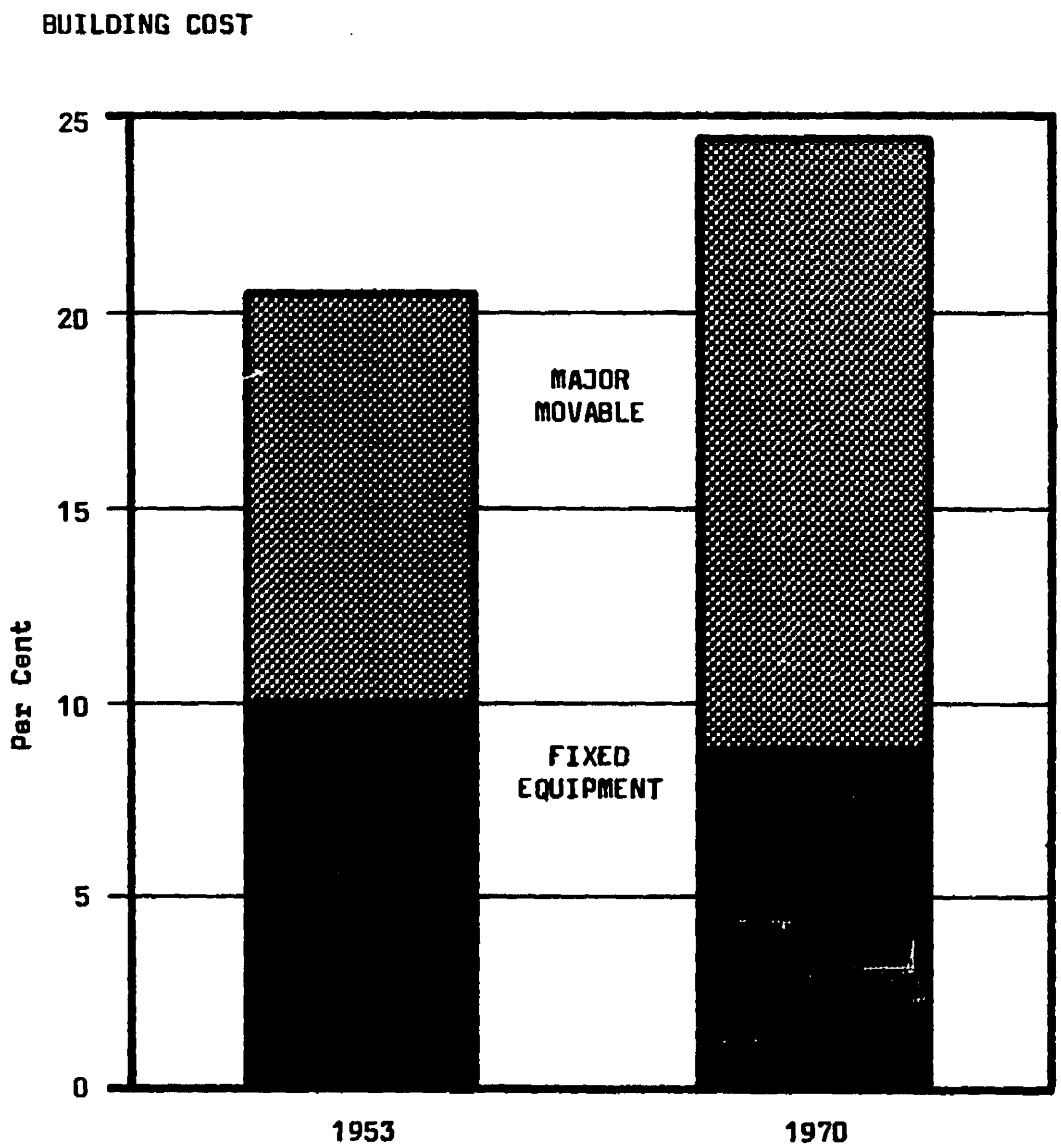


Figure 5--Equipment Shift.

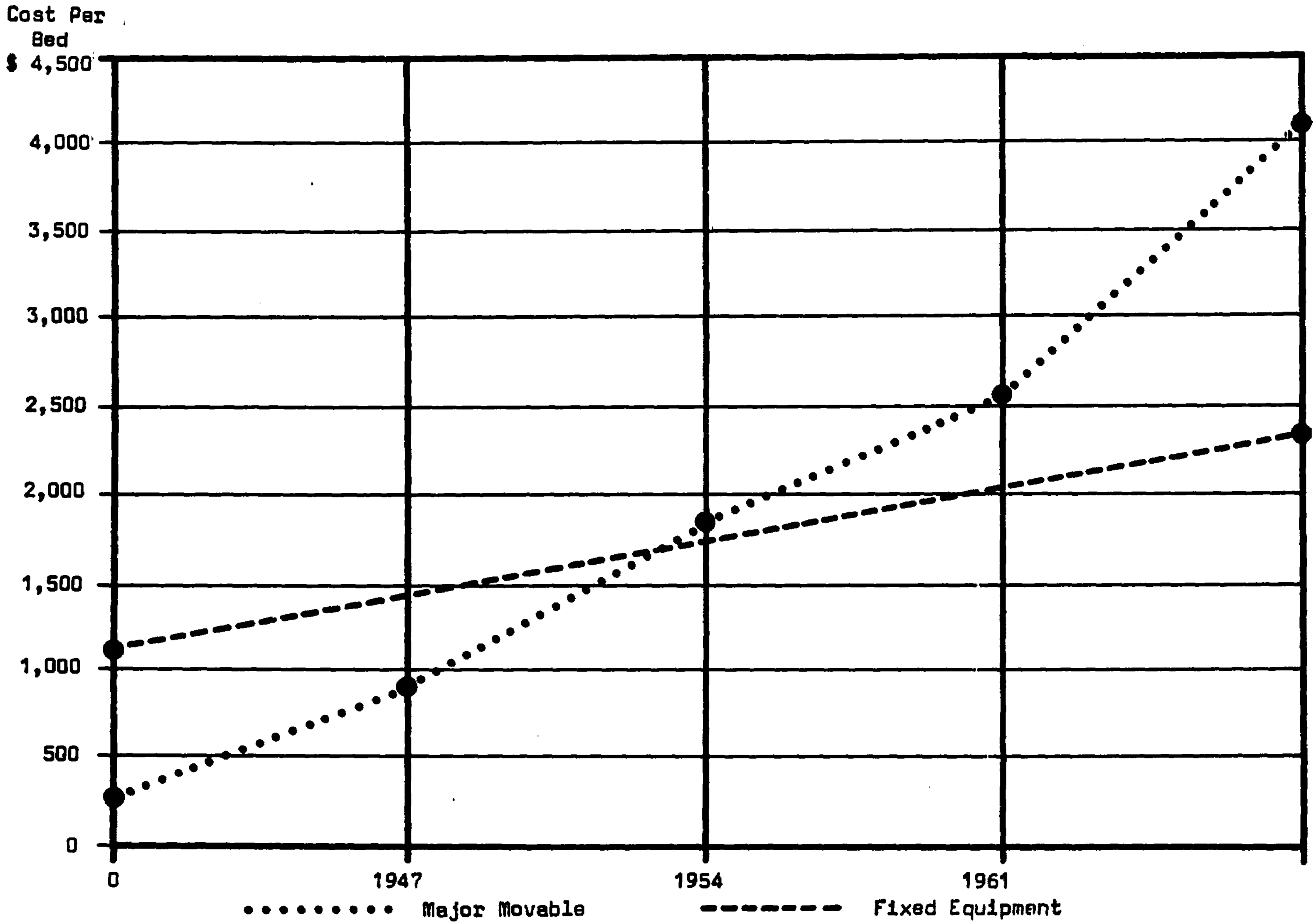


Figure 6—Equipment Trends.

of obsolescence and requires growth and change.

Scientific planning and procurement are necessary for the effective and economical use of equipment.

CHAPTER V

ANALYSIS AND RESULTS

The process of planning within the health institution will be different from the processes of planning in business and manufacturing for reasons of certain peculiarities within the health field. Some of the characteristics of the health field which influence planning are the prevalence of small organizational units lacking formal or effective coordination and direction, the absence of strong economic or other pressure to move in this direction, and the resistance of special factions to any type of organizational control or direction.

The factors presently generating urgent needs for more effective planning in the health field include those which have led to formal planning in other fields, i.e., complex technology and large investments. More complex technology and larger investments bring about longer-term implications of present decisions and the consequent greater uncertainty and inflexibility. Also, the rapidly-changing science and technology of health care delivery create higher "opportunity costs" for ill-advised decisions.

Although there is a great deal of concern for and discussion of the need for planning in the health field, most of the relevant literature of substance contains primarily discussions of and information on the physical planning and design of specific units of the hospital. Discussion of other aspects of the health planning process is almost non-existent; e.g., the determination of need, organization for planning, setting objectives, managerial decisions, designing efficient and effective systems, methods of analysis and comparison of alternatives, and operational planning.

The largest impetus to planning in the health field in recent years has been federal legislation. The Hill-Burton Program requires hospitals to perform a certain amount of planning before construction funds are approved. This legislation has stimulated the States to pay more attention to the systematic determination of facility needs. It does not cover the entire hospital field, however, and does not provide a comprehensive planning process. Legislation regarding the Regional Medical Programs provides funds and incentives for planning and developing programs to provide better health care for heart disease, cancer, and stroke. This legislation assigns a key role to medical schools as resource centers for knowledge, talent, and leadership. Comprehensive Health Planning legislation is even stronger in its support of regional planning. It is not limited to specific disease categories. It provides funds to establish and operate state and regional planning offices. The regional programs are governed by local personnel representing the health institutions, health professions, and consumers. Their basic purpose is to achieve comprehensive and coordinated planning toward common goals, and the development of effective and efficient systems for delivering health care.

Most of these programs are still in their infancy. They do not yet provide any significant assistance to the health institution in developing its plans for clinical programs and facilities. They do, however, represent factors which require coordination and evaluation.

Types of Planning Involved

For many reasons, clinical facilities have traditionally been constructed to last a very long time and planned for very little flexibility. Many hospital facilities have been used for 30 and 40 years or more. While a legitimate question is whether the planned life should be so long, there will probably have to be dramatic changes in custom, procedures, and the planning and design process before it is significantly shortened. At the present, it seems that a planning horizon of at least ten years is desirable in planning hospital facilities. With the large monetary investment required and the relatively low degree of flexibility typically achieved, the development of facility designs for ten or more years definitely calls for well-developed, long-range managerial and program plans.

The long range and strategic plans of the health institution should consist of at least the following three elements for each of the major functions of the institution, viz., education, research, and service:

a) An assessment of the needs of the "community" which the institution intends to serve.

b) The specification of the role which the institution is to serve in regard to providing for the needs of the "community".

c) The development of the philosophy of the institution with regard to its role, major objectives, and approach.

One of the most critical aspects of specifying managerial objectives in the health institution is the inter-relationships of education, research, and service, and the relative degrees of emphasis to be placed on each.

Specifications for these inter-relationships along with estimates of anticipated resource availability are necessary in order to translate general, top-level statements of objectives into more operational terms. Basic to this process of specifying objectives is the question of how to provide for society's future needs—while at the same time providing much needed service to the "community" in the present.

The long-range and strategic planning of top management may include the specification of general means of achieving the stated objectives. In most cases, a consideration of alternative means will be involved in the process of establishing objectives, especially for those objectives stated in terms having specific operational and program implications.

The formulation of objectives will involve the anticipation of various aspects of the future of the entire health field, and the selection of the best courses of action to meet the demands of the future and to realize the full potential of the institution in making that future what it is desired to be. It requires an intimate knowledge of the field, and the use of a great deal of intuition and judgment which only those experienced in the field can effectively provide.

Another level of institutional planning upon which facility plans must be based is the selection and development of programs for accomplishing institutional goals and objectives. A program is a unified set of sub-objectives, resources, organizational arrangements, and procedures. The development of program plans is the first step in translating long-range and strategic plans into facility plans.

There will necessarily be many program plans, each to be developed by the organizational unit responsible for the program. Service program plans should include descriptions of the types of services, organizational arrangements, numbers of patients, resource requirements, and new models to be developed.

Operational planning involves the development of methods and systems for carrying out the planned programs and providing the required supporting services. This is largely technical planning. The process of operational planning should include such things as the incorporation of the best available operating equipment and technology, the development of the organization structure, and the design of efficient methods of operation. It also should involve the development of plans to correct or improve present deficiencies in operations. This phase of planning is very closely related to facilities design.

Throughout the entire planning process at all levels there are needs for special and technical project work, including systems analysis and design, forecasting, methods study, and economic analysis. Much of this project work may be performed by a technical staff. For example, architects and engineers working on systems and facilities design are performing project planning.

The general relationships among these three types of planning are illustrated in Figure 7. Obviously this sketch oversimplifies the actual relationships; the feedback and recycling which must take place in a planning process are not reflected.

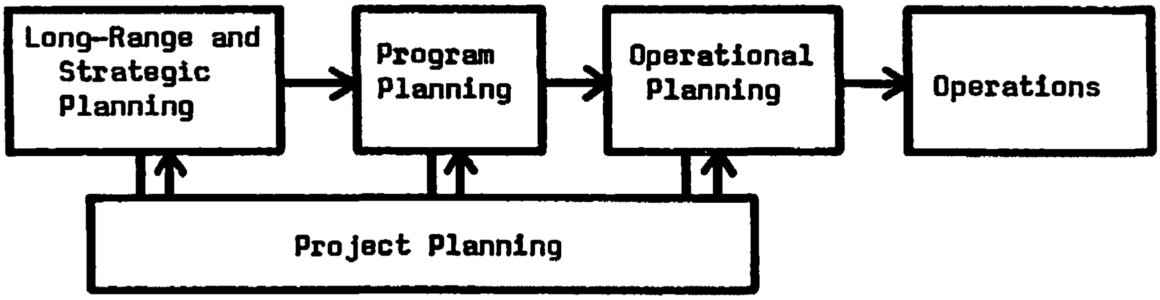


Figure 7—Planning Relationships.

Since there is no technical methodology for setting objectives, this phase of the process will depend upon experience, intuition, and judgment, and may even involve a relatively high political content. The political content may be especially high in establishing objectives related to the teaching hospital, since these objectives must be carved out of a complex and conflicting mixture of considerations involving community needs, educational objectives, accreditation requirements, governmental planning and regulation, affiliated institutions, the private practice of medicine, etc. To the extent that this process allows autonomy in setting objectives and selecting means, the type of planning which has previously been called developmental planning exists.

The primary objectives of the health institution involve the satisfaction of health care needs of the public through education, research, and service, including the development of demonstration models. Public demands provide significant indications of these needs. Therefore, the institution is responsive to public demands in the development of its plans, especially plans for the teaching hospital. While many of the more general public demands are expressed through the Federal and State governments, there may be other significant demands upon the institution from the local community.

The process of planning for clinical facilities also involves many elements of allocative planning, i.e., the allocation of resources among competing uses in those cases where there are quantitative measures of effectiveness and where the optimality criterion is the primary guide. This process is an objective one, and usually involves the comparison of alternatives on the basis of technical and economic measures. It appears that, because of a lack of specificity in objectives and a lack of good quantitative measures of effectiveness, allocative planning plays a minor role at and above the level of program selection and design. As the process moves closer to operational planning and design, allocative planning comes more into play. For example, alternative supporting service systems and operational facility designs are more frequently selected on the basis of their costs and benefits.

Another type of planning required involves the introduction and development of new arrangements and programs for the accomplishment of dramatically new objectives which may not have received general acceptance and support within the institution. Such seems to be the case, for example, in the development of "comprehensive health care" programs under the auspices of the institution. In the case where major new facilities are being planned, and where these facilities must be specifically designed to accommodate these new programs, a process of rapid and radical change may be required. The process of mobilizing personnel and resources and guiding change toward the yet unaccepted new objectives has been called innovative planning. With the major problems facing health institutions today, and with the complexity, resistance to change, lack of coordination, and disunity which presently exists within the health field, elements of innovative planning will probably be very important in the process of planning for clinical education facilities.

Finally, almost all of the various types of plans will be produced at some point in the process of planning for clinical facilities.

Policies and objectives will be developed for the institution and for each relevant subdivision. Operational plans will be developed for each major function, including education, research, patient care, and supporting services. Those procedures having implications for facilities design will be designed. And, both captial and operating budgets will be prepared. All of these types of plans will be combined into what the planning literature calls a "program".

As is true in the planning field, in general, there are few established procedures and techniques for planning for clinical facilities. This is clearly indicated by the literature related to this field. While it is not expected that a scientific or even a mechanistic methodology will ever be developed for this process, there are many opportunities for making it more organized, systematic, rational, and, hopefully, more successful.

Although one of the primary objectives of the process should be to achieve maximum rationality in planning, the roles of objective and scientific methods and approaches are limited by many factors, including the following:

a) The value judgment content of the process.

b) Incomplete information.

c) Lack of time and resources for thorough study.

d) Inappropriateness of data on past operations in a process which has as its primary purpose establishing new patterns for future operations.

e) Inadequacy of present objective and scientific methods and approaches involving many of the most important problems in such a process.

It is apparent that new directions, approaches, and methods are called for in the health and education fields. Planning which involves an extension and gradual improvement of old forms of operation may very well not be adequate to meet even the short-range needs. To fulfill the role that is needed for planning in these fields, a great deal of imagination and creativity will be required.

As indicated in previous paragraphs, planning for clinical facilities should be a comprehensive process involving all of the major elements and activities of the organization. Because of this, the selection of the critical elements for study and redesign, timing, and organization are of utmost importance.

Because of the scarcity of acceptable data, the incompleteness or knowledge regarding health care needs and the operation of the health care system, and the radical changes anticipated, analytical-quantitative forecasts and predictions for long-range planning in the health care field are probably less accurate and reliable than in business and manufacturing. The use of analytical quantitative methods of forecasting should be carefully considered and viewed critically. About the best that can be done in many cases is to attempt to anticipate the possible futures so that the right risks are taken, and so that the appropriate flexibility to respond to major anticipated developments can be achieved. A valuable approach in this connection is the performance of sensitivity analyses on alternative plans and designs, i.e., test each alternative against the possible future consequences in order to predict results under the various conditions.

"Uncertainty absorption" is another important aspect of this planning process. Assumptions and decisions made at various levels of the planning organization tend to "absorb" some of the actual uncertainty which exists, so that subsequent levels perform under less apparent uncertainty. This is an important consideration in the organization and management of the planning process. Some of the uncertainties will involve the patient care process, supporting services, and managerial and administrative matters. Each type of uncertainty may require a different type of person to make the necessary assumptions and judgments.

Special Considerations in Health Facility Planning

Many of the previously described changes taking place in the health field may affect the design of clinical facilities. One of these is the implementation of progressive patient care. Under this concept there are usually three levels of care, i.e., intensive, intermediate, and self-care. These levels are defined in a manner which indicates decreasing nursing and medical care requirements. Likewise, the features required in the facilities for each level are somewhat different. These differences involve utility and equipment requirements, e.g., equipment in intensive care areas require extensive electrical, suction, and oxygen support; layout, e.g., ambulant self-care patients will need recreational space; support systems, e.g., different items and quantities of supplies will be needed in the intensive care unit than in the self-care unit; and staffing, e.g., fewer nursing personnel per patient will be required in self-care than in intensive care. The varying needs in the progressive patient care concept will probably lead to compartmentalized facilities, with each compartment designed to meet the needs of a particular level of care. In some cases separate structures may be justified for one or more of the levels of care. For these reasons it is important that program plans indicate expectations regarding numbers and types of patients in the various levels of care.

The trend towards shorter lengths of hospital stay is another factor which could have a significant impact on facility requirement. Some of the reasons for this trend stem from the rapidly increasing cost of hospitalization, but others are primarily medical in origin. For example, in many cases early ambulation is felt to be good for the patient, therefore shorter periods of hospitalization are possible. Assuming that the same relative mix of types of cases will occur in a given hospital and that the level of occupancy will remain the same, then with a shorter hospital stay more clinical supporting services (e.g., X-ray, laboratory, surgery, and physical therapy) must be provided within a given time period. This type of change tends to invalidate existing rules-of-thumb and planning ratios for supporting services. Investigations will be required to determine better planning information. The requirement that the same or increased supporting services for a patient be provided in a shorter period of time will also place heavier demands upon the communication, logistical, and scheduling systems of the hospital. New and improved systems may have to be designed.

Health facilities planning must anticipate the use of new and improved equipment and managerial support systems. Examples of these are computers and "management information systems", integrated communication systems, automatic material handling and distribution equipment, and sophisticated medical equipment such as auto-analyzers and electronic patient-monitoring. The architect should know early in his design process which of these will be used, since he will have to incorporate specially designed areas for certain equipment, provisions for utility lines, and increased utility capacity. Decisions on these matters will also affect staffing, traffic, and material flow, all of which the architect must consider in facilities design. Examples in other hospital areas are not difficult to suggest, e.g., convenience food systems.

The dramatically increasing costs of health care today are causing a general questioning of many aspects of the health system. These higher costs may eventually change the pattern of hospitalization, i.e., the types and numbers of patients hospitalized, as significantly as hospitalization insurance has in the past. Such a shift in utilization patterns would have significant effects on facilities requirements. Another effect of rising costs is increasing pressure for improved operational efficiency. Some of the possibilities for improved efficiency are found in automatic equipment, electronic data processing, and different staffing patterns. Facility design must accommodate these types of changes.

Facility design itself, especially internal layout, is a good area for innovations to improve efficiency. Potential returns from the substitution of capital for labor seem exceptionally good in view of the fact that labor cost usually make up 60-70 per cent of hospital operating expenses, and since 1.5-2.5 years of operating costs normally equal the construction cost of the facility (2).

The relative locations of various functions and areas within the facility is another factor to be considered by the planning team.

These decisions cannot be left exclusively to the architect since many of the relevant criteria are derived from the objectives of the various organizational units and from other technical and operational considerations on which the architect may not be the best judge.

Important proximity relationships involve the patient care process. For example, certain types of patients require frequent use of X-ray and other supporting services. Close proximity to these services reduces inconvenience and travel time. Other types of patients need to be close to certain facilities and equipment which might be needed urgently; e.g., an obstetrical patient may need to go to the operating suite on short notice. Some proximity relationships are derived from the need for certain types of staff to be close to patients, e.g., nurses and on-call doctors. The requirements for these types of proximity, however, are changing with design innovations and new systems such as nurse-servers, baths in each bedroom, improved audio and visual communication systems, and material handling systems. These changes increase the capacity to effectively and efficiently bring services to the point of use without having the service area in close proximity to the user area.

With a field as dynamic and changing as the health field is today, flexibility should be one of the primary criteria in evaluating alternative designs. There are several ways to achieve flexibility. One is to design the structure so that it can be efficiently modified internally to accommodate changing functions. This is difficult to achieve in a hospital because of the nature of the process and of the product, the amount of plumbing and other utilities involved, and other special design requirements. The use of standard sized modules and rooms which would suit several different functions will give some flexibility, however.

Another way of achieving increased flexibility is to shorten the planned economic life of the facility so that complete changes can be made more frequently. The successful application of this approach, however, even if proven to be economical, would probably require changes in attitudes and methods of financing hospital facilities and operations. The agencies providing funds for facilities may not encourage designs requiring significantly higher capital funds over the years even with the promise or hope of decreased operating costs, especially since these same agencies are usually not responsible for providing operating funds.

Some other problem areas in health facility planning are as follows:

a) Confusion of primary goals.

b) Lack of knowledge, quantifiable goals, and operational data.

c) Lack of good coordination and a decision making body.

d) Conflict of medical practice and the needs of planning.

e) Lack of good measures of "need".

f) Rapid growth and development.

g) Newness of planning to many personnel in the health field.

With these difficulties, it should be no surprise that examples of good planning are hard to find in the literature.

Hospital Technology and Choice

In planning for the application of new technology in clinical facilities, it is important to distinguish between changes from one technique to another already known technique. Technical change without scientific progress occurs for two different reasons. Traditional economic analysis emphasizes the change that occurs in response to a shift in the relative prices of inputs. Because hospital wage rates have risen much faster than the prices of their other inputs, hospitals have economized on labor by using more disposable items, by automating laboratory and clinical procedures, and, in general, by other forms of substituting equipment and supplies for personnel. The effect of this substitution has been to prevent costs from rising as fast as they otherwise would have. The importance of this factor as a determinant of the rate of the hospital cost inflation in the past and as an influence on future cost increases is a potentially rich but currently unexplored subject for research. From 1955 to 1968, hospital wage rates rose approximately 92 per cent, and other input prices, as measured by the wholesale price index, rose 17 per cent. Moreover, in 1955, 62 per cent of total expenses were for labor input (68). The general theory of this type of input substitution is well understood, but because there is insufficient information to examine this process in hospitals, this type of technical change will not be discussed here.

The second reason for technical change without scientific progress is a change in the demand for hospital care. This type of technical change generally yields a new product and not just a different way of producing the old product. An increase of demand can also change technology without changing the product if institutions grow in response to the increased demand and a different technology becomes less expensive at the larger scale. Although actual changes in product and in production technique are often the result of both new scientific knowledge and a changing demand, the logical distinction between changes with and without new scientific knowledge is important for understanding the process of change and its effects on cost. This discussion of technical change can be clarified by using a diagram to represent the two components in the analysis: (a) the relation between cost per patient day and the benefits of hospital care as perceived by patients and (2) the preference of patients that determine their choice between more expensive hospital care and other forms of consumption.

Figure 8 represents the benefit-cost possibility curve, the relation that prevails at a given time, with the particular current state of scientific knowledge, between average cost per patient day and the benefit of hospital care as perceived by patients. This relationship represents the different possibilities that are in principle open to each hospital with its given diagnostic mix of admissions and with fixed input prices. The shape of the curve indicates that as the cost increases, so do the benefits. In addition, at increasingly higher levels of cost, the rate of increase for the benefits of hospital care decreases.

Cost per patient day can be varied by changing the technology of care through different staffing patterns, equipment, and supplies. Each point on the curve therefore represents a particular technological configuration. The term "benefit" should be considered quite broadly to include not only the expected degree of success of the medical care but also the patient's comfort while in the hospital and the reduction in

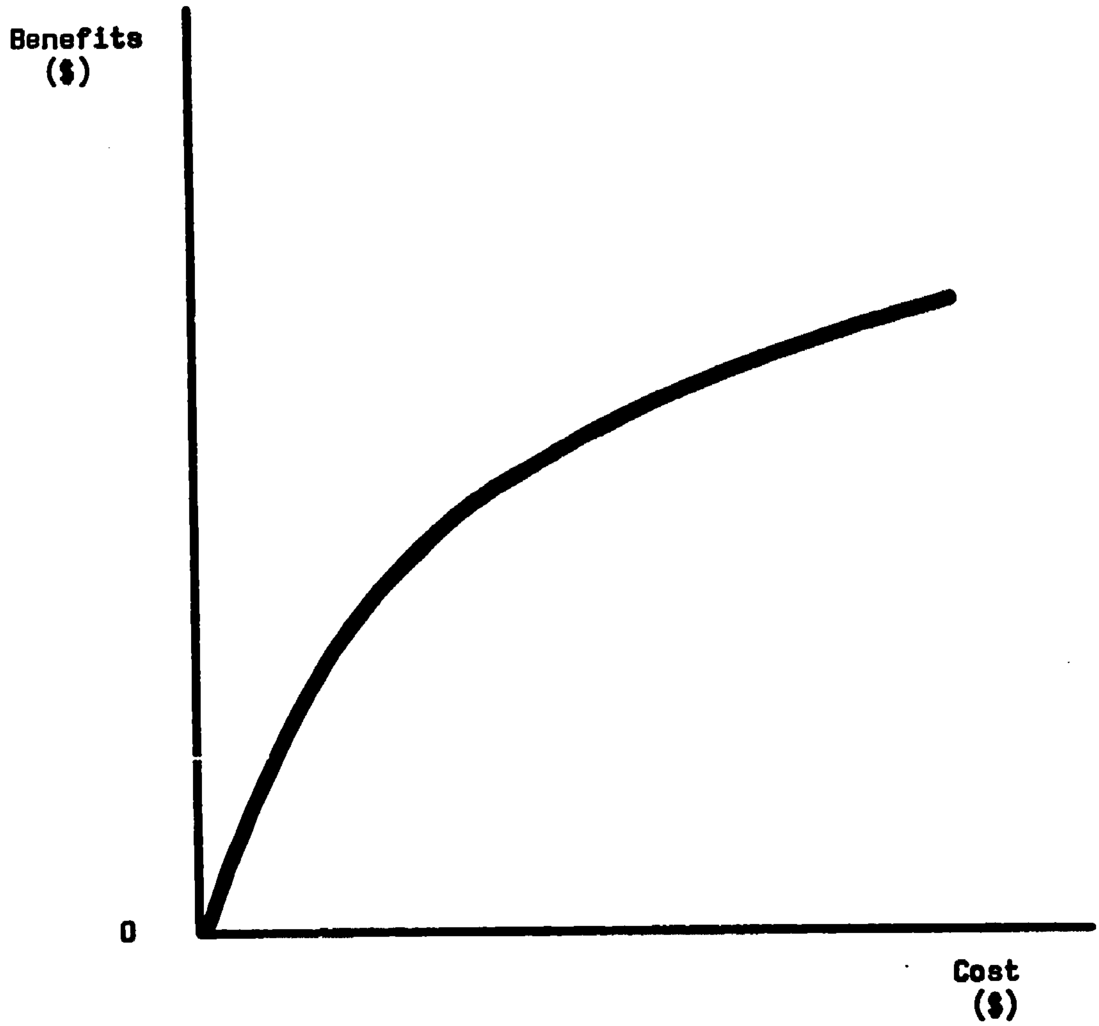


Figure 8—Relation of Benefits to Cost.

uncertainty that is provided by more expensive diagnostic procedures. There is no natural physical unit in which the benefits can be measured. It is useful, therefore, to consider a dollar measure: the maximum amount that an average individual would be willing to pay for the expected medical gains, comfort, and reduced uncertainty. The shape of the benefit-cost curve implies that an increase in cost per patient day raises the level of benefits, but less than proportionately.

It is difficult to determine the point on the benefit-cost curve where a hospital will choose to operate. In a community in which a single hospital serves the entire population, the chosen technology will reflect the preference of the patients, the medical staff, and the hospital administration in an indeterminate way. However, when patients can choose among several different hospitals, it is likely that their preferences will dominate in determining the technology. Although a patient rarely has many hospitals among which to choose, the patients of any given hospital will come from different locations and, therefore, have different hospitals among which to choose. The hospital is therefore in competition with a larger number of institutions than any single patient's range of choice. This spatial characteristic of the market weakens the potential oligopoly power of hospitals. However, because anti-trust regulations do not apply to voluntary and public hospitals, there may be more collusion that would prevail in a profit-seeking industry with the same market structure. This analysis will assume that patients' preferences to determine the benefit-cost point that prevails. The assumption that patients' preferences prevail is not crucial to the analysis. If the preferences of the physicians or hospital administration were assumed to prevail instead, the benefits could be redefined in terms of their preference instead of the patients'.

"Indifference curve analysis," a diagrammatic method widely used in the economic theory of consumer behavior, can be adapted to represent preferences in the current context. Figure 9 shows three indifference lines, labeled I_0, I_1, and I_2. Indifference line I_1 represents one set of benefit-cost combinations, among which the "representative" patient is indifferent; he has no preference between the relatively low-cost hospital care (point A) and a higher cost hospital care if the benefits are sufficiently higher (such as point B). By construction, at every point on I_1 the patient values the benefits at $20 more than the price he would have to pay. (To say that the patient "values" the benefits at $20 more than their price is equivalent to saying that he would be willing to pay up to $20 more than that price for those benefits.)

Points on indifference curve I_2 represent benefit-cost combinations that are preferred to those on indifference curve I_1; point C is more costly than point A but offers much greater benefits. At every point on I_2, the patient values the benefits at $40 more than their price. Similarly, points on I_0 are less desirable than those of I_1 and I_2; more specifically, these are points at which the charge represents the maximum amount that the patient would be willing to pay for the corresponding benefits. Although only three indifference lines are drawn for illustration, every possible benefit-cost point lies on some difference line.

Figure 10 combines Figures 8 and 9. Since the only technically feasible benefit-cost combinations lie on or below the benefit-cost possibility curve, it is clear that point E is the benefit-cost

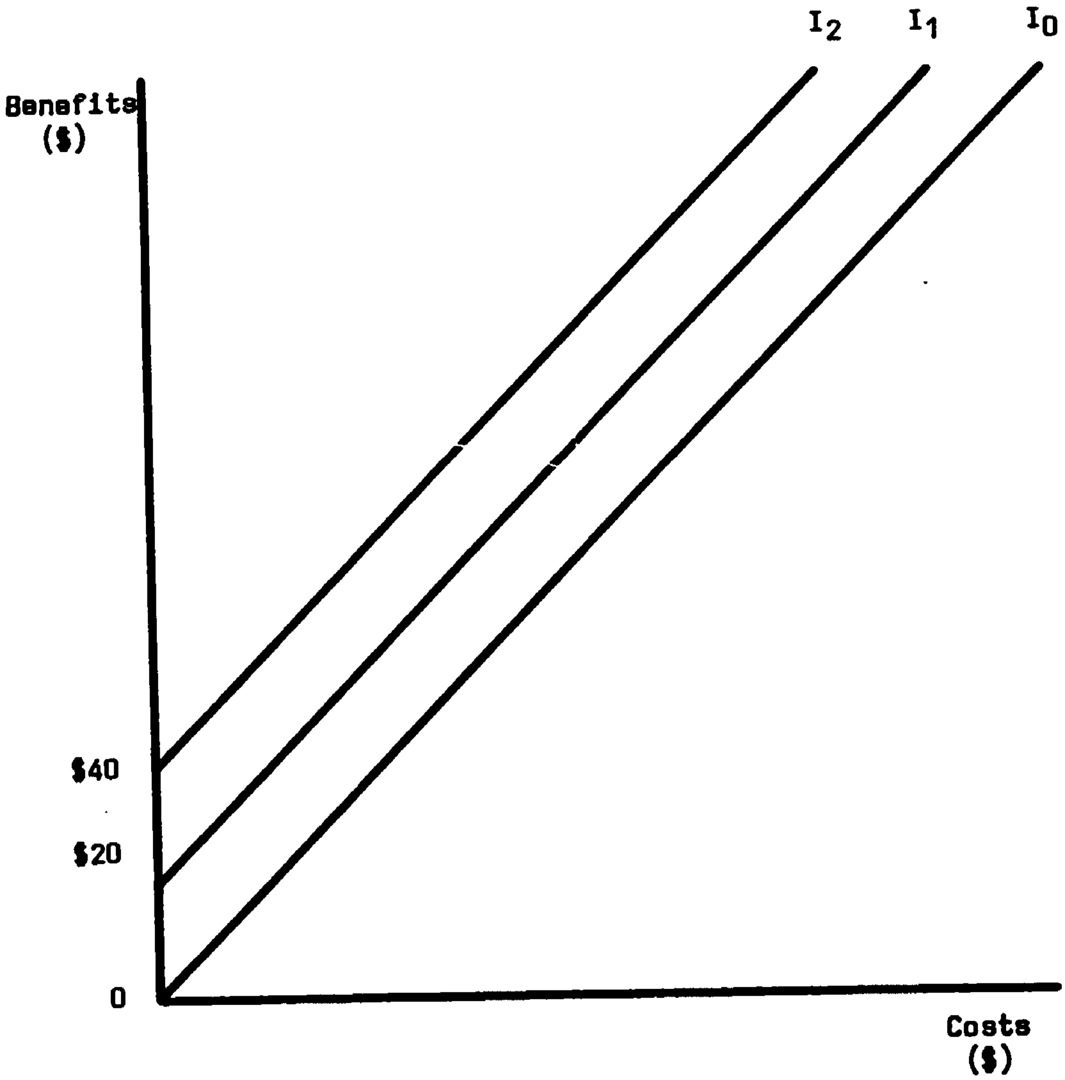


Figure 9—Indifference Lines.

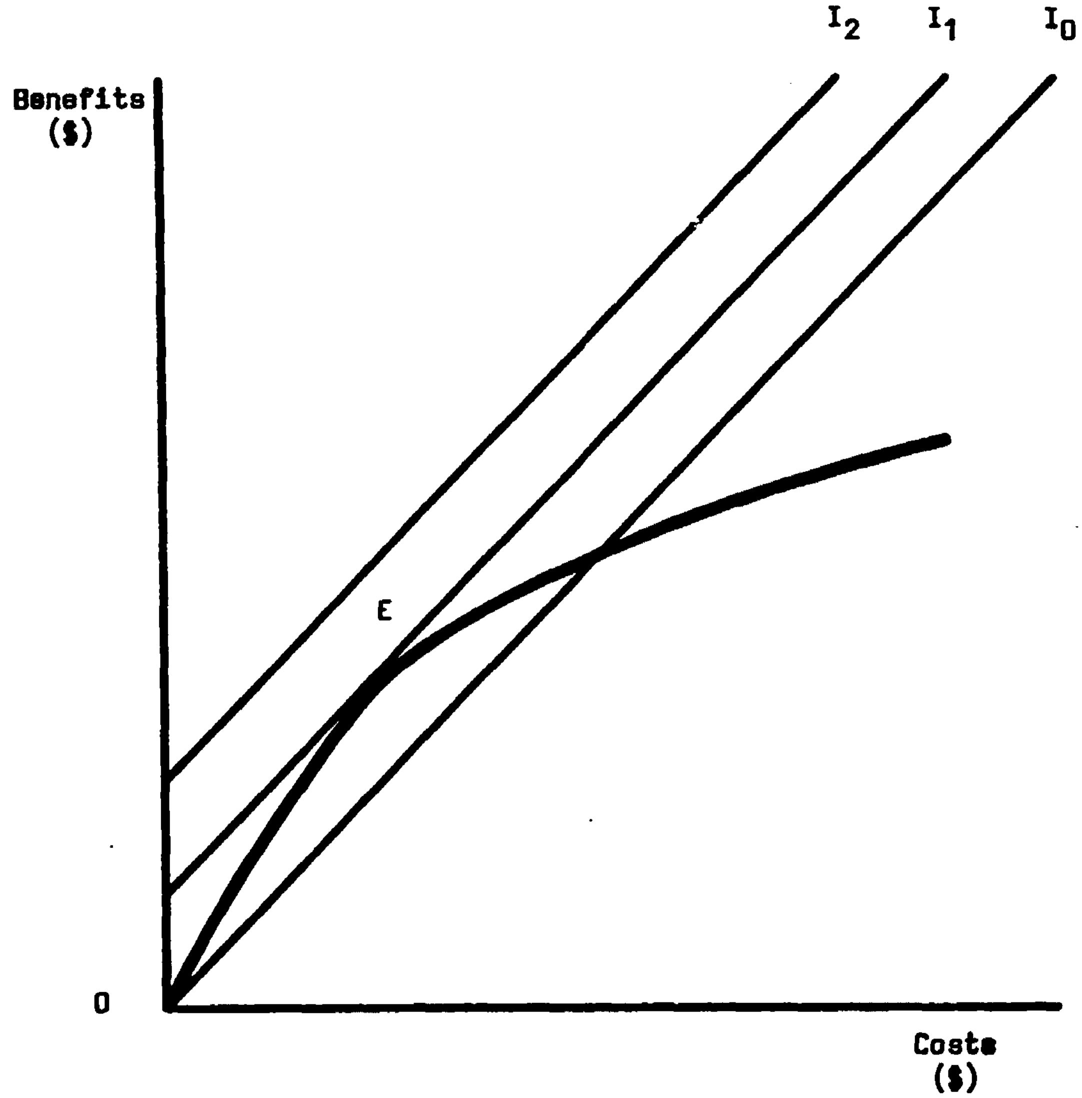


Figure 10—The Preferred Cost Point.

combination that the patient prefers. All of the other points on and below the benefit-cost curve lie on lower (i.e., less preferred) in difference lines, and points on higher indifference lines such as I_2 cannot be attained. The technology marked by point E, with the cost per patient day approximately $40, would therefore occur if patients' preferences prevailed. At any cost per patient day up to approximately $90, the benefits indicated by the benefit-cost possibility curve exceed the cost. The hospital which is a local monopoly could therefore adopt a more expensive technology than the one most preferred by patients and still be able to sell its services.

An important part of evaluation of technology is the comparison of alternatives in terms of the consequences of its implementation. In making such comparisons there are two principal conceptual approaches:

a) Fixed effectiveness approach. For a specified level of effectiveness to be attained in the accomplishment of some given objective, the analysis attempts to determine that alternative which is likely to achieve the specified level of effectiveness at the lowest economic cost.

b) Fixed budget approach. For a specified cost level to be used in the attainment of some given objective, the analysis attempts to determine that alternative which is likely to produce the highest effectiveness (61).

Either of these approaches may be used, depending upon the context of the problem at hand.

Technical change without scientific progress

At any time there are substantial differences among hospitals in staffing patterns, the use of equipment, and the sophistication of diagnosis and treatment. Expensive new techniques are introduced by a few hospitals and spread gradually over time to an increasing number of institutions. This spreading of high-cost techniques does not, of course, represent new scientific knowledge. The primary reasons for such technical changes are rising income and increased insurance coverage. The spread of intensive care units—from 10 per cent of hospitals in 1960 to 42 per cent in 1968—is an important recent example (2). The American Hospital Association Annual Survey of Facilities presents other examples of this aspect of technology change.

With a higher income, the patient will generally be willing to pay more for any given set of hospital care benefits (i.e., expected medical success, comfort, and reduced uncertainty). In terms of the diagram, higher income raises the benefit possibility curve. Figure 11 shows how such a shift of the benefit-cost possibility curve, from BC1 to BC2, can increase the cost per patient day of the preferred benefit-cost combination from E to F. In the current context this relationship is implied if, as income increases, patients raise the valuation of the less costly care. Since this is more likely than the converse, a rising income will generally lead to a more expensive technique.

Technical change with scientific progress

No cause of rising hospital cost is more frequently cited than the lack of or low rate of technical progress. Such a statement is very misleading. With the aid of the diagram it is easy to see that gains in scientific knowledge (including managerial innovations) that have the potential of lowering the cost of care may actually have the opposite effect.

With the level of income and the extent of insurance both

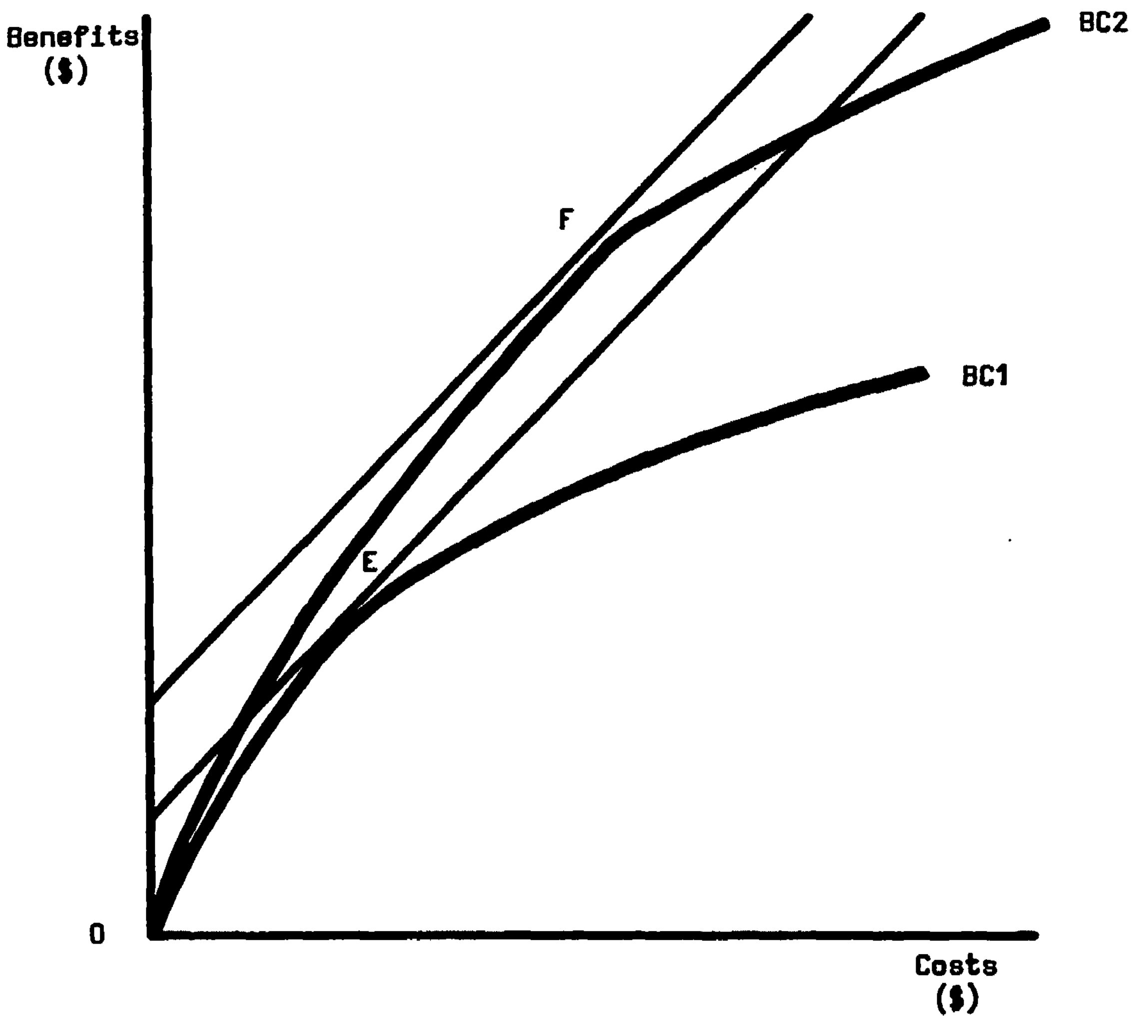


Figure 11--Higher Income and the Benefit Cost Curve.

constant, scientific progress can be represented by an upward shift in the benefit-cost possibility curve (see Figure 12). At every level of cost per patient day, the new scientific developments permit a higher level of benefits to be produced. That is, every level of cost per patient day corresponds to a new "product" or technology, for which patients would be willing to pay more. Before the technical change, the hospital was producing at point E, where the benefit level is B1 and the cost per patient day is C1. The new scientific knowledge represented by BC2 permits the B1 benefit level to be produced at a substantially lower cost, C2. This decrease in the cost of producing the original benefit level would be an appropriate measure of the productivity gain entailed in the new scientific knowledge. An alternative measure of productivity gain is the increase in benefits that would be possible at the old cost per patient day, i.e., the increase from B1 to B2. These measures will not generally agree with each other or with other more complicated measures involving changes in both costs and benefits that might be used. Such is always the nature of the index number problem involved in comparing two curves. The important point, however, is that, by any appropriate measure, the change is scientific knowledge can be said to imply a productivity gain. However, the gain in productivity does not imply that the cost per patient day with the new technique will actually be lower than the cost per patient day with the original technique. In Figure 12 the new preferred service occurs at a point (F) where the technology implies a higher cost per patient day and, of course, substantially higher benefits. Although patients could have continued to obtain the same benefits of health care as before, but at a lower price,

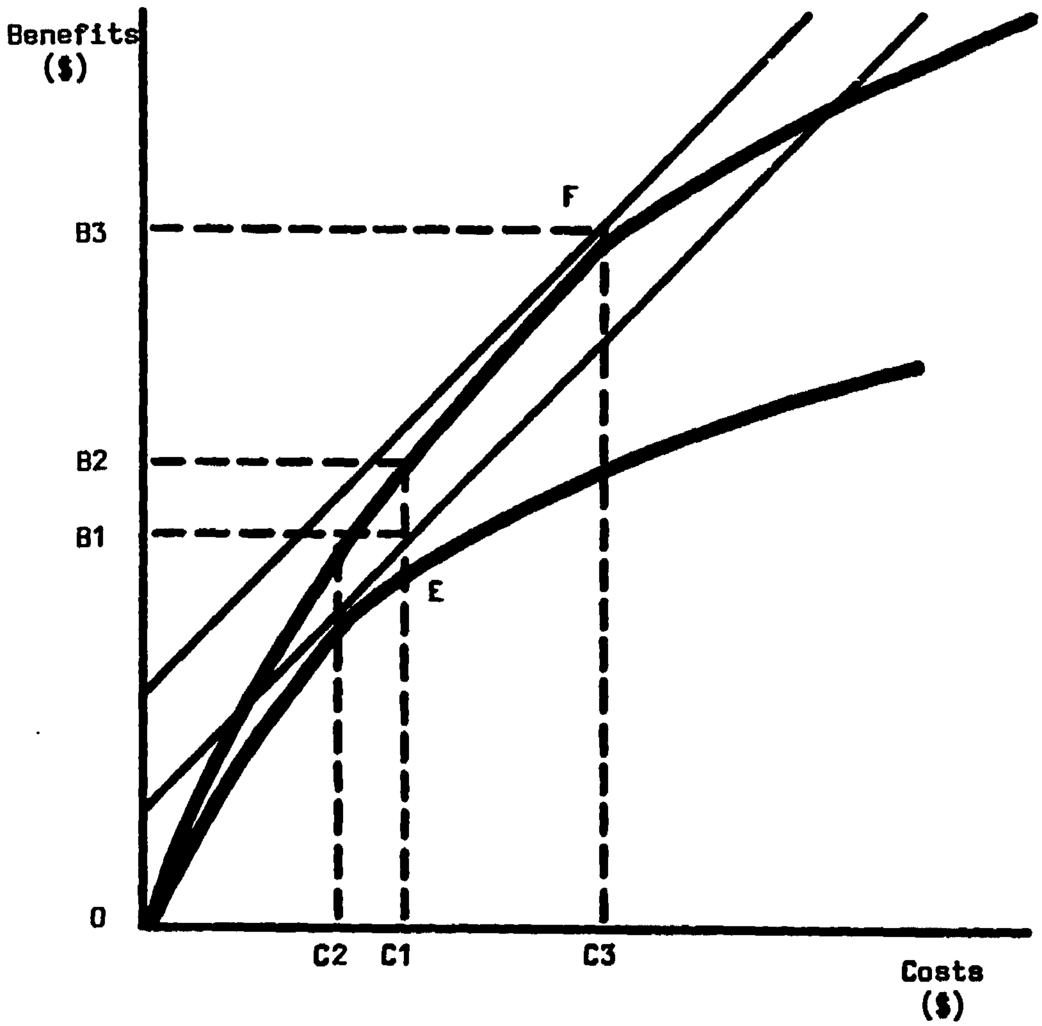


Figure 12—Technical Progress and Higher Cost Per Patient Day.

the new opportunity for much greater benefits with a relatively small increase in cost led them to prefer F. The new level of benefits might also be used as a basis for measuring the productivity gain. More specifically, the productivity gain could be defined as the percentage difference between the cost of producing B3 after the technical change (i.e., C3) and the cost with the old technology (not shown). Moreover, with the old knowledge, such a benfit level might not be achievable at any cost.

The determinants of scientific progress are too complex to permit simple generalization about the economic forces that influence whether technical progress increases or lowers cost. It seems likely, however, that research effort is biased away from attempts to reduce the cost of providing the current or somewhat lower level of benefits and toward attempts to raise the benefits associated with higher levels of cost. This likelihood reflects both the standards of academic medicine and the ethics of "the best possible care for my patient."

This analysis reveals: (a) the rise in cost per patient day is not evidence that there has been no technical progress or productivity gain; (b) changing demand can alter technology without any scientific progress; (c) technical progress can increase, as well as lower costs; and (d) the current approach to medical research may be biased toward producing information that causes technical progress to increase cost.

Hospital Services and Technology Demand

Concern with the adequacy of resources for meeting expanding commitments for care has directed attention to the way in which hospital and health capital is and could be formed. The belief has been current that capital accumulation depends on availability of capital funds, and that this availability, in turn, depends on government decisions and philanthropy. These assertions leave unexplained the basic reasons why voluntary hospitals seek additional funds.

It can be shown that increased complexity of services requires increasingly capital-intensive use of resources. In addition, there may be a scale effect, with larger hospitals requiring relatively more capital.

In the course of their operations, hospitals are obliged to choose among alternative uses of resources, and they do in fact select some option from the array presented. The selection itself implies a preference and can reasonably be interpreted as implying comparison and evaluation of outcomes of the various alternatives.

One must assume that changes in the conditions which provide the basis for evaluating the outcome of various alternatives do influence the target goals of hospitals in seeking out funds, and thus the amounts eventually received and spent, that is, hospital initiative and demand take on an autonomous role in the capital allocation process. Factors which are believed to be influential in evaluating alternative allocations include the hospital-doctor relationship. Admitting privileges of doctors stem from private arrangements with hospitals. Doctors are therefore disposed to go where they will have the greatest possible array of services and facilities to support their private practices. The hospital thus acquires a motive for taking into account the capital it will require both for the patient load it anticipates and for satisfaction of the requirements of the physicians admitting the patients. The basis is laid for an investment policy, a planned response to new technology and to the expansion of services and the treatment of more patients. The hospital must respond because the doctor can withdraw his affiliation if he becomes dissatisfied with the hospital's services. Implicit in this reasoning is the fact that doctors at levels of skill and range of specialization that the hospital would like to retain or attract are relatively scarce.

The tendency of hospitals to duplicate facilities flows from their competition for doctors. The result is that unmet needs coesist with excess capacity, and the community loses services. The present relationship, in which doctors, although neither owners nor employees, have a voice in management decisions, may pass into history as a transitional form of hospital organization as more doctors assume full-time posts at hospitals. However, given the relative scarcity of doctors, the incentive for hospitals to try to provide doctors with technically optimal facilities will remain.

The relationship between such variables and actual investment data was tested on data for years of operation (1945-1965) of forty voluntary hospitals in New York City. These data were made available by the United Hospital Fund. Annual reports were examined, and time series were developed for investment in plant and equipment, extensive and intensive aspects of services provided, and extent of teaching commitment and activity.

The principal findings were as follows: when annual aggregates for the forty hospitals were treated as variables, 68 per cent of the variance in annual real investment was explained by three factors - yearly changes in an output index, yearly changes in the ratio of semiprivate days to admissions, and an allowance for a distributed lag in carrying out desired investment projects. In a cross-section of means for each variable, the lag disappeared, and somewhat different variables stood out as predictors. Of the variance in mean annual real investment per hospital, 56 per cent was explained by mean annual differences in admissions and in the extent of teaching commitment. Investment data on an annual basis are presented in Table 3, along with measures of the extensive and intensive changes in services provided (64). The rate of investment per year in current prices is defined as the annual change in adjusted book value of plant and equipment, as reported by the hospital to the United Hospital Fund.

Seven variables were selected to account for investment in the period. These were the increment between periods (t-2) and (t-1) in the following areas: (a) admissions (this was taken as a measure of extensive demand for hospital services); (b) operations per admission; (c) X-rays per admission; (d) laboratory tests per admission. These ratios were taken as measures of intensive demand for hospital service. Also studied were (e) semiprivate days per admission, a measure of the hospital's shift away from ward care to care of solvent insured patients; (f) interns and residents per bed, a measure of teaching activity, a major service product of metropolitan hospitals; (g) ratio of special to general professional staff, a general measure of the relative intensity of services. Special professional staff includes those in such departments as X-ray, laboratory, and operating room. General

TABLE 3

TOTAL GROSS INVESTMENT, ADMISSIONS, AND SELECTED FUNCTIONAL RATIOS FOR FORTY HOSPITALS, 1945-1965

Year	Gross Investment	Admissions	Functional Ratios: Operations/ Admissions	X-Ray Films/ Admissions	Laboratory Examinations/ Admissions	Semi-private Patient Days/ Admissions	Professional Care: Special Staff/ General Staff
1945	$	273,379	.533	2,525	8,516	3,706	.220
1946	1,261,379	303,252	.568	2,981	9,292	3,449	.226
1947	2,367,903	323,492	.550	3,253	9,827	3,388	.229
1948	4,425,011	324,434	.549	3,545	10,743	3,587	.232
1949	7,762,421	325,927	.550	3,821	11,652	3,578	.242
1950	10,282,013	334,154	.547	4,103	11,660	3,740	.246
1951	15,375,865	341,394	.543	4,008	11,647	3,774	.247
1952	10,410,972	344,960	.525	4,247	12,010	3,927	.246
1953	14,279,434	354,161	.526	4,434	12,506	4,175	.254
1954	11,929,146	364,058	.508	4,674	12,703	4,656	.254
1955	21,926,987	371,280	.509	4,996	13,726	4,553	.253
1956	8,788,423	383,909	.512	5,274	14,553	4,763	.259
1957	14,519,396	391,845	.503	5,258	15,769	4,805	.248
1958	20,641,059	398,515	.493	5,540	17,436	4,806	.255
1959	17,675,633	408,745	.503	5,808	18,751	4,927	.262
1960	15,404,627	410,872	.499	6,152	19,043	5,087	.266
1961	26,480,726	415,042	.496	6,422	19,755	5,252	.276
1962	28,889,981	421,653	.515	6,763	22,148	5,264	.278
1963	36,625,322	428,318	.522	7,199	23,805	5,314	.284
1964	38,333,310	438,990	.521	7,737	24,904	5,386	.281
1965	32,954,581	448,497	.518	8,457	27,393	5,491	.309

professional staff includes interns, residents, and nurses on inpatient service, pharmacists, social workers, etc. A final predictor variable, investment in period (t-1), was included to take care of the lag arising from the fact that an investment plan, a desired adjustment, takes several years to complete.

The 21-year trends in the values of the variables show a noteworthy increase in the various aspects of hospital service. Admissions rose from 278,000 to 448,000. X-rays per admission went from 2.5 to 8.5, and laboratory tests per admission more than tripled, going from 8.5 to 27.4. The number of interns and residents per bed rose from 0.06 to 0.14 and the ratio of special to general professional staff rose from 0.22 to 0.31. Semi-private days per admission went up 50 per cent (from 3.7 to 5.5) in the period.

The trend of investment in the time period studied was upward. At current prices, investment by the forty study hospitals rose from $1,261,000 in 1946 to $32,955,000 in 1965.

The eight predictor variables were used in an early trial of the first version of the relationship with yearly aggregate data. Over half the variance was explained. However, intercorrelations between three pairs of variables were found and the large number of variables imposed a high threshold for statistical significance. Accordingly a revised version of this equation was created. An average output equivalent was developed, combining the influence of admissions and the ratios of operations, X-ray films, and laboratory tests to admissions. An output equivalent was calculated for each ratio variable in each year, using the value of the ratio in 1945 as a base. For example, in

1945 there were 2.5 X-ray films per admission (103). For each succeeding year an output equivalent was calculated for this variable by dividing actual total X-ray films by 2.5. For each year admissions and the output equivalent calculated for the three service ratios were summed and divided by four. The year-to-year changes in the resulting variable were substituted in the regression equation. The effect of using this variable is to give more weight to an absolute increase in services when the base year intensity (ratio to admissions) is low. The output equivalent is an admittedly rough attempt to amalgamate the impact of growth of various services, and so to reduce the number of predictor variables. These results show that over two-thirds of the variance in investment is predictable by the combined effect of changes in output, changeover to semiprivate care, and a distributed time lag.

The result of this analysis reveals that the use of technology is increasing in hospitals and that much of the increase is related to the growth in ancillary services. This large investment necessitates careful evaluation of uses and complete analysis of alternatives to determine the most appropriate uses of the resources available. The limited resources of manpower, capital, and equipment force an intensive review of each proposed application of technology to insure that the resources are being used efficiently and as achieving the desired results. The application of management science and operations research permits objective analysis of investment alternatives. Specific methods, such as decision-theory, have direct application to the analysis of investment decisions. The following discussion of the applications of management science is directed towards the administrator or board member who must make the decisions on equipment selection and plans for the effective use of technology.

The Application of Management Science

Decision making is a major portion of management activity. Managers are rated on their ability to make and implement correct decisions because the success of a firm is dependent upon the cumulative results of many previous decisions. In years past most business decisions were made without considering the effects of uncertainty, and were made in a qualitative manner in which a major ingredient was the experience of the decision maker, supplemented by subjective considerations known as intuition or hunch. Today, while many problems still cannot be approached from any other angle, there is a growing body of technique that guides rational decisions on quantitative problems. Problems involving costs, time, rates of return, proportion defective, and other quantified variables are amenable to rational analysis, even though precise values for these items are unknown and perhaps cannot be known. Even variables that are not inherently quantified may be treated with these techniques by rating the various items against an arbitrary scale of preference termed a utility scale.

Intuition and experience can be invaluable to the administrator as he makes decisions. But they cannot be depended on as the sole guides to decisions about the control of complex activities. Today's complex systems and organizations require the well-planned application of quantitative methods. Operations research involves the systematic application of such methods to the decision-making process; it supplements intuitive judgment with quantitative analysis.

Theoretically, there are no managerial and administrative organizations to which the approaches and techniques of management science do not apply. There are, however, certain characteristics of organizations and their decision-making processes which affect the extent to which management science applications are practicable. This discussion will draw upon the descriptive framework established in previous chapters in order to discuss some of the primary considerations regarding the present and potential application of management science in planning for clinical implementation of new technology in facilities, and to provide some example applications.

The intangible factors only limit the potential application of management science; they do not eliminate it. The impact which management science may have on any particular process will depend to a large degree upon the management scientists' understanding of the process, their proceptive ability in selecting the problem areas to study, in timing, in the method of their involvement, and in their willingness and ability to make personal and professional adjustments to meet the needs of the planning process. It will also depend upon the understanding and appreciation by the general managers and planners of the techniques of management science, and upon their willingness and ability to adjust the process as necessary to provide the opportunities, time, and resources required by the management scientists in order to make significant contributions.

There are many ways in which management science can contribute to the planning process, at least in theoretical concept. This discussion concerns potential applications directed to decision making for the implementation of new technology.

Decision Theory

Decision theory is the theory of quantitatively and rationally selecting the best alternative from among several on the basis of their degrees of objective achievement. Some objectives have natural measures, but many do not. Decision theory attempts to provide methods for obtaining quantitative measures of the degree of achievement for those objectives and alternatives not possessing natural measures. In many respects quantitative measures provide more information than other types of measures, and, more importantly, in the present case, quantitative measures are necessary for most management science techniques.

Utility theory may be helpful in providing indications of value for factors with no natural measure, and for converting some "natural measures" into a scale which better measures the power to satisfy human wants. An example of the meaning and the use of utility measures is as follows: if a physician owns a certain number of instruments, then he derives satisfaction, or utility, from owning them. If he has only one instrument, the purchase of another will give him a large increase in utility, but if he has fifteen, the next one will give him only a small increase.

Where the attainment of objectives is measured on a continuous scale rather than a two-point (0, 1) scale, utility may be better reflected by the assignment of weights to the various factors contributing to the objective. For example, a manufacturer might be trying to select a box to package his product from among several types which are different as to their strength, weight, and cost. To make a selection the decision maker must make trade-offs among these characteristics. In effect, he must weight each factor according to its contribution to value relative to the other factors. The weightings may be subjective.

Various methods might be used to compute or assign the subjective weightings. One method is to measure the critical factors of a group of alternatives and then get the decision maker to furnish his judgment of the overall value of each alternative. It might then be assumed that the sum of the products of the factor measures and their respective subjective weightings will be equal to the overall value of a particular alternative. For example, the equation for the value of one of the alternatives might be as follows:

$$W_1R_{11} + W_2R_{12} + W_3R_{13} + \cdots W_iR_{ij} + \text{Error} = V_I$$

where W_i = weighting, R_{ij} = factor measures, and V_I = overall value. With a sufficient number of such evaluations multiple regression procedures could be used to solve for the subjective weightings for each factor. Another method is for one decision maker, or a group of decision makers to make direct assignments of weights to contributing factors.

As an illustration of the potential application of these types of techniques in the facilities planning process, consider the case in which a large number of items of equipment must be evaluated and selected for use in a building. Decision theory applied by computer techniques might be used to reduce the burden on the decision maker in the following way. Suppose there are five factors to be considered in evaluating each item of equipment, i.e.:

a) cost/use

b) reliability

c) patient safety and comfort

d) employee safety

e) employee satisfaction

It might be assumed that the decision maker's evaluation of each item of equipment can be expressed as some mathematical function of these five factors, e.g.,

$$W_1F_1 + W_2F_2 + W_3F_3 + W_4F_4 + W_5F_5 + E = V,$$

where F = factor 1, W_1 = relative weight of factor 1, and V = the evaluation of the item under consideration. If measures are available or can be developed for each of the factors, the relative weights can be determined by one of the methods mentioned above. If such an equation were developed on the basis of a large sample of a decision maker's evaluations and proven to be a satisfactory predictor of his evaluations, then, with the appropriate factor measures, the remaining items of equipment could be evaluated by a computer through the use of the equation. This selection methodology might reduce the time required of the planners and lead to greater consistency in the decision making process. It should also enable the evaluation of a larger number of alternative items.

There are other potential benefits of this type of approach in addition to that of preventing the decision maker from having to make essentially the same decision over and over. Where a large number of complex and interacting variables must be considered in making a particular decision, this approach should make the decision process easier and better by breaking one complex decision down into smaller, easier-to-handle decisions. It should also permit increased use of management by exception since the equations could be applied by computer and lower level personnel. Higher levels of personnel would then have to consider only those decisions which don't fit the pattern of the decision model represented by the equations. Another use of this approach might be to develop objective functions for use in quantitative models.

Table 4 illustrates a factor analysis chart. This example concerns renovation of a radiology department. Eleven factors are considered relevant and each of these is given a weight or importance in relation of the other factors. Each alternative is then listed and rated as to its success in satisfying each of the factors. Table 5 lists other factors which must also be considered, such as cost and output.

In some cases it may be extremely difficult for the decision maker to assign ranks and to use them meaningfully. For example, three alternative programs--A, B, and C--may have to be evaluated in three dimensions, i.e., patient care, education, and research. A may be preferred to B in terms of patient care, but B may be preferred to A in terms of education and research. C may be preferred to B in terms of education, whereas B is preferred to C in terms of patient care and research, etc. For the decision maker to rank these alternatives in order of preference, he must subjectively determine tradeoffs among the objectives.

TABLE 4

FACTOR ANALYSIS CHART,
RADIOLOGY DEPARTMENT

Factor/Consideration	Wt.	Ratings and Weighted Ratings: Existing Major Renovation	Existing Minimum Renovation	Maximum Renovation
Adaptability and Versatility	6	U/0	O/6	I/12
Flexibility of Layout	5	U/0	O/5	I/10
Patient and Personnel Flow Effectiveness	8	U/0	O/8	E/24
Information Flow Effectiveness	4	O/4	I/8	E/12
Relationship of Space to Organization Structure	3	O/3	O/3	O/3
Effectiveness of Supporting Services Integration	1	O/1	I/2	I/2
Storage Effectiveness	2	O/2	O/2	I/4
Environmental Factors (Human Factors)	8	U/0	O/8	I/16
Ease of Supervision and Control	7	U/0	O/7	I/20
Quality of Service	10	I/20	I/20	I/20
Maintenance and Safety	9	O/9	I/18	I/18
Totals		39	87	135

Ratings:
A = almost perfect (4)
E = especially good (3)
I = important results obtained (2)
O = OK, ordinary results (1)
U = unimportant results (0)
X = impossible

Key: Total = Wt. x Ratings = 6 x E = 18

TABLE 5

COST EFFECTIVENESS EVALUATION,
RADIOLOGY DEPARTMENT

	Alternative A	Alternative B	Selected Alternative C
Operating Costs:			
Personnel	$ 250,200	$ 236,200	$ 221,700
Benefits	30,876	28,376	27,216
Meetings and Travel	2,400	2,400	2,400
Consultant Services	540	540	540
Supplies	40,000	40,000	40,000
Other	-	-	-
Total	$ 323,916	$ 307,516	$ 291,456
Work Load: Examinations	70,000	70,000	70,000
Unit Cost:	$4.63	$4.39	$4.16
Investment Cost:			
Equipment	$ 1,084,000	$ 1,084,000	$ 1,084,000
Space	183,000	443,000	530,000

Even where rankings and priorities are possible, their value to analysis is limited. For example, the relative difference in value between rank 1 and rank 2 is not necessarily the same as the difference between 2 and 3. Also, there is no "absolute zero" point in such measures. Most of the ordinary arithmetic manipulations of these numbers have no meaning. Since ranks and priorities do not provide information regarding marginal returns, they do not provide an adequate basis for determining analytically an optimal allocation of resources among alternatives. For example, if education is given priority 1, how does one know whether to put all resources into education or to stop putting resources into education at some point and begin allocating them to patient care and research?

Most important decision problems involve major elements of uncertainty, and a systems analysis of such problems must provide for explicit treatment of uncertainty. This may be done in numerous ways.

For purposes of discussion, two main types of uncertainty may be distinguished:

a) Uncertainty about the state of the world in the future. Major factors here are technological uncertainty and uncertainty about the role of other institutions.

b) Statistical uncertainty. This type of uncertainty stems from chance elements in the real world having a more or less objective or calcuable probability of occurrence. It would exist even if there were no uncertainties of the first type.

Uncertainties of the first type are typically present, and they are most difficult to take into account in a systems analysis. Techniques which are often used are sensitivity analysis, contingency analysis, and a fortiori analysis.

Sensitivity Analysis may be understood by supposing that in a given analysis there are a few key parameters about which the analyst is very uncertain. Instead of using mean values for these parameters, the analyst may successively use several values (say, high, medium, and low) in an attempt to see how sensitive the results (the ranking of the alternatives being considered) are to variations in the uncertain parameters.

If a certain alternative is superior in all of these sensitivity investigations, it is referred to as a dominant solution. Dominance is a characteristic that the analyst is always seeking, but its existence is rare in types of problems of concern in this book.

Contingency Analysis investigates how the ranking of the alternatives under consideration holds up when a relevant change in criteria for evaluating the alternatives is postulated, or a major change in the general environment is assumed.

A Fortiori Analysis may be understood as follows: suppose that in a particular planning decision problem the generally accepted judgment favors alternative A. However, the analyst feels that A could turn out to be a poor choice and that alternative B might be preferred, particularly if certain assumptions about uncertainty are postulated. In performing an analysis of A versus B, the analyst may choose deliberately to resolve the major uncertainties in favor of B and see how A compares under these adverse conditions. If A still looks good, the analyst has a very strong case to support its selection.

While these three techniques may be useful in a direct analytical sense, they may also contribute indirectly. For example, through sensitivity and contingency analyses the analyst may gain a good understanding of the really critical uncertainties in a given problem area. On the basis of this knowledge he might then be able to come up with a newly designed alternative that will provide a reasonably good hedge against a range of the more significant uncertainties. This is often difficult to do; but when it can be accomplished, it offers one of the best ways to compensate for uncertainty.

Risk and uncertainty are other conditions dealt with in decision theory. A planner will usually have to consider different possible states of nature when selecting a strategy. If he knows the probability of occurrence of the possible states of nature, then it is said that he is making a decision under risk. If he does not know the probabilities, then it is said that he is making a decision under uncertainty. Consider the following matrix of strategies (S_1, S_2), states of nature (N_1, N_2, N_3), probabilities of states of nature (P_1, P_2, P_3), and value outcomes (X_{ij}):

	P_1	P_2	P_3	
	N_1	N_2	N_3	
S_1	X_{11}	X_{12}	X_{13}	EV_1
S_2	X_{21}	X_{22}	X_{23}	EV_2

In decision making under risk, the P_j are known, and the expected value of each strategy can be computed as follows:

$$EV_i = (P_1)\ (X_{i1}) + (P_2)\ (X_{i2}) + (P_3)\ (X_{i3})$$

If the X_{ij} represent the actual values of the outcomes to the decision maker, then the rational choice would be that strategy with the maximum expected value. The maximum expected value would not necessarily be the best choice when X_{ij} do not represent an absolute measure of "value" or utility, e.g., when X is measured in monetary units, while the utility of money to the decision maker is some non-linear function of dollar value.

To illustrate the possible application of expected value in planning, consider a hypothetical problem in which the hospital is trying to decide whether to add a cobalt therapy unit to its therapeutic capabilities which would be beneficial in treating special types of medical cases. It is possible that a new institution will locate near this hospital and provide this same clinical service, which could be used by the physicians and patients utilizing the hospital's services. The hospital must make a decision regarding the addition of its cobalt therapy unit now; the other institution's decision may not be made until two or three years later. Hospital management has decided to evaluate their alternatives in terms of the values of outcomes ten years from now, and have estimated these values in numerical terms. Also, they have been able to estimate the probability that the new institution will provide this service. This decision problem can be expressed as follows:

	P_1	P_2	
	N_1	N_2	
S_1	X_{11}	X_{12}	EV_1
S_2	X_{21}	X_{22}	EV_2

	.25	.75	
	N_1	N_2	
S_1	10	2	EV_1
S_2	0	8	EV_2

where

N_1 = condition of new institution not providing service
N_2 = condition of new institution providing service
P_1 = probability of N_1 = 0.25
P_2 = probability of N_2 = 0.75
S_1 = strategy of adding cobalt therapy unit
S_2 = strategy of not adding cobalt therapy unit
X_{ij} = value of outcome from strategy S_i under condition N_j
EV_i = expected value of strategy S_i

Therefore, with expected value as the decision criterion, the cobalt therapy unit would not be added.

The decision is made under the condition of uncertainty if no information is available regarding the probabilities of the various states of nature. Under this condition there is no one best criterion for decision, although several might be suggested. One possible criterion, which reflects a pessimistic view, selects the strategy with the best of the worst possible outcomes. This is called the "maximin" criterion. For example, in the decision problem described above, the worst that can happen if S_1 is selected is an outcome with a value of 2, and the worst with S_2 is an outcome of 0; therefore, S_1 would be selected.

The "maximax" criterion suggests the selection of the strategy with the highest possible return; it is the criterion of optimism. This criterion, also, would lead to the selection of S_1 in the problem above.

Under the "regret" criterion the decision maker attempts to minimize the possible regret, i.e., the difference between the value of the strategy chosen and the best strategy for a particular state of nature. To apply this criterion to the problem described above the payoff matrix is converted to a regret matrix, as follows:

	N_1	N_2
S_1	0	6
S_2	10	0

A "minimax" criterion is applied to the regret matrix by selecting the strategy with the lowest of the maximum possible regrets. In this case, the maximum possible regret is 6 for S_1 and 10 for S_2. Therefore, S_1 would again be selected.

The final criterion to be described is the "Laplace" criterion. Under uncertainty, this criterion assumes the probabilities for the states of nature to be equal. (There are many philosophical arguments against this criterion which will not be discussed here.) The expected value of each strategy is then computed using equal probabilities, and the strategy with the highest expected value is selected. In the above problem, $EV_1 = 6$ and $EV_2 = 4$; therefore, S_1 is again chosen.

It should be pointed out that the various criteria under uncertainty do not usually lead to the same decision, as happened to be the case above.

Another aid in decision-making is the use of "decision trees". The decision tree can clarify for management the choices, risks, objectives, gains, and information needs involved in an investment problem.

Previously, the decision problem concerning adding a cobalt therapy unit was described in a payoff table form. However, particularly for complex investment decisions, representation of the information pertinent to the problem in a decision tree is useful to show the routes by which the various possible outcomes are achieved.

Figure 13 illustrates a decision tree for the cobalt therapy unit problem. This tree is a different way of displaying the same information shown in the payoff table. The tree is made up of a series of nodes and branches. At the first node on the left, hospital management has the choice of adding the unit or not adding it. Each branch represents an alternative course of action or decision. At the end of each branch or alternative course is another node representing a chance event. Each subsequent alternative course to the right represents an alternative outcome of this chance event. Associated with each complete alternative course through the tree is a payoff, shown at the end of the terminal branch of the course. A decision tree of any size will always combine (a) action choices with (b) different possible events or results of action which are partially affected by chance or other uncontrollable circumstances.

The requirements in making a decision tree for management include: (a) identify the points of decision and alternatives available at each point; (b) identify the points of uncertainty and the type or range of alternative outcomes at each point; (c) estimate the values needed to make the analysis, especially the probabilities of different events or results of action and the costs and gains of various events and action; (d) analyze the alternative values to choose a course.

The previous decision problem is brought into better perspective when demand considerations for the service and more alternatives are used to evaluate a course of action for the hospital. The demand for the cobalt therapy unit may be high or low and a small or large

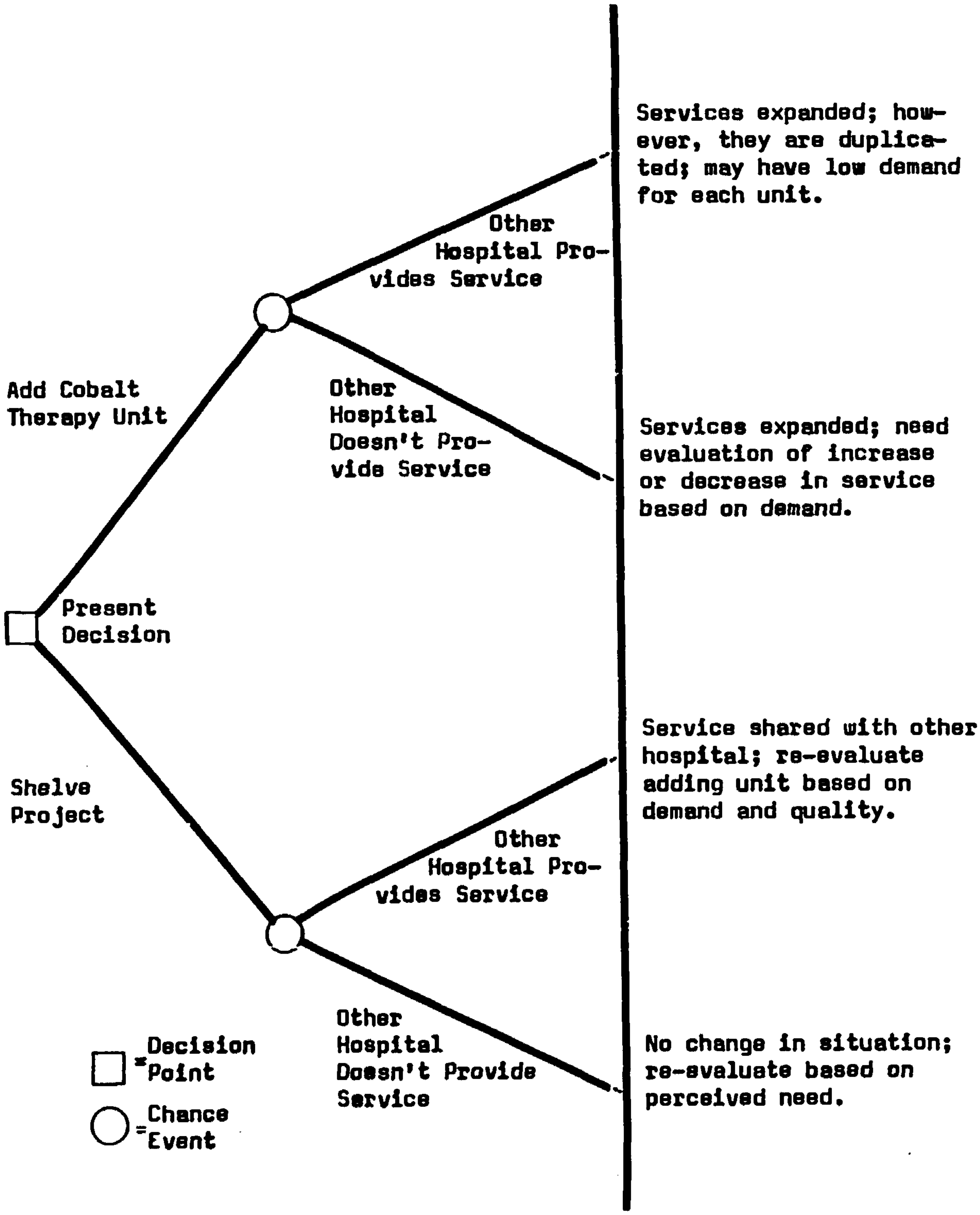


Figure 13—Decision Tree.

unit may actually be added. In addition, there are costs and benefits involved in each course of action. The problem is further complicated by the fact that the addition of a small unit may create a demand for the larger unit at a later time. The expanded decision tree is shown in Figure 14.

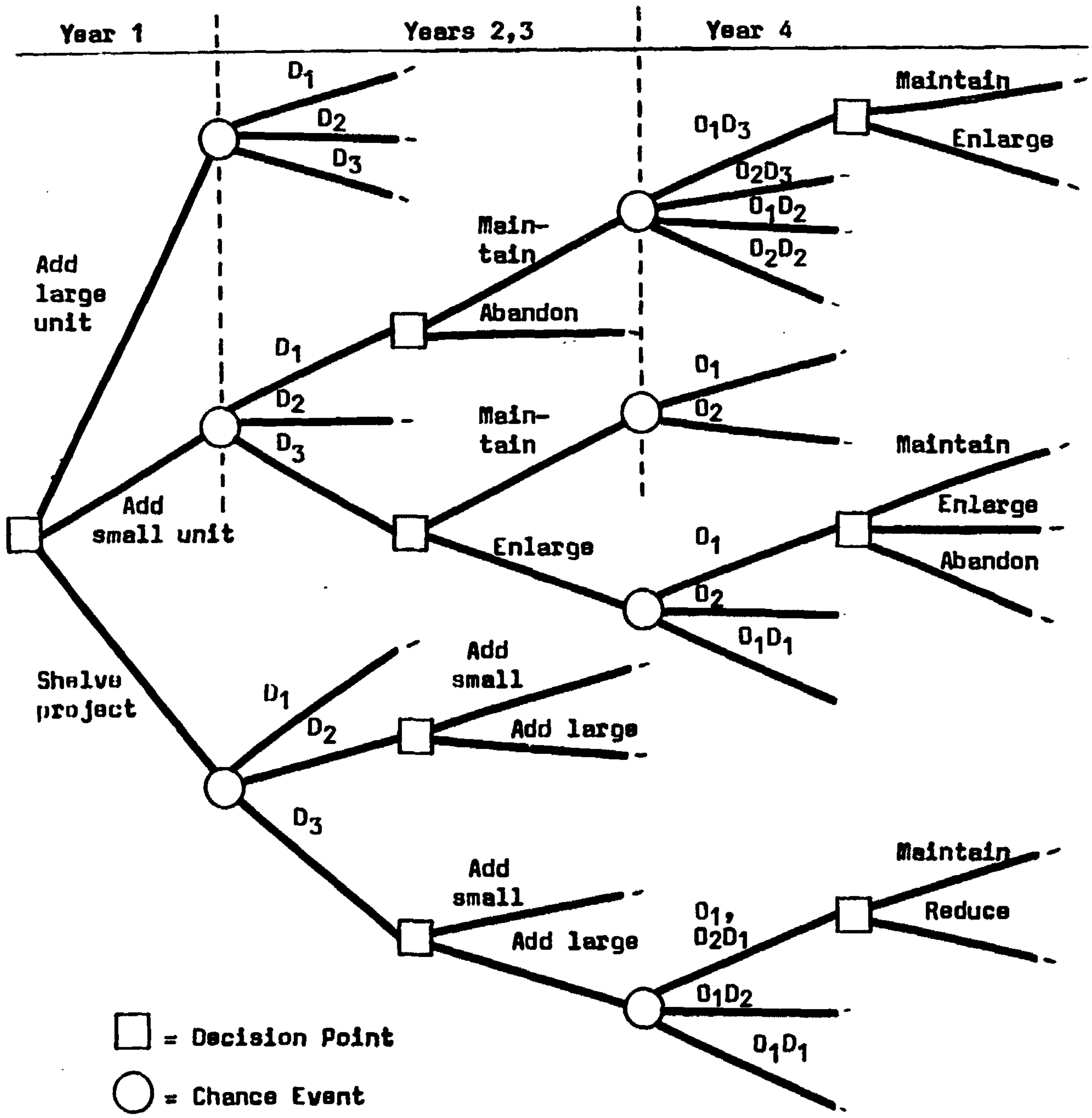
Cost-Benefit Analysis

Cost analysis is essentially a field of Management Science, and as such assists in evaluating the implications of alternative courses of action.

Cost-Benefit Analysis is concerned with the selection of resources. Decisions involving large expenditures may have to be made long before the systems using such items become "operational" and before the characteristics of these systems are very clear. In deciding among alternatives, in such situations, management is invariably faced with limited resources. The choice of the preferred alternative will involve the evaluation of important performance and cost tradeoffs. It is this class of problems that Cost-Benefit Analysis treats.

Cost-Benefit Analysis problems may call for the use of any of a number of familiar Management Science techniques, such as those of mathematical programming, reliability analysis, present worth analysis, simulation, etc. In addition, the techniques of cost analysis and the analysis of uncertainty are needed in most, if not all, problems.

The term "cost" is used in the definition in its broad sense: although dollars are the units most generally used in this type of analysis, any economic resource might, for a given problem, be the limiting factor, e.g., personnel. A useful concept in this regard is that an economic cost is a benefit lost. Each such analysis involves as one



D_1 = Low Demand for Service
D_2 = Moderate Demand
D_3 = High Demand
O_1 = Other Hospital Provides Service
O_2 = Other Hospital Doesn't

Figure 14--Expanded Decision Tree.

stage a comparison of alternative courses of action in terms of their costs and their benefits in attaining some specific objective. Usually it consists of an attempt to minimize dollar cost subject to some requirement or, conversely, to maximize some physical measure of output subject to a budget constraint.

Cost analysis is essentially a sequential process: identification, measurement, and then evaluation of alternatives. Yet, the three steps are often accomplished almost simultaneously, especially when we use dollars to facilitate the cost analysis process.

The following are four possible procedures to measure costs:

a) Estimate the resources required for the proposed new capability: the manpower of various types, the real estate, the production facilities and the transportation services.

b) Identify some of the alternative uses of these resources. For example, determine what alternative capabilities could be produced with the same resources.

c) Estimate the value of the alternatives. For example, estimate the effectiveness of the alternative capabilities that could be producad with the resources. In other words, we could attempt to evaluate the benefits foregone.

d) We could estimate the dollar expenditures that will be entailed by the procurement and implementation of the proposed capability including original cost, operational cost, maintenance cost, "downtime" cost, modernization costs, and salvage cost (life cycle cost).

The life cycle identification is important for several reasons. One is that it help insure that the total resource impact of a proposal will be identified. Oftentimes decision-makers may become preoccupied with investment costs, to the relative neglect of the fact that a stream of operating cost over a period of years is an inevitable consequence of their decision. Life cycle costing helps to avoid such a pitfall. Again, we are brought back to the fundamental point of attempting to identify the full economic cost of a proposed future course of action.

In summary, estimate (a) the resources required, (b) the alternative uses of these resources, (c) the value of these alternatives, and (d) the dollars spent.

Following are the five elements in a cost-benefit analysis:

a) The objective (or objectives). Cost-benefit analysis is undertaken primarily to help choose a policy or course of action. One of the first and most important tasks of the analyst is to attempt to discover what objectives the decision-maker is, or should be, trying to attain through this policy, and how to measure the extent to which they are, in fact, attained. This done, strategies, forces, or equipment are examined, compared, and chosen on the basis of how well and how cheaply they can accomplish these objectives.

b) The alternatives. The alternatives are the means by which it is hoped the objectives can be attained. They need not be obvious substitutes for one another or perform the same specific function.

c) The costs. The choice of a particular alternative for accomplishing the objectives implies that certain specific resources can no longer be used for other purposes. These are the costs. In analyses for a future time period, most costs can be measured in money, but their true measure is in terms of the opportunities that they preclude.

d) A model. A model is a simplified representation of the real world which abstracts the features of the situation relevant to the question being studied. The means of representation may vary from a set of mathematical equations or a computer program to a purely verbal description of the situation, in which judgment alone is used to predict the consequences of various choices. In cost-benefit analysis the role of the model is to predict the costs that each alternative would incur and the extent to which each alternative would assist in attaining the objectives.

e) A criterion. A criterion is a rule or standard by which to rank the alternatives in order of desirability and choose the most promising. It provides a means for weighing cost against benefits.

The analyses in Chapter IV concerning hospital technology and choice is an example of an application of cost-benefit analysis.

The problem facing hospital management is to develop and apply concepts and techniques for assessing the economic cost of proposed alternative future actions under conditions of uncertainty.

Such alternative actions usually take the form of some combination of the following:

a) Proposed new capabilities for the future - for example, new medical services.

b) Proposed modifications of existing or presently programmed capabilities.

c) Proposed deletions from the presently planned services.

d) Proposed combinations of (a) through (c).

Quantitative Models

It has been said that man does not really understand a thing until he can measure it and assign numbers to it. While this may be true, it is also true that life forces activities to proceed whether or not there is real understanding. Planning for clinical facilities involves many areas which are not very well understood. There are, however, several kinds of decisions which must be made in this process for which quantitative methods are appropriate. Even though most of the quantitative methods will provide the context of other nonquantitative factors, they can be useful in the decision process and can provide insights which might not otherwise be obtained.

A few hypothetical examples of potential applications of quantitative management science models in the process of planning for clinical facilities are provided in this section.

Suppose that in planning for a new hospital one of the critical decisions is the mix of minimal care, intermediate care, and intensive care beds on each nursing unit. The decision maker wishes to select that mix which will minimize the loss to the hospital (the collection rate is less that cost on all categories of patients), within the constraint of nurse staffing requirements. The loss to the hospital per patient day has been estimated as $20 for intensive care, $15 for intermediate care, and $10 for minimal care. Because of considerations of general operating economy, it has been decided that there will be at least 30 beds per nursing unit. Also, there must be at least five intensive care, ten intermediate care, and seven minimal care beds. Because of nurse staffing limitations there must be no more than 80 hours of direct nursing care required per day on the nursing unit, where intensive care patients require four hours per day, intermediate two, and minimal one. This problem may be stated mathematically as follows:

Minimize $20X_1 + 15X_2 + 10X_3$

ST $X_1 + X_2 + X_3 - 30$ — for general operating economy

$4X_1 + 2X_2 + X_3 - 80$ — nursing constraint

$X_1 - 5$

$X_2 - 10$ other constraints

$X_3 - 7$

Where X_1 = the number of intensive care beds

X_2 = the number of intermediate care beds

X_3 = the number of minimal care beds

The optimal solution is five intensive care beds, ten intermediate, and fifteen minimal. This results in a daily loss of 5($20) + 10($15) + 15($10) = $400.

General Considerations Regarding the Application of Management Science

The above sections show a few of the types of planning problems to which the quantitative analytical methods of management science might be applied. While there are many other types of problems involved in this planning process to which quantitative/analytical methods might be applied, it should be obvious that there are significant problems for which these methods are not appropriate or are not available. Also, there are many practical limitations which restrict the use of quantitative/analytical methods even where their theoretical structure might otherwise be suitable.

First, many numerical measures and estimates are required for the use of quantitative methods. In many planning problems these measures and estimates are either not available or are obtainable only at considerable expense. This is especially true in the health field since good managerial and operational information are often lacking; in most cases even basic cost accounting information is not available.

Another limitation on the usefulness of available management science techniques in planning situations is the relatively small number of variables which can be handled in any one model. Usually planning problems involve a large number of interacting variables which must be considered simultaneously. Many of the interrelationships among variables which would need to be included in a comprehensive quantitative model probably will not be known. Also, some of the interrelationships will depend upon the decisions of the managers whom the quantitative model is supposed to benefit, presenting a problem of circular search. In such situations the decision makers will have to understand the analytical methodology and take an active part in it.

Most planning problems involve significant intangible variables, i.e., variables for which there are no quantitative or objective measures. Where intangible factors are predominant, quantitative methods may be of little use. For example, the determination of an optimal solution relative to two variables of a ten variable problem, the others of which cannot be quantitatively or objectively measured and analyzed, may add little if any valuable information to the decision regarding a long-range or strategic planning problem.

There are also many factors which affect the decision maker's perceived probability of successful application and consequently the expected value to be derived from application attempts. These are important considerations since the costs of applying most quantitative methods are relatively high. Some of these factors will be discussed briefly.

In most cases quantitative techniques identify an optimal strategy, with the implied assumption that tactics for carrying out that strategy will be available. The decision maker must consider the potential of quantitative methods.

Lack of certainty adds another dimension to the problem of the decision maker. Since quantitative techniques usually cannot select an optimal decision for all possible occurrences, the decision maker must select an appropriate decision criterion to apply to the situation. His approach to the problems of uncertainty and risk may affect the potential and the selection of quantitative methods.

A decision maker's willingness to accept the results of analytical solutions may also depend upon the degree of reversibility of the solution. Other forms of validation of the solution may be required if the decision is extremely difficult or expensive to reverse.

The expected degree of permanence of the solution relative to changes in states of nature may affect whether and how the decision maker implements the solution. This factor involves consideration of uncertainty and flexibility, which may not be fully reflected in the analytical model.

In spite of the difficulties there are many aspects of planning for clinical facilities to which management science techniques can be helpful. Some of these have been indicated above. The real question from a practical point of view is how management science resources can be integrated into the planning process and brought to bear on the right problems at the right times. The considerations involved in this question are actually the subject of this paper, although it should be apparent by now that no clear and definite answers exist.

CHAPTER VI

SUMMARY AND CONCLUSIONS

The purposes of this study were to investigate the types of impacts which technology has made on health facilities and the delivery of health care through the systems approach, and to investigate the applicability of management science principles, approaches, and techniques in planning and evaluating potential applications of technologically advanced systems in the health field. Sources of information for this investigation included actual experience in planning equipment for health institutions, accounts of other planning efforts for similar projects reported in the literature and by discussions with professional people working in this field, and a review of corporate and managerial planning literature. The nature of this research was essentially exploratory and descriptive, and it was intended to establish a clarification of the concept of planning for the application of technology in health facilities. Conclusions and recommendations relative to each of the three primary objectives stated in Chapter III are contained in the following sections.

The Planning Process

The first objective of this research was the development of a description and conceptualization of the process of planning for and evaluating technological applications in health care institutions. The process was described in terms of the types of planning involved, the nature of the process, steps required, approaches and methods, and certain other considerations in health facilities equipment planning. In addition, the process was further conceptualized by the development of flow diagrams of planning activity and by the development of illustrative decision problems to which management science techniques might be applied. Therefore, it is concluded that the first objective has been satisfactorily accomplished.

The concepts and findings from other fields of planning were found to be applicable and useful in describing and understanding the planning decision process for health care technological applications. In order to understand the planning decision process, it was necessary to describe the impacts of technology on health facilities. This was analyzed by describing the four stages of technology. These included: a) improvement of existing devices, b) creative utilization of new technology, c) accommodation for the new technology, and d) consequences of using the new technology. The planning decisions involving technology and choice were then described and conceptualized, illustrating the complex problems involved in the planning decision process and the need for applied research in technological applications in health facilities.

Applicability and Practicability of Management Science

The second objective was an investigation of the applicability and practicability of management science principles and techniques through an analysis of the planning decision process, and the development of examples of the application of management science techniques. Based upon the description and conceptualization, it is concluded that the principles and techniques of management science are theoretically applicable to many areas of the process of planning for technological application in health facilities. Several illustrations were provided in Chapter V in support of this conclusion. There are several critical variables which affect the practicability of the use of management science in this process at this time. These include a general lack of understanding of the planning process by most management scientists and a lack of understanding of management science by the managers of the process. Complex considerations include: timing requirements, characteristics of the planning framework, politics, intangibles, the difficulty of selecting appropriate projects, data, uncertainty, and a critical need for other more basic improvements in the planning process, such as improved managerial planning.

It is concluded that the most promising forms of management science contribution to this planning process are the following:

a) The use of qualitative (both descriptive and normative) study and modeling of the process to provide a better understanding of the process, to provide a systematic approach to the planning process, to provide a general design methodology, and to provide a framework for other forms of management science contribution.

b) The use of quantitative analytical models in certain aspects of facilities planning such as the selection of capacities for certain functional units which must serve stochastic demand, and the economic evaluation of alternative facilities and operational systems.

c) The use of computer simulation in the evaluation of facility designs and operational systems and in predicting the consequences of alternative policy decisions.

d) The use of cost-benefit analysis in evaluating alternative uses of scarce resources.

e) The use of decision theory through the application of payoff tables, decision trees, and evaluation under risk and uncertainty.

Suggested Areas for Further Research

The third objective of this research was the identification of promising and important areas of the planning process which require further research and development regarding the application of management science. It is apparent that many management science techniques are applicable in theoretical concept to the process of planning clinical facilities. This study has revealed the need for applied research in this area. The most urgently needed forms of research involve the application of management science methods and techniques to new problem areas, the study of data requirements and data availability, the development of new models, and further study of the planning process itself and the implications of its characteristics for the application of management science approaches and techniques, the area in which the present research has made a contribution. These forms of needed research are described below:

a) The development of systems models of patient-care processes. These models would reflect and describe the various components of the processes and their interrelationships. They could be used to provide a systematic framework for analysis and for planning. They could also benefit the management of the planning process by facilitating communications and decision making.

b) The development of computer simulation models. These might be similar to the models indicated in Number 1 above, but would be constructed to represent the dynamic operational characteristics of the systems. They would probably be more precise in an operational sense. These simulations models could be used to test alternative plans and design and to identify sensitive variables in the planning process. They could also be used to predict the results of alternative decisions.

c) The development of micro-economic models. These models would be relative to this type of institution similar to those of the "Theory-of-the-Firm." Such models would be helpful as guides for decision making throughout the planning process by revealing the economic implications of decisions.

d) Further research on the planning process itself. This research would focus on the nature and characteristics of this particular planning process and ways of improving it. Several types of research are needed in this category. For example, additional research is needed in the actual application of management science techniques and approaches. Data and information requirements for planning should be identified and studied. Studies should be made to determine the characteristics of organization arrangements required for this type of planning process. Alternative activity networks and schedules for this planning process should be developed and studied. Decision flow diagrams should be developed as guides to the planning and design process. Finally, there should be further descriptive analysis of the various phases of the planning process, e.g., the architectural design phase.

e) Planning for flexibility. Research should be performed on ways of achieving flexibility in the planning process as well as in the resultant facilities. For example, methods should be developed for evaluating alternative facility plans in terms of their flexibility. In addition to the development of evaluation models, research might be performed for the development of decision models and specific design characteristics which emphasize flexibility.

f) Evaluating alternative technological systems. The development and the application of methodologies for evaluating alternative operational systems. The evaluation should be in terms of economic and other measurable criteria as well as intangible factors. Simulation will probably be one of the most useful techniques in these methodologies. Examples of operational systems to which methodologies should be applied include material handling, information, supply, and support systems.

g) Forecasting and anticipating the future. Since long-range facilities planning must be performed within the context of forecasts and anticipations regarding the future, the development of improved methods for doing this is most important. Various types of methods are needed, including quantitative techniques, technological forecasting, "expert" and group judgment approaches, and methods for the evaluation of planning assumptions.

h) Application of new approaches. The further development and application of an improved approach for planning technological applications in health facilities. The methodology should include the development of performance specifications, the identification and measurement of critical design variables, and the use of cost-benefit analysis throughout the process.

General Conclusions

The planning of health facilities technological applications has been found to be a fertile field for further work, both research and actual applications. This field, however, is not like other fields of more traditional interest to the industrial and systems engineering researcher and academician wherein sufficient insights, understanding, and motivation are obtained through courses, text examples, personal contacts, journals, and consulting experience. Research of the present type, descriptive and conceptual in orientation, was needed in order to provide a background for the more scientific, tightly structured, in-depth forms of research. It is hoped that the present investigation will serve as a foundation for such further work.

The author feels that the special challenges of this planning decision process to management science will be met, both because of the importance of the problems involved and because of the potential for management science to contribute increased rationalism to the process.

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APPENDIX

Hill-Burton Program Description

Hill-Burton Program Description

In many ways the passage of the Hill-Burton program in 1946 significantly effected the field of hospital planning and design. In order to qualify for financial support for construction of new facilities or modernization of old facilities under this program a detailed plan of the function of the facility must be developed. In addition, the plan of the structure must meet certain standards regarding such items as floor space allocations, types of services, necessary equipment, and mechanical/electrical considerations. "These standards constitute minimum requirements for construction and equipment and shall apply to all projects for which Federal assistance is requested under the Act. They are considered necessary to ensure properly planned and well constructed medical facilities which can be efficiently maintained and operated to furnish adequate services."

From July 1, 1947 through December 31, 1970, a total of 10,584 projects had been approved under the Hill-Burton Program. Through this program more than 3,800 communities throughout the country have built hospitals and nursing homes, providing more than 460,000 beds, nearly 1,300 public health centers, 1,050 outpatient facilities, and over 500 rehabilitation facilities. For each dollar of the $3.6 billion of Federal money distributed through the Hill-Burton matching-grant formula, over two additional dollars have been raised by communities from private and public sources. Total expenditures during the 25 years since the enactment of the program have reached $12.3 billion. Hospital expenditures have totaled almost 84 per cent or $10.3 billion; this accounts for a large portion of the $26.6 billion total assets, land, buildings, and equipment of hospitals reported by the American Hospital Association in 1971.