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SYSTEMS ANALYSIS IN THE HEALTH FIELD*

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This paper reviews the application of systems analysis to the planning of health services. Planning models which have employed a systems analysis approach in the health field are critically examined, their strengths and limitations are considered and areas where more research is needed are indicated. New approaches which attempt to eliminate these limitations are presented.

The use of health indices as performance indicators of the health services system, as social development indicators and their use as intrinsic variables in the models of development is also critically examined.

HEALTH SERVICES AS A SYSTEM

THE TERM system often gives the impression of referring necessarily to a tight set of relationships that are fully deterministic, predictable, or controllable. A recent report, for instance, claims that "the word (health services) system is a convenient one . . . but we recognize that it is inaccurate if it implies the existence of an organized, coordinated, planned undertaking" [1]. The health services, however, do constitute a cybernetic system in the sense of one of many components, being subject to random uncontrolled influences, and containing a complex, perhaps untraceable, interconnecting pattern of communications [2]. The models of the cybernetic system are mainly probabilistic rather than deterministic, and they not only deal with probabilities but they also include "black boxes" to indicate areas of ignorance and assumptions [3].

Components of the health services system can be grouped by sub-systems, the composition of which depends on the criterion for the grouping. If the criterion is type of care, *e.g.* hospital care, nursing-home care, etc., then the term subsystem is interchangeable with the term state of care. The elements grouped in each state of care are called units, *e.g.* several hospitals (units) constitute the hospital care state [4].

There are three phases through which individuals move within states of a system, i.e., input, throughput and output. They are not clearly differentiated although arbitrary lines can be used to demarcate each.

Input is determined by actual "demand" for services per unit of time. If "need" is the criterion, however, rather than actual demand, input can be defined as desired potential demand. Such a shift assumes, of course, that need, i.e. the submerged part of the iceberg of disease, can be translated into demand [5]. The conceptual distinction between these two approaches has been considered elsewhere [6].

Several studies have dealt with these first admissions interfaces using techniques of market analysis of consumer use. Brooks *et al.* [7], for instance, predicted future demand on hospital beds by multiple regression analysis of 117 variables, such as demographic

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data, mean life expectancy, mean effective buying income, average length of stay in hospitals, average occupancy rate and ratio of physicians to population, etc. Feldstein and German [8] used a similar approach. A more elegant technique, the multi-sort technique* was developed by Reinke and Baker [9] which improves the analysis of the effects that multiple demographic variables have on utilization. More recently Kalimo and Sievers [10] have used the factor analysis approach in determining manpower and facility requirements.

The first admissions interface also includes those operations that detect or take cognizance of individuals in the population who ought to be brought into some care or service aspect of health services. These include multiphasic screening programs that are being widely discussed currently [11, 12]. Emlet [13] has developed a comprehensive mathematical model that employs a systems analysis approach in evaluating cost/benefit ratios for multiphasic screening.

Throughput refers to the time movement of patients through successive states of the system. Very few studies have been done on the movements within the system, documented by data on the transfer and referral of persons [14, 15]. Fewer still have been carried out on the decision elements of the utilization strategies that determine the patterns of patient transfer and referral [16].

Output from the different states of care is measured by the number of discharges from each per unit of time. This output can be defined as process output, *e.g.* the percentage of the population receiving medical services, or as product output, *e.g.* the decline in infant mortality. In the first instance, the output is usually measured either by number of services provided or by the percentage of the population covered. In the second case, the output is defined as reduction or control of mortality, morbidity, disability dissatisfaction, etc.[17]. The measurement of this output includes the broad bibliography on health indicators [18]. Burack [19], for instance, has developed an ordinal scale classification for blind persons who are institutionalized and aged that includes measurement of functional capacity and social activities. Sokolov and Taylor [20] have created a disability evaluation scheme that can be used in evaluating physical rehabilitation. Sanazaro and Williamson [21] have proposed a classification to indicate the output of medical care provided by internists. Hagner *et al.* [22] in studying the output of psychiatric outpatient clinics, defined a scale for measuring patients' behavior.

SYSTEMS APPROACH TO HEALTH PLANNING

Planning health services can be based upon analysis of the performance or the structure of the system. In the methods based upon the performance of the system, the resources required are determined by the amount and type needed to achieve a certain product output, which is measured in terms of performance, such as reduction or control of death, disease, disability, discomfort, etc. In those methods based on the structure of the system, the requirements are determined by the number and type needed to achieve a defined process output, measured in terms of services provided or population covered. Effectiveness is the relationship between input and output in the system performance method,† efficiency is this relationship in the system structure method.

* The multi-sort technique is an approximation procedure that simplifies computations while maintaining the analysis of variance approach.

† Some authors prefer the term efficaciousness to that of effectiveness. It seems, however, that the former has most meaning on individual or personal bases and the latter has a greater applicability on community bases.

MODELS BASED ON EFFICIENCY

Most of the planning of health services has been based on the knowledge of the relationship between the input and the process output. Most often this planning has been sectoral in character, i.e. hospital planning, nursing-home planning, etc., with no consideration being given to the interdependency among the different states or subsystems of the whole health services system. This approach has added a considerable element of unreality to the plans, since in actuality there are close relationships among the different subsystems. Indeed, the number of hospital beds required for a system serving a population depends, for instance, on the number, as well as on the admission policies of the nursing homes in the system.

From a methodological point of view, failure to plan on a holistic basis has been due mainly to this lack of knowledge regarding the degree of interdependency among the different units and states in the health services system. This omission can be remedied by use of probabilistic models. Navarro and Parker [23] have used stochastic models to estimate manpower and facilities requirements at the regional and national levels, using transitional probabilities to define the flows of persons within the system. In these models the health services states are postulated and the probabilities of going from one state to another, defined by the transitional probability matrix, determine the number of people in the various states throughout time. The postulated states can be chosen to meet any desired criteria, and can be extended depending on the complexity and comprehensiveness of the desired analysis.

The predicted fractions of the population (or probabilities of being in the states) in time period t is given by the expression

$$\vec{P}(t) = \vec{P}(0)\, Q^t$$

where

- $\vec{P}(t)$ is the vector representing the fractions of the population in the different states, at time t days.
- $\vec{P}(0)$ is the vector representing the initial fractions of the population in the different states.
- Q is the daily transitional probability matrix and
- t is the time (in days) from the initial period to the end of the t time period.

Thus, given $P_i(0)$ and P_{ij}, one may predict $P_i(t)$. Knowing $P_i(t)$ and the productivity parameters of the system, the manpower and facilities requirements can be calculated [24].

Besides its utility for prediction, this mathematical model can be used as a vehicle for studying the effects on the numbers of people and resources required in the various health services states as functions of changes in referral patterns defined by the transitional probability matrix. By varying the relevant transitional probabilities parametrically, one may simulate the effects of changing patterns of referral among two or more states.

A practical example of this latter application could be, for instance, to study the repercussions that a certain percentage increase of nursing-home beds in the health services system have upon the utilization of the other states [24], p. 41.

When the interdependencies among the states are known, then several analytical techniques, such as mathematical programming, can be used for planning purposes. Indeed, mathematical programming is an analytical technique that is increasingly being used in building mathematical models of health services systems. This technique is applied in order to determine optimum relationships among the input variables required to reach a defined output.

The commonest types of mathematical programming are: linear, quadratic, convex, non-linear and dynamic. Linear programming has been used recently in a variety of health services research studies. Feldstein [25] has applied linear programming to the allocation of health resources in developing countries; Gurfield [26] has used linear programming for the isolation of bottlenecks, and establishment of staffing requirements in hospitals; and Revelle *et al.* [27] have approached the balancing of tuberculosis control activities through the use of linear programming.

Navarro [28] has used quadratic programming in a goal-seeking application, i.e., calculating the alternative referral pattern which will minimize an objective function as "cost" or "change in current resources" in such a manner as to reach in a given period, specified utilization patterns, or require a desired amount of resources. For example, a health planner might be interested in knowing how the present resources, manpower and facilities, should be utilized at different time periods to reach a certain utilization pattern in say 5 yr in a way that would minimize the number of additional resources required.

MODELS BASED ON EFFECTIVENESS

Planning health services has not often been based on analytical studies dealing with effectiveness, primarily because little, unfortunately, is known about the effectiveness of the health services. Most analytical studies of health services have been concerned with productivity, expressed in terms of efficiency, but not with effectiveness. The paucity of effectiveness studies is due to present limitations in the knowledge of the relationships between the different variables involved in the output as well as in the input of the system and their interrelationships. In most cases the relationship between the system and its performance is not known; even less is known about methods of quantifying them. There is no evidence, for example, that in providing X units of prenatal care one will save Y children's lives. It is in the study of these relationships that epidemiological studies are greatly needed. Only in those cases with a known quantifiable relationship between input and product output, such as kidney dialysis and prevention of death in certain forms of chronic renal failure, is it possible to use techniques, such as cost-benefit or cost-effectiveness analysis [29]. Otherwise, the usefulness of the technique is conditioned by the validity of the assumptions about this relationship [30].

The absence of objective standards for measuring the relationship between systems and their product output explains the use of subjective measures, such as the opinions of experts [31]. The Centro de Estudios de Desarrollo (CENDES) and the Pan American Health Organization (PAHO), for instance, have developed a health planning method [32] whose goal is to decrease mortality for specific disease categories subject to the constraints of cost. In this method, a factor included in the mathematical model is vulnerability of the disease to proposed curative and preventive activities as determined by "experts".

Indeed, the first step in this method is to establish a priority rating according to a mathematical model for each cause of death by disease category.

$$P = \frac{MIV}{C}$$

where

P stands for relative priority
M represents the relative index of incidence; i.e., the proportion of deaths due to a specific disease to overall deaths.
I represents the relative importance of the disease.
V is the vulnerability of the disease to proposed curative and preventive activities as determined by "experts" and
C is the cost of the proposed activity.

Ruderman [33], using the same variables, prefers to relate them in a more flexible model

$$P = f\,(M,I,V,C)$$

where f means that the designated priority is a function of (bears an identifiable but unspecified relation to) each of the other variables. He does not specify, however, the type of function. Clearly, the choice of formula and the method used to express the relative importance of the elements in the calculation have a substantial effect on the resulting priority.

In the United States, the Division of Indian Health Services of the United States Department of Health, Education and Welfare has developed a planning method that defines its objectives as the quantifiable reduction of morbidity and mortality [34]. The determination of health problem priorities is based on a Health Problem Index, which takes into account the morbidity, mortality and utilization of each disease category according to the mathematical model,

$$Q = MDP + \frac{274\,A}{N} + \frac{91\,B}{N} + \frac{274\,C}{N}$$

where

Q is the health problem index,
M is the health problem ratio, i.e., the ratio of the deaths from a disease observed per 100,000 population in the group planned for, to the deaths per 100,000 of the population as a whole or some other rate which is chosen as a target.
D is the crude death rate per 100,000 in the group planned for,
P represents years of life-expectancy lost because of death from the disease in the group being planned for,
A is the number of inpatient days of care,
B is the number of outpatient days of care,
C is the number of days of restricted activity, caused by the disease,
N is the actual population for which services are being planned,
274 is a conversion constant equal to 100,000 divided by 365 (and aimed at reducing hospitalization and restricted-activity rates to a yearly basis).
91 is a conversion constant, simply one-third of 274, that is used by the planners in case of outpatient visits.

The resources required are estimated by the plan of action chosen, with choices based upon a cost-benefit analysis of the different alternatives. In this method the factor vulnerability or reduction is also defined by "experts".

The Office of Program and Evaluation of the United States Department of Health, Education and Welfare has used a similar approach in planning categorical programs [35, 36, 37, 38, 39].

The models are deterministic. The relationship between the system and its performance is "fixed"; it is given by the "experts". Because of the deterministic nature of these models, the planner using them may be severely constrained in dealing with the stochastic nature of socio-biological events. Much research is needed to define these relationships more adequately.

USE OF PERFORMANCE INDICATOR FOR HEALTH PLANNING PURPOSES

A further difficulty in planning based on performance is the difficulty in defining the product output or performance of the health services systems. Several indicators have been used to define output, e.g. mortality, morbidity, disability, discomfort and dissatisfaction [40].

Mortality

Reduction of mortality is one of the indicators most frequently used to measure the performance of the health service system. The use of this indicator, however, seems more related to the lack of others rather than to its own relevance for the evaluation of the impact of health services on the mortality rates of a population. Indeed, except in a very few instances, we do not know the relationship between health services and reduction or control of mortality. This is in spite of statements to the contrary. For example, it is continually stated that low-cost public health measures, by reducing drastically the mortality rates in developing countries, are among the main causes of the "population explosion". The Committee on Science and Public Policy of the U.S. National Academy of Sciences reported: "The death rate in less-developed areas is dropping very rapidly . . . without regard to economic change . . . The less-developed areas have been able to import low-cost measures of controlling disease . . . The result of a precipitous decline in mortality while the birth rate remains essentially unchanged is, of course, a very rapid acceleration in population growth" [41].

Pierre Moussa puts forward the same thesis: "The population growth is due to the success of the fight against sickness and death carried on with the brains and usually with the money of the West. For example, DDT has wiped out malaria in Ceylon and thus lowered the mortality rate from 24.5 per thousand in 1935–39, to 10.4 in 1954" [42]. Moussa fails to mention, however, that the spectacular reduction in mortality was the same for the non-malarious areas of Ceylon which were not sprayed by insecticides as for the malarious areas which were [43]. In fact, Frederiksen has shown that Ceylon's decline in mortality was associated with a commensurate development of the economy and rise in the levels of living [44].

Mauritius [45] and British Guiana [46] are also cited in support of claims that public health measures have caused a drastic reduction in mortality in less-developed countries, independently of any improvement in the levels of living which may decline or be difficult to attain as a result. Frederiksen's studies question these claims by showing that in Mauritius, the spraying of insecticides started in 1949, two years after the dramatic reduction in the death rate [47]. In British Guiana, the DDT control program began in 1947 and extended to the entire coastal area by March 1948, three years after the mortality rate had already begun a steady decline from the wartime peak [47].

A similar situation is found in mortality due to chronic conditions. Ahluwalia and Doll, for instance, have recently questioned the assumption that the programs of cervical screening had reduced mortality from cancer of the cervix in British Columbia [48]. These authors show that a similar decline occurred in comparable regions in Canada without such a public health measure [49].

Indeed, this lack of knowledge about the effect that health services utilization has on changes on mortality excludes mortality as a performance indicator. Several institutions are currently collaborating in investigating, among other things, the relationship between health services utilization and mortality rates in twelve different communities in seven countries [50].

Morbidity

When reduction or control of morbidity is chosen as the indicator of performance of the health services, the planner finds a similar difficulty in relating the health services provided with the changes in levels of distribution of diseases in a population. Even if such an association existed, it cannot be readily demonstrated by means of the current nosological systems. The current notions of diagnoses, as reflected in the International Classification of Diseases, are professionally orientated and hospital-based. The I.C.D. includes little about complaints, symptoms and problems that are the major work load presented by patients to physicians. Perception of disease as seen by patients is different from the professionals' perception of them. Koos, in one of the few studies of health services from the consumer's viewpoint includes this telling comment: "I wish I really knew what you mean about being sick. Sometimes I've felt so bad I could curl up and die, but had to go on because the kids had to be taken care of, and besides, we didn't have the money to spend for the doctor—how could I be sick? . . . How do you know when you're sick, anyway? Some people can go to bed most any time with anything, but most of us can't be sick—even when we need to be" [51].

Disability

Most health services have to do with medical care more than with cure. Disability is the measurement level where the full impact of medical care begins to be felt and is the level at which useful evaluation becomes feasible. The objectives of the health services are maintenance of the functional capacity, productivity and well-being of the population served. Ideal standards are difficult to define scientifically, but there are reasonably objective descriptions of disability and impaired function. Absenteeism and bed confinement are simple indications of disability and easy to obtain.

Discomfort

Discomfort is a lesser form of general disability that collectively accounts for a large amount of functional incapacity. The largest workload of medicine has to do with reduction of discomfort. How to measure this discomfort has been described elsewhere [40].

Dissatisfaction and discontent

The relationship between the health professionals and society is governed by an unwritten social contract in which society, in the long run, has the dominant voice in re-negotiating this contract [40].

Thus, in spite of the public's limited competence to assess the quality of medical care, its satisfaction with the end results of that care influences its overall evaluation and planning of the health care system. It is at this level that planning of health services openly becomes a political issue, and most often the objectives of the plan are chosen on the basis of political considerations.

MEASUREMENT OF HEALTH INDICATORS

In weighing the performance of the health services system, emphasis has been placed on the economically measurable value of this output. Very rarely, however, have other "utiles" than dollars been used to define the social values of that output, defined as reduction of either death, disease, disability, dissatisfaction, etc. The doctrine of utilities, using "utiles" other than dollars, has been rarely used in the health services [16]. Much more research is needed at this level since " in principle everything can be measured; all research should be directed to this end. The fact that it cannot be accomplished immediately should not excuse loose thinking and conceptual laxity" [52].

Health as a social development indicator

Some of the health indicators mentioned before have been used, in conjunction with others, to establish an indicator of societal development. This was a result of dissatisfaction with some indicators, like "income per capita" which do not indicate the levels of living since they fail to include those social variables that define the level of citizens' well-being that is generally agreed to be the goal of social and economic development. The assumption made by social scientists, mainly economists, that takes "income per capita" as the development indicator is that all "non-economic" factors will rapidly and inevitably adjust to development of the "economic" factors.

The limitations of this assumption have motivated several authors and agencies to look for a better indicator with which to group countries according to their overall economic and social development. Thus, the United Nations Research Institute of Social Development has defined an index which includes as its components, nutrition, shelter, health, education, leisure and recreation, security and surplus income. The health component is measured by three indicators: (a) access to medical care; (b) percent of deaths due to infectious and parasitic diseases; and (c) proportional mortality ratio (ratio of deaths of those aged 50 and over to the total number of deaths) [53].

According to this index, a "social profile" can be established and countries can be listed and analyzed. Their ranking by no means corresponds to a ranking by per capita income. Singer showed that when a country in 1950 had a "favorable social profile", its social ranking was higher than its per capita income ranking and it had a more rapid economic development in the following decade 1950–60, than those with an " unfavorable social profile" [54]. In fact, "the social profiles of the underdeveloped countries in 1950 were as good an explanation of the differences in their rates of economic growth during the period 1950–60 as variations in the more conventional economic variables, such as rates of investment and availability of electricity [54], p. 32.

In the United States, Gross and others have also advocated the use of social indicators to better express the state of the nation [55, 56].

HEALTH IN MODELS OF DEVELOPMENT

Within these social variables, health, at whatever parameter one chooses to define it, is increasingly included as an explicit factor in the models of development. Actually, health has always been, although implicit, a factor in those models. For example, in the classical Harrod–Domar model, the ratio of savings and the production ratio are determined by people's expectations, aspirations, quality of labor and other social variables including health.

Health and other social variables were included more explicitly in the production function of the Cobb–Douglas model, under the all inclusive factor "improvement in knowledge" [57]. This factor was included to account for all growth which was not due to expansion of the more classical factors of land, capital and labor. The ill-defined nature of this factor has led to its being referred to by some authors as the "coefficient of ignorance" [58].

More recently, a third category of models of development has been described which considers social development, mainly in education and health, as the instrument of economic growth [59, 60]. In that respect "consumption" is treated as "investment". The relationship between the input of social variables and the output of economic ones is not yet well known. An increasing amount of research is being done in this area. Malenbaum, for instance, has studied the degree to which certain selected health indicators, e.g. percentage improvement in malaria death rate, infant mortality and others, "explain" the total variation in agricultural output of a selected group of countries [61].

A fourth group of models considers economic growth as the instrument for reaching social objectives [55]. As was the case with the previous group of models, the main difficulty, from the methodological point of view is our ignorance about the relationships among the different economic and social variables defined in the models. Within these conceptual models we find "black boxes" translating areas of uncertainty and ignorance. Several steps have been taken, however, to further an understanding of these relationships. Millendorfer and Attinger have described a cybernetic model that explains, for instance, parallel developments in economic and health sectors within groups of countries. The aim of their model is to find relationships between meaningful parameters that can be evaluated in other than monetary terms [62].

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