A HEALTH-STATUS INDEX AND ITS APPLICATION TO HEALTH-SERVICES OUTCOMES

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In order to develop an operational definition of health, we found it necessary first to develop the concept of function/dysfunction as a continuum, based on one's ability to carry on the usual daily activities appropriate to social roles. Then, to those operating the health system, each member of the population can be seen as belonging to one and only one state from a class of functional states that can be defined on an ordinal scale. Next, we found it necessary to assign to each state a weight defined on a cardinal scale, the set of weights for these states being called the Health Status Index (HSI). The HSI rests on value judgments, of a societal nature, expressed by the administrators responsible for policy decisions. Prognosis is then defined as the transitional probability of a change in functional state with time. Thus, the concepts 'state of health' and 'severity of illness' are decomposed into the parameters function/dysfunction and prognosis. Finally, together with an operational definition of time and target population, it becomes possible to give a quantitative definition of the output of a health program (or health system) as the changes in the functional history of the target population resulting from the intervention of the health program (or system). Other concepts that are given quantitative definitions are program effectiveness and population health status. This study next explores the relation between health program output and modern decision theory for program planning, and shows how these analytical tools are useful for fitting the results of the study into larger conceptual frameworks. Finally, the method developed is illustrated, first with a simplified simulated program for computer use, and then with an analysis of a small section of a tuberculosis-control program.

THERE HAS been an enormous increase in the demand for health services. Concurrently, the objectives of the services have expanded from the extension of life expectancy to the achievement of physical, mental, and social well-being. It has become apparent that meeting these objectives requires comprehensive health planning. Public Law 89-749, passed by Congress in 1966, states:

The Congress declares that fulfillment of our national purpose depends on promoting and assuring the highest level of health attainable for every person, in
an environment which contributes positively to healthful individual and family living... To carry out such a purpose, and recognizing the changing character of health problems, the Congress finds that comprehensive planning for health services, health manpower, and health facilities is essential at every level of government.

Recognizing that planning demands a broad scope, in this study we look at the health complex as a system whose output, or end-product, is the change in the level of health of the population.

Systems analysis, as applied to societal problems, has been receiving wide recognition as a result of the work done, for example, by the Rand Corporation for the Defense Department, and the implementation of program-planning-budgeting systems in a large number of government agencies.[62] Social scientists are recognizing the possibilities offered by systems analysis for synthesizing the wide variety of disciplines that comprise the social-science field.[16] It is encouraging to note that the health field is also receptive to this development.[22,27,38]

To conceive of health services as a system is an analytical tool useful for rational planning. Thus, we say that the health system has a structure in which people and other resources are grouped together into subsystems (programs, institutions, etc.) for the purpose of delivering all types of health services (environmental, educational, financial, etc.) The health system also has a functional relation to the environment about it (such as non-health governmental agencies and organized consumers). The performance of the system relates the output to the input and to the activities performed by the various structural elements.

Here, we concern ourselves with one aspect of the performance of the health system—defining an indicator that will allow quantification of the change in the population health status over time. A more complete performance analysis would include a wider range of indicators of quality of output; a measure of efficiency of utilization of men, machines, materials; and money; an analysis of its investment in capacity for future output; and how it conforms to society’s rules of ethical and rational behavior.

The present indicators, based on mortality (crude and age-adjusted death rates, infant mortality rates, and life expectancies), are inadequate; the need is for indicators based on morbidity as well. At present, for the structural elements of the system, the emphasis is on their activities, not their outputs; thus, the usual indicators are caseload, ratio of beds to population, nurse utilization, cost per day, and the like. These measures could become more useful if we could establish what the end-products, or outputs, of the system are. The provision of health services is a $60 billion-a-year enterprise, yet no comparable industry spends so little on evaluating its own performance. More is known about the consumption of macaroni and corsets than the health status of the population.[62]
In comparison with large corporations, the health services are at a disadvantage. The former have a monolithic administrative structure, with the power to set goals and establish procedures for information and control; the latter is pluralistic, with multiple, conflicting goals and weak mechanisms for information gathering and control. Furthermore, health services are part of society generally, and are in dynamic, complex interacting relations with other social systems. Too, the impact of poverty, malnutrition, over crowding, and population pressures on health status may be greater than the activities of the health system. We need output criteria that will allow analysis of the correlations with these societal phenomena.

This concern with health goals and their measurement is part of a general concern with national purposes and goals (see the report of the President's Commission on National Goals, 1960), or the concern for what Galbraith in The Affluent Society refers to as the "quality of life." Concurrently, there has been a great preoccupation with our values, and a critical examination of the basis for our value judgments. The Gross National Product and the distribution of Gross National Income are incomplete indicators of social well-being in the unmeasured presence of starvation, urban crises, and the pollution of the environment.\[20\]

Our problem is still further complicated by the fact that data are presently inadequate. Much of the needed data is not gathered, or exists in a form of limited usefulness. True, there will always be a gap between what we know and what we want to know. As new concepts and methods develop, they will generate a demand for new and more precise measurements. A time lag occurs between desire and availability because of resistance to change, the cost of information gathering, and uncertainty about its utility. Thus, at present, our data are inadequate because we lack unifying concepts to correlate them; the concept gap is wider than the data gap. The plethora of economic data available today is not due simply to the difference in the nature of the health and economic problems, but in the conceptual breakthroughs of theorists like John Maynard Keynes, who have demonstrated the usefulness of certain aggregate measures of the economy. Collection of most of the data began after their potential usefulness had been demonstrated.

These considerations make the task of constructing quantifiable health indices a complex one. While there are many indicators in use to measure the efficiency of meeting the demand for medical care, to date there is no indicator that can fairly be called a Health Status Index. Some indicators are widely used in the United Kingdom, Scandinavia, and the socialist countries, where health planning is done by a national ministry of health with the power of fund allocation;\[43,11,15,64\] but health agencies, from the World Health Organization down, have repeatedly called attention to the
need for measuring health status and relating it to the performance of the system (see reference 55, page 5).

In conducting this inquiry, we were well aware that to attempt to define 'health' in operational terms, one must deal with many controversial questions. Our purpose was to define these questions as sharply as possible. While we offer answers to the questions raised, it is also our hope that these answers will stimulate criticism, and challenge others to further the essential task to which this paper contributes.

1. PREVIOUS RESEARCH ON OUTCOME CRITERIA

SULLIVAN reviewed the state of knowledge on health indicators before 1966.[46] He pointed out that most morbidity concepts involve three types of evidence, clinical, subjective, and behavioral (reference 49, page 8). He discussed the difficulties involved in basing a morbidity concept on clinical and subjective evidence. For behavioral evidence, we already have such indicators as absenteeism, bed-disability days, and institutional confinement. He proposed that general disability, identifying morbidity in terms of restriction of the usual capacities of the individual, be considered the basis for a health index. He was careful to point out that disability is relative to a social setting. There are societal standards (ideals) for the various activities that a person is expected to be able to perform at different ages and in different situations. To the extent that he is unable to perform these activities (roles), he is to that extent disabled, regardless of the cause. Such a concept requires defining a hierarchy of functions and their relative importance. Dysfunction thus is seen as a close surrogate for the effect of illness on the individual. Therefore, restrictions on usual daily activities are prima facie evidence of deviation from well-being in a broad sense. Thus, for Sullivan, restoration of capacity for usual daily activities can be conceived as the objective for any defined health system.

SANDERS[47] recommends that the end-product of health be measured by its contribution to the increase in economically productive man-years. For planning and evaluation, this suggestion suffers from all the disadvantages of economic criteria (as discussed later) as well as depending primarily on mortality and 'total' disability states.

SOKOLOW AND TAYLOR,[48] working in the field of physical rehabilitation, found it necessary to assess function as the common denominator for all disabilities. They created an instrument in the form of a disability evaluation chart that had sections called medical, social, psychological, vocational, and rehabilitation potential. The scales for these sections were di- or trichotomous. The authors tested the usefulness of the chart by distributing it among counselors in vocational rehabilitation agencies. Because of the narrow range of the functions evaluated, they concluded that
the chart did not have as much usefulness in a vocational rehabilitation agency as they found it to have in a physical rehabilitation center. Nevertheless, by defining function as a unifying concept and calling attention to the need for a total evaluation, an important contribution was made.

Burack, working with institutionalized blind aged, also proposed extension of the medical classification scheme to include functional capacity and social activities. A four-step ordinal scale was developed for each section of the scheme. Unfortunately, when tested in three different, but narrow, settings, the agreement among the professionals doing the classifying was limited.

Sanazaro and Williamson proposed a classification to indicate the outcomes of medical care provided by internists. The study was based on the cooperation of 1211 physicians of high professional reputation. A dichotomous scale (beneficial/detrimental) was created for six patient end-results, including patient attitude toward the physician. The classifications developed represent an important step forward in the definition of the full range of outcomes directly attributable to medical care, but are not quantifiable as they were defined.

Hagner et al., in studying psychiatric outpatients, could establish no significant statistical correlation between treatment and response. They noted the absence of a scale on which patient behavior could be defined, before and after treatment. They attempted to construct such a scale, but slanted it heavily towards psychological factors, thus limiting it for more general use.

Katz et al., working with the elderly and chronically ill, developed a scale that they termed the "Index of Independence in Activities of Daily Living" (Index of ADL). This index was used to study the results of treatment and prognosis. It summarizes the over-all performance in: (1) bathing, (2) dressing, (3) going to toilet, (4) transferring (locomotion), (5) continence, and (6) feeding. The degree of independence, or adequacy of performance, is graded on an ordinal scale, using the letters A through G; A means complete independence, B means independence in all but one function, etc. Statistically, the components of the Index were highly ordered; that is, loss of independence occurred first in bathing, then in bathing and dressing, etc. While the scale is clearly demarcated and excellent for research purposes, it cannot serve well for health planning, since it is restricted both in the population and range of disabilities considered. Other important activities, such as walking, were tested, but since the same ordering could not be demonstrated, they were omitted from the scale. In addition, the relative importance (weights), of the disabilities would need to be specified for use in quantitative models.

There is a large body of literature dealing, as above, with the quality
of medical care and its impact on health status. Most authors have emphasized some aspect of function and demonstrated that, with careful design, the criteria can be operationalized. Most, however, have not attempted a quantitative description of output, which is the focus of the present effort.

Chiang[6] has developed a mathematical formula to express the state of health of a population over a specified time period, usually a year. The formula aggregates three parameters: the frequency of illness, the duration of illness, and the death rate during a year. It assumes all illnesses are alike regardless of severity; the parameters are age-dependent only; the probability of occurrence of an illness is independent of the number of previous illnesses; the probability distributions for the number of illnesses and the duration of the illnesses are independent; both illness and death are states of ill health; and the times lost because of death or illness are weighed equally. The formula is \( H_x = 1 - \tilde{N}_x \tilde{T}_x - \frac{1}{2} m_x \), where \( H_x \) is the mean duration of health, or the fraction of the year in which an individual in age group \( x \) is living and free of illness, \( \tilde{N}_x \) is the observed average number of illnesses per person in age group \( x \), \( \tilde{T}_x \) is the average duration of an illness for that group, and \( m_x \) is the age-specific death rate for the year (\( \frac{1}{2} \) gives the average for the year). If \( P_x \) is the age-specific population, \( P = \sum_x P_x \) is the total population. The weighted average \( \bar{H} = (1/p) \sum_x P_x H_x \) is the mean duration of health, or the index of health, for the entire population for the specified time period.

The premises upon which Chiang's formula is based, namely that health is the absence of illness of any kind or degree, and that the state of health is independent of past history, appear too sweeping. Any formula so based seems too crude a model of reality for general health planning.

The Centro de Estudios de Desarrollo (DENDES) and the Pan American Health Organization (PAHO)[1] developed a mathematical formula in order to compare the relative importance of various disease categories, based on their impact on mortality rates. The formula reads

\[
P = \frac{MIV}{C},
\]

where

- \( P \) = priority, or relative importance, of the disease.
- \( M \) = incidence of deaths due to the disease, as a ratio to over-all deaths.
- \( I \) = product of the number of deaths resulting from the disease, and an arbitrary coefficient that is age dependent.
- \( V \) = vulnerability of the disease, i.e., probability of causing less deaths because of health program intervention, as determined by medical and health professionals.
- \( C \) = cost of the health-program activity.

Since the product \( MIV \) is an effectiveness measure, \( P \) is then a figure
of merit expressing an effectiveness-to-cost ratio. \( I \) is a weighting factor that values the lives of some members of the population more highly than others, based on their contribution to the economy. \( V \) is an indication of the expected number of lives that will be saved by an activity designed to combat the disease.

That \( V \) should be multiplied by \( I \), rather than added to it, is debatable. Furthermore, whether \( M \) gives any information not already contained in \( I \) and \( V \) is questionable, since its only purpose is to give an indication of priorities for activities designed to combat specified disease categories. Since the formula addresses itself only to mortality, it has limited usefulness for health planning in countries where mortality has stabilized and the reduction of morbidity is a major objective.

The \( Q \)-index,\[^{141}\] developed by the Division of Indian Health of the Public Health Service, is a method of ranking the diseases that affect the Indian population. The index combines mortality with morbidity data. Assuming productivity as the basis for value judgment, it weights the impact of disease on normal function by days lost due to premature death, hospitalization, and clinic visits. The values assumed are:

- A day spent as an inpatient in the hospital is equivalent to a day lost due to premature death.
- A day spent as an outpatient at the clinic is equivalent to \( \frac{1}{3} \) of a day lost in the hospital, or due to premature death.
- Everyone from infancy to the age of 15 is treated as of equal importance; they are assigned a potential of 50 years of productivity (to age 65).
- Everyone over 65 years old is treated as having a productivity potential of one-half year, or 1 per cent.
- Mortality and morbidity are weighted by a factor that gives priority to attacking the diseases from which Indians suffer most, relative to the national average.

The \( Q \)-index formula is

\[
Q = MDP + 274A/N + 91B/N + 274C/N,
\]

where
- \( M \) = health-problem ratio: (target group rate)/(reference rate).
- \( D \) = crude target group mortality rate per 100,000.
- \( P \) = years of life lost because of death.
- \( A \) = number of inpatient days.
- \( B \) = number of outpatient days.
- \( C \) = days of restricted activity.
- \( N \) = target-group population.

\( 274 \) = a conversion constant = \( 100,000 / 365 \).
\( 91 \) = a conversion constant = \( 274 / 3 \).

The method has the advantage that it distinguishes between disruption
of life-style resulting from clinic visits and hospitalization. It does not, however, give weight to any other evidence of illness, such as school absence or work loss. The origin of the weights is not specified and seems questionable, especially in the case of hospitalization. The economic criterion of productivity, if implemented, would virtually deny medical care to the elderly. Because of its narrowness, the special features constructed for its target population, and its essentially economic orientation, the $Q$-index seems unsuitable for general health planning.

It seems clear from the diverse efforts noted above that function is central to any generalized notion of well-being. It is also clear that, because it is nonquantitative, it competes with economic criteria as the defined objective of the health services. Despite the efforts of many highly qualified researchers, a quantitative notion of function, useful over the whole spectrum of the delivery of health services, has proved to be elusive. As indicated in the introduction, we are aware of the difficulties inherent in this problem. It is our hope that our study will shed some light on the underlying issues, so that further research can be focused on the essential task of developing appropriate quantitative indices.

2. THE CONCEPT OF FUNCTION/DYSFUNCTION

In common language, a person is well if he is able to carry on his usual daily activities. To the extent that he cannot, he is in a state of dysfunction, or deviation from well-being. Our usual daily activities constitute a complex, multidimensional set as numerous as we see fit to conceive it. It is our purpose to transform this complex into a single-dimensional scale of function/dysfunction, conceived as a continuum that underlies a description of health status.

To sociologists, dysfunction only has meaning in terms of a ‘situation.’ Thus, Parsons defines illness as “a state of disturbance in the normal functioning of the total human individual, including both the state of the organism as a biological system, and of his personal and social adjustments,” and analyzes illness as deviant social behavior, albeit excused, in which the individual is unable to perform his usual functions; that is, he deviates from society's ideal (norm) of what he should be able to perform. The common denominator of all illness is this deviation, imposed by various disease processes on people with widely differing social roles.

Based on known disease processes, we offer a description of functional states to be used for reference and further investigation. It should be noted that if any activity can be conceived as included in ‘positive’ health, then its absence can be noted in a concept of ‘negative’ health, or dysfunction. Thus, function and dysfunction are conceived as complementary terms, one is present only to the extent that the other is absent. However,
many activities, or experiences, considered to enrich life and therefore to promote positive health, such as recreational, cultural, and educational opportunities are outside the offerings of the health services, although the health services sustain the capacity to enjoy them. It should also be noted that a person with symptoms, restricted activities, inability to work, or even bed-disability, has a large portion of function remaining; that is he is conscious, converses, moves about, or continues to work.

**Classification of Functional States**

Certain points (states) on the continuum of function/dysfunction can be defined and given operational meaning by professional judgment for different social roles and disease categories. On any given day, there is a distribution of the entire population or target group among the states; all members of the population belong to one and only one state.

\[ S_A - \text{Well-being.} \]  This is a theoretical state analogous to the mathematical asymptote line. It corresponds to the World Health Organization's "positive physical, mental, and social well-being."

\[ S_B - \text{Dissatisfaction.} \]  In this state, all the subjective and social behavioral indicators are within acceptable limits, but there are undesirable conditions like dental caries, or air pollution. It includes much of the population at large not in a lower state, since almost everyone has some type of unsatisfactory condition that must receive some weight. It is a very slight, but significant, deviation from well-being.

\[ S_C - \text{Discomfort.} \]  This state arises from symptoms, such as colds, mild headaches, itches, irritabilities. Daily activities (work, school, family care) are continued with no significant reduction of efficiency.

\[ S_D - \text{Disability, minor.} \]  This state includes illness from whatever cause and/or emotional disturbance. Daily activities are continued but with significant reduction of efficiency.

\[ S_E - \text{Disability, major.} \]  This state includes persons who can carry on only in a restricted way the activities usual for their ages and sexes, such as special schools for the mentally retarded or sheltered workshops for adults. Therefore, there is a severe reduction of efficiency in the performance of their expected functions.

\[ S_F - \text{Disabled.} \]  Persons in this state are unable to go to school, to work, or to the equivalent, but are ambulatory and able to move about the community.

\[ S_G - \text{Confined.} \]  Here they are not bedridden, but very likely institutionalized.

\[ S_H - \text{Confined, bedridden.} \]  Whether the bed is at home, in a hospital or
a nursing home is a matter of professional judgment, based on the
cause of the illness and its prognosis; but in each instance here the
person's functional status is confinement to bed.

$S_I$—Isolated. This state requires separation from family, friends, and
activities, such as confinement to a special-care unit, operating room,
delivery room, psychiatric security ward, or comparable isolation.

$S_F$—Coma. This state contains those with no significant functional
distinction from death, except a nonzero probability of transition
to a higher state.

$S_K$—Death. This state implies absolute dysfunction, with a zero transi-
tional probability to a higher state.

Note: If a person is in surgery for several hours, but confined to bed be-
fore and after, he is in state $S_I$; i.e., we take the worst state of the day as
the definition for the day.

It is important to note that no statement has been made about the
cause for lack of well-being, whether it is due to air pollution, job tensions,
poverty, or chronic disease. Thus, a person may be unable to work be-
cause of tuberculosis, alcoholism, mental retardation, or heart disease, but
if he is not in a lower state, he is in state $S_F$ (disabled). Likewise, air pol-
lution may yield simply $S_H$ (dissatisfaction) or be the cause of a respira-
tory illness requiring confinement to bed ($S_H$), or even death ($S_K$). Schizo-
phrenia can vary from mild behavior disturbance ($S_D$), to hallucinations
and confinement ($S_I$), or to suicide ($S_K$).

Similarly, function/dysfunction is independent of social role. A child
may be inhibited in play ($S_D$), bedridden ($S_H$), or comatose ($S_I$). Old
people may be symptomatic ($S_C$), shut-in ($S_o$), or bedridden ($S_H$), or in
other states.

Treatment itself may be dysfunctional, even in the absence of illness.
A person who goes into the hospital for a diagnostic evaluation is away from
work and family, even if the work-up is negative. If a potentially danger-
ous condition is detected and corrected, prognosis has been improved
(prognosis is discussed later), but the person involved was made temporarily
dysfunctional. A person suffering from multiple diseases is classified ac-
cording to functional state, depending on whether their total impact is mild
or severe. Such a classification emphasizes that it is the rehabilitation of
the total individual rather than the cure of a single disease that is the ob-
ject of the health system. (The problem of multiple diseases is a difficult
one, and is only mentioned here.)

As a convenient shorthand, we have used a single word to describe each
state $S$. This is not without disadvantage, since it gives more latitude for
misinterpretation. A complete definition of the states would require an
interdisciplinary team of experts to classify the function levels of each social role and major disease category.

We are interested in the population aggregate, not in the odd case, and so we say that, on the average, a person is worse off in going from $S_A$ toward $S_K$. We take it as self-evident, a ground value of society, as well as individuals, that it is better to be in a higher state than a lower one, and worth the expenditure of more resources to move from a very low state to a high state than from a middle state to the same high state. Therefore, we say that with each of the states there is associated a value, both to an individual and to society as a whole; and that, in the progression from $S_A$ to $S_K$, the value decreases monotonically. The problem is the relative values, i.e., what weights to give these states so as to quantify the values on a linear scale with a zero level. The set of weights assigned to the states of dysfunction are what we choose to call the Health Status Index (HSI).

**Theoretical Basis for Value Judgments**

Since the Health Status Index is to be used as a planning tool, we emphasize value in a societal sense without limiting it to economic criteria (as we shall see in section 4). Etzioni and Lehman\[13\] point out that, when measures are made of collective attributes, one should distinguish between aggregated measures and global measures. Thus, if we ask each individual to place a value on each of the above states, and then average it over the population, we will get an aggregate measure. But, if we note the allocation of a scarce resource, such as medical manpower, to each state and use this as a measure of society’s social values, then we are using a global measure. Ours is a global measure, because, as we show later, we see the public representative in the role of reflecting society’s judgment of the value of the states. We would bring to his attention what Alexander calls the “humanist criterion” for his guidance: “Alternative A should be done rather than alternative B if and only if a reasonable, well-informed man, free of personal and cultural bias, would prefer to be anyone at random in the state consequent on A rather than B.”\[2\]

The theory of decision-making including value judgments has received considerable attention. Value is usually taken as a primitive, that is, it is assumed that we know intuitively what it means. Thus, Fisburn\[14\] simply states that ‘value’ is the quantification of the concept of worth, importance, or desirability (reference 14, page 10). It is important to have a better understanding of ‘value’ however, because it is inherent in a health status index, and there is a strong tendency among planners to equate health with its purported economic benefit. Gross (reference 16, pages 204, 221) points out that every society exhibits a complex and shifting structure of values that indicate the different ways in which people try to satisfy
universal human interests. The terms “interest satisfaction, or dissatisfaction” are almost impossible to observe directly, and therefore we must resort to a variety of surrogates, or indirect indicators. He warns that national economic accounts do not directly incorporate figures on health, and that the progress of health may be ignored when formulating national goals or evaluating performance, if economic criteria are used as the basis for indicators of health status.

Kaplan\textsuperscript{24} discusses extensively the role of values in the conduct of an inquiry. He says that: the term ‘value’ refers to the standards or principles of worth, and is the basis for the value judgments; intrinsic value is the ground of value—it is the sense of satisfaction, the direct experience of gratification (reference 24, page 389); value is a subject for scientific investigation (reference 24, page 377). Interestingly enough, such an investigation has been attempted: Hartman\textsuperscript{19} has undertaken a study of values, traditionally a branch of philosophy called axiology, and has constructed a science of values, a scientific axiology.

It is apparent that, in its most rigorous form, value is a complex phenomenon. In ordinary usage it is equally complex and pervasive. Some of the words frequently used as synonyms for value are: worth, importance, satisfaction, utility, desirability, significance, preference, goal, reward, need, function. Satisfaction and its complement dissatisfaction, or function and its complement dysfunction, seem best. It applies to all people readily. It is an intrinsic value. It is neutral with respect to ambition, or work goals. It applies to basic physiological, emotional, and social responses. In all, it seems to distinguish the universal objective of well-being (ends) from instrumental values of how that well-being should be pursued or utilized (means to ends).

3. RELATED PARAMETERS: PROGNOSIS, POPULATION, TIME

For the purpose of improving the health of the population, there is a wide variety of health programs in operation. The spectrum of medical care ranges from public health, preventive medicine, and environmental control, through diagnosis and medical care, to convalescence and rehabilitation. Many programs affect the probability of occurrence of dysfunction in the future, rather than altering the present functional status; for some, the benefits are not visible until after the programs have been terminated; all are aimed at more than one person. If we wish to quantify the output of these various programs, it becomes necessary to examine concepts other than functional status.

The term ‘health’ is taken loosely to mean not only the ability to function now, but the outlook for future functional ability. For example, a person who is perfectly functional and asymptomatic on one day, but har-
bors a disease with a poor prognosis, such as Hodgkin's disease, cannot be considered 'healthy' even though functional. Similarly, the term 'severity of illness' is a composite of dysfunction and prognosis. Most medical treatment, even if there are symptoms, is directed toward preventing future and more severe dysfunction. For example, a hernia is repaired so as to decrease the likelihood of an incarceration; cases of hypocardial infarction are placed in coronary-care units because the services offered decrease the likelihood of death; the emotionally disturbed are hospitalized, not because they are so severely ill that they cannot function, but because the treatment offered will allow them to function better in the future. For purely preventive procedures, with no symptoms, this is more obviously true. For example, Pap smears are done and hysterectomies performed to decrease (almost to zero) the likelihood of cancer; annual checkups and multiphasic screening are done in the absence of dysfunction to detect correctable conditions and decrease the probability of future dysfunctions. Therefore, we believe it to be essential to decompose 'state of health' and 'severity of illness' into the separate concepts function/dysfunction (F/D) and prognosis (P), and to define the general terms as composites of these two distinct parameters. As a consequence, all the terms related to health status can be given mathematical definitions.

The Concept of Prognosis (P)

Based on the concept of function/dysfunction, as we have discussed it, we can readily define prognosis. A person in any individual state $S_i$ can logically move to any other state $S_j$ with the passage of time. Which state of dysfunction the person will actually be in at the end of a specified time period cannot be stated with certainty, but only probabilistically. The prognosis gives, for each state $S_j$, the transition probability $P_{ij}$ that the person will be in this state at the end of the time period, if he was in state $S_i$ at its beginning. This relation can be visualized as shown in Fig. 1.

Figure 1 shows that, on the average, if a large group of persons is in state $S_i$ at the beginning of the time period ($T_0$), at the end of the time period ($T_1$), 10 per cent will move to $S_{c}$, 75 per cent will remain in $S_{r}$, and 15 per cent will move to $S_{f}$.

Prognoses as used here are not judgments about individual patients, but groups of patients. If a group of patients is not subject to a single probability distribution, it is decomposed into 'cells' by demographic and disease characteristics until transition-probability statements can be made for each cell.

To minimize the computational task, it would be desirable that $P_{ij}$ be independent of the states prior to $T_0$, and be time-independent thereafter, i.e., a stationary Markov process, whose mathematical properties have been
studied extensively.\textsuperscript{[28,40,4,5]} However, only empirical investigations can confirm or deny this desirable condition.

Data for the prognoses can be derived from a variety of sources. Mortality rates, for instance, can be incorporated into the model as the probability of moving to death $S_k$ from any other state $S_i$. From survey data on restricted activity and bed-disability days, similar calculations can be made for other states. Health program analyses are oriented toward specific disease forms. They may be studies such as the Framingham study for heart disease, registries such as those for malignancies, tuberculosis, birth defects, or controlled clinical experiments of all types. In addition,

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\textbf{Fig. 1. The prognosis or transition probability $P_{ij}$.}

there is the working knowledge of the professionals involved with treating the diseases and running the programs. Experience is being developed in the group determination of such prognoses, or responses to therapy and programs, using groups of experts.\textsuperscript{[54]} While the process is painstaking and time consuming, it represents a major step forward toward the quantification of the output of health programs.

\textbf{The Concept of Population ($N$)}

A population group $N$ may be defined administratively as the population over which a health service has jurisdiction. For example, a tuberculosis (TB) control center is county based, and therefore the county population is
the concern of the TB control director. TB is a communicable disease, and therefore all members of the population are under the risk of contracting it. But the transfer mechanism is such that the risk is extremely small, except for those in direct contact with active TB cases. The strategy of the director is then to seek out the active cases, the suspects, and the contacts; these are then his target population. Because his resources are limited, he never knows his target population completely, and hence can never completely eradicate the disease. He can only estimate the total target population from the known target population. If he knows the social characteristics of the disease—if, for example, the disease concentrates in the poverty and ghetto areas—these facts influence his search strategy. Finally, since

![Graph](image)

*Fig. 2. Functional history—example and ideal.*

the purpose is to eliminate the disease, he concerns himself with the time trends of the known active cases, known death rates, etc.

We note that no weighting factors are applied to any segment of the population according to productivity, income, or other economic criteria of value (this is discussed more fully in section 4). For measurement purposes, days in all lives are equal for all members of the population.

**The Concept of Time (T)**

Time here refers to the duration that each person spends in any functional state, without reference to the duration of the program. For each individual, our ideal is a dysfunction-free life history, and may be visualized in Fig. 2.

Life expectancy has increased markedly since the turn of the century as social conditions have improved and medical knowledge has increased.
It is the mission of the health services to continue this increase, while simultaneously minimizing dysfunction. In Fig. 2, the example person is in state $S_x$ from time $T_0$ to time $T_1$, in state $S_y$ from time $T_1$ to time $T_2$, etc. He dies in time $T_{*}$. The 'ideal person' lives in a state of well-being $S_A$ until he dies at time $T_S$.

Even for ideal conditions we must have a reasonable expected duration of life. If not, it would mean that morbidity has no significance when compared to mortality; mathematically, finite quantities are insignificant when compared to infinity. Thus we have chosen a standard life duration $T_s$ of 90 years. This is the age used for actuarial purposes, and is an age reached by less than 7 per cent of the population from birth. With such a small number of people involved, our definition yields no significant errors in the computations. In practice, policies for persons over 90 do not differ from policies for the elderly in general, and so no significant discriminatory effect is introduced by this definition.

With this definition of standard life, we are able to put on an operational basis several important concepts. First, people dying before age 90 have by definition, died 'prematurely.' To die at age 5 is to lose much more life 'time' than to die at age 70. We can now quantify this concept, using function-time as the unit of measure, where time can be days, months, or years. Secondly, the mystique of life and death is removed. Thus the expression 'this treatment or health program saves life' is poor; more precisely, 'this treatment or health program postpones death.' In operational terms, death is a state of total dysfunction $S_K$ for the remainder of the standard life, i.e., to age 90 (or any other age that may be chosen if social conditions change).

The standard life $T_s$ also avoids the discriminatory effect that would result if we were to use age-specific life expectancies for lost life-time, since they do not attribute as much lost life to younger people as they do to older people. For example, a child at age one has a life expectancy of sixty-nine, whereas a person at age 70 has an age-specific life expectancy to age 75. Using the same standard for all simplifies the computations considerably.

4. METHODS OF WEIGHTING THE FUNCTIONAL STATES

So far we have defined an ordinal scale of function/dysfunction, and a cardinal scale as the set of weights assigned to the functional states, and we called this set the Health Status Index (HSI). We have emphasized that the HSI must be comprehensive in the sense that it is applicable to the total population, regardless of age, sex, other demographic characteristics, or disease category.

The problem of assigning the weights is complex, and many approaches are possible. We will discuss a number of methods, pointing out the limi-
tations and contributions of each, in order to devise an acceptable method. These methods are not mutually exclusive, and the method of equivalence developed finally uses some notions from all of them. The methods considered for creating the HSI can be characterized as: (1) economic, (2) behavioral, (3) survey, and (4) paired comparisons.

Economic Methods

To use cost to society, or to the health system, as a surrogate for the values of the states has some appeal. Money value is recognized as a universal unit, a common denominator for the relative value of all goods and services. It is inherently quantitative, and a variety of techniques, such as cost/benefit analysis, have been developed and applied to the health field.

In 1965, a directive from the Bureau of the Budget of the Federal government to the heads of all executive departments required that their budget requests be based on analyses of objectives, weighing costs against benefits, using the planning-programming-budgeting system (PPBS). When it comes to analyzing the benefits of health programs, there is recognition of such health benefits as lives saved, disability days prevented, and reductions of hospital stays. In the final stages of the analyses, however, in order to obtain a quantitative measure, all benefits are transformed into the common denominator of money. Costs have a direct component, including the direct expenditure for health services and capital investment, and an indirect component, including the loss to the economy as a result of the reduction in productivity caused by illness. Premature death is treated as a limiting case of illness, i.e., the loss is the production loss for the years of premature death. In such a scheme, the benefit of a health program is the saving achieved in these costs by the intervention of the program. The stream of costs and benefits, which are functions of time, are discounted to obtain their present worth (the correct discount rate is a subject for controversy). The figure of merit used to judge the relative worth of the health programs is the ratio of the present worth of the cost to the present worth of the benefit.

It is acknowledged that cost/benefit analysis has its limitations, that there are value issues involved, and that good judgment, compassion, etc., should not be ignored (reference 44, pages 98–100). Some economists have avoided translating health benefits into dollar values. We have already commented that productivity gives little rational basis for evaluating benefits to such segments of the population as the mentally retarded, the elderly, housewives, and children. In fact, public policy makes clear that societal values are such that more, not less, resources are devoted to these and other dependent persons. We share with the economists the view that it is desirable to seek to quantify the benefits of health programs,
because it makes visible implicit judgments and subjects them to analysis. But we take exception to the attempt by some planners to make ‘measurable,’ and ‘dollar value’ synonymous. Where economic benefits are sharply defined, while noneconomic benefits are only qualitative, in the decision-making process, the economic factors tend to be overwhelming. We believe that quantification in the broad sense is much more justifiable. Hence, in the previous sections, we concerned ourselves with describing the benefit of the health services in terms of dysfunction-free-years as an operational definition of the mission of the services. Later on, we define output criteria. This permits the use of the cost/output, or cost/effectiveness ratio as a figure of merit to judge the relative worth of health programs. In so doing, we seek to avoid the trap, that people often fall into, of equating the expenditure of money with doing good!

**Behavioral Methods**

Restricted daily activities are deviations from well-being. If we could construct a battery of indicators of behavior, a tabulation of their states would be a measure of dysfunction, or deviation from well-being. Sociologists could classify the population into demographic cells, and, for each cell, define the usual daily activities in terms of a situation and the roles and positions fulfilled by the members of the cell. The roles selected and their relative importance are a matter of judgment. Also, restrictions in activities are not definable on a percentage basis, but are di- or trichotomous. Thus, if we wanted to create a scale of dysfunction, we would have to consider the number of roles that a person can fulfill, and, according to our value judgment of the relative importance of these roles, we could create such a scale.\[^20\]

It is clear that this procedure does not avoid the question of value judgment, and, in the attempt to dissect ‘usual daily activities’ so as to be ‘objective,’ many difficulties are created. Now, dealing with a complex idea such as ‘usual daily activities’ is nothing novel. For example, a psychologist will test the response of people to color stimuli, or their preferences for products, without tracing the path of the light beam to the eye, its transformation to the nervous system, and finally to cerebral activity—an enormous task! Yet he discovers relations that are deemed to be significant and useful. It is our judgment that this is how ‘usual daily activities’ should be treated. We do not deny the usefulness of classifying the population into demographic cells and describing their roles, but then, having done so, we say that their disabilities should be described by their states of dysfunction $S$, that these descriptions are meaningful to medical specialists and health planners, and that to use the one-dimensional term ‘dysfunction’ to describe the $n$-dimensional term ‘activities’ is as meaningful as, for example, the word ‘color’ or the word ‘humanitarian.’
Survey Methods

We consider here the possibility of carrying out a population survey to obtain a consensus of the values to be placed on the states $S$. However, to design a meaningful population survey is a difficult and time-consuming methodological problem. For example, Lee[41] has noted that the values people place on health and medical care depends on their social status (reference 31, page 194); for the poor, who need medical care the most, health is valued the least, so that the differences from one state to another will mean less for the poor than the well-to-do. Clearly this consensus of range of values for the HSI is not static; it will change with time and the general socioeconomic conditions of society.

In addition, there are conceptual problems in determining social values from a consensus of values that people place on health. In the field of welfare economics, Arrow[8] argues this point carefully. He takes the following strong view: suppose that we are concerned with a social welfare function, made operational through some social decision process. He asserts that you cannot give any meaning to an interpersonal comparison of utilities (relative values), which, of course, is what is involved in consensus. More strongly, he states that the behavior of an individual in making preferences is describable only by an ordinal scale, and not by a cardinal scale. Therefore, to make the relative values of different individuals dimensionally compatible requires a definite value judgment, not derivable from individual sensations; and still further value judgments are required to aggregate them for any particular mathematical formula. (See reference 3, pages 9–11, 74.)

Method of Paired Comparisons

In view of the difficulties of survey methods, the possibility of using public officials to assign the values presents itself. Prognoses, durations of illnesses, and the numbers of people affected are all matters of data and expert judgment. But the weights to be assigned to states are questions of societal values. Thus the public officials would not function as ‘experts’ but as representatives of society’s judgments about the relative importance of the various states. Theirs should be an informed, ethically-concerned, socially-oriented judgment that is consistent with existing social rules for the transformation of individual values to social decisions. In addition, since they would be the ones to use the instruments developed, they would have a direct interest in their appropriate development.

We see the public official as making social policy with regard to health. Health is an end value, and is an instrument for other end values (freedom, security, equality, etc.); i.e., it is one of a complex set of concepts currently referred to as ‘the quality of life.’ The public official has the responsibility of making quantitative allocation of scarce resources, based on these inter-
acting values (the costs associated with these allocations should be made separately, as we indicated earlier). The question then becomes: Is there a 'rational' way of making these allocations?

Again we wish to emphasize that to measure deviation from physical, mental, and social well-being, which is a complex, multidimensional concept, with a value scale, which is a one-dimensional concept, is not a new problem. For example, citizens voting for a President of the United States do so with attitudes on a wide variety of crucial issues. They amalgamate these attitudes, some of which may be self-contradictory, into a single vote for a single man, because this is one of the social decision-making rules. So here too the public official projects 'health,' a complex phenomenon, onto a single scale. He does this in order to make decisions, such as comparing the value of one health program with another. The key word is value.

![Fig. 3. Transitions and their weights.](image)

Of necessity, intuition, based on experience, becomes very much involved. It is our hope that this study, by analyzing the values involved and constructing a framework for the assignment of weights, makes this task more rational and manageable.

The method under consideration consists of questioning the decision-makers' value judgments in such a fashion that, in order for the responses to be consistent, weights or values are assigned to the states.\(^{[18]}\) It has been observed that preferences are most readily stated in terms of indifference; i.e., one states that he is indifferent in his choice of \(a\) units of \(x\) as compared to \(b\) units of \(y\). Therefore, we ask the decision-maker to consider the comparison of transition from the various states to state \(S_A\) as shown in Fig. 3.

By assigning the weights to the transitions as shown, and by making paired comparisons to all the possible combinations, then, on the basis of
consistency, the weights of the transitions will be obtained. The weights for each of the states is obtainable by simple arithmetic. Furthermore, since function and dysfunction are complementary terms, to assign a functional weight of 0.8, for example, to a state, is equivalent to assigning a dysfunctional weight of 0.2 to that state.

The method assumes:

1. To assign a number $F_i$ to state $S_i$, and to call it the functional weight of the state is a meaningful and valid operation in the real world.

2. $F_i$ is greater than $F_j$, if $i$ is a letter that precedes the letter $j$.

3. Additivity is valid; i.e., for the transition $(S_A - S_B)$ and the transition $(S_A - S_P)$ there is a valid transition $(S_A - S_B) + (S_A - S_P)$ whose functional weight is $(F_A - F_B) + (F_A - F_P)$. This assumption makes sense if a day in the life of a person is equal to any day of any other person, and one person has a transition $(S_A - S_B)$, while another person has a transition $(S_A - S_P)$. Note that we cannot speak of a person being in states $S_B$ and $S_P$ at the same time.

When would the assumption of additivity not hold? It would not hold if the law of diminishing returns applied—for example, if being in state $S_D$ for 10 days were not 10 times as bad as being in state $S_D$ for 1 day, or if a transition from state $S_F$ to $S_C$ for one person has less value than a transition from state $S_F$ to $S_B$ for one person, plus a transition from $S_B$ to $S_D$ for another, plus a transition from $S_D$ to $S_C$ for a third. Additivity may also not hold because some things are simply not additive; for example, two medications when taken separately for two separate illnesses may be beneficial, but taken jointly may be harmful. We have assumed additivity on the grounds that all days in a person’s life are equal, and that a transition from $S_F$ to $S_C$ simply means ‘passing through’ states $S_B$ and $S_D$.

There is a long history for the method of paired comparisons described above to obtain the values (or weights) to be assigned to social phenomena. For example, the psychologist Thurstone developed an interval scale to describe the attitude of an experimental group toward nationalities (with all the implied biases), and the attitude of another experimental group towards the seriousness of crimes, to demonstrate that judgments involving social values can be quantified.

Another assumption that creeps in subtly, but is worth noting, is as follows: What we are doing is estimating values in order to use them as a foundation for making decisions. There is an implication that, if decisions are made, this in turn implies values—the very same values that we are estimating. If true, then there is an option of studying past decisions and deriving the values imputed—assuming the value foundations are stable. But there is a difference; the latter is actual decision-making, whereas the former is simulated decision-making. If you are responsible for the decision, as against playing the game, are the results the same? We have as-
summed that they are on the ground that the decision maker has had the experience. As experience is gained in the method, the accuracy can be expected to improve.

We next consider the problem of obtaining real data to test the validity for our HSI. If we consider specific programs, such as for coronary heart disease (CHD), or vocational rehabilitation, the target population is of a specific kind with specific disabilities. Values imputed from the decisions made are valid for this specific population. But we seek a scale of values valid for the total population, so that it is useful for comprehensive health planning. Can we say, for example, that values derived from employed males are applicable for infants, nonworking women, and the retired? Clearly, it is only after we obtain values by the method indicated above that we can then test the cost/effectiveness of a program such as CHD, where cost is measured, say, in dollars, and effectiveness is measured in dysfunction-free days induced by the program.

5. DETERMINING FUNCTIONAL-STATE VALUES

The method of paired comparisons that we will use to assign weights for the HSI involves constructing an equivalence through another property, or dimension. It resembles roughly the method used by economists for creating curves of constant utility for two or more commodities. The problem of constructing multidimensional scales based on equivalence has been treated systematically by Torgerson, and the method used here is consistent with his work.

In order to define a scale, we make the following assumptions:

(a) For convenience, let $F_A$, the functional weight of state $S_A$ (well-being) be equal to 1. This becomes our maximum value, i.e., the 'asymptote line.'

(b) Let $F_X$, the functional weight of state $S_X$ (death) be equal to 0. This is our minimum value of weights. We have thus made the range of the HSI to be from 0 to 1, since we are only concerned with the relative weights of the states $S$ of function/dysfunction.

(c) $F_Y$, the functional weight of $S_Y$ (dissatisfaction) differs from $F_A$ by a small, but significant, amount. The existence of environmental and other causes leads to conditions that are not as serious as actual discomfort $S_C$, but are commonly regarded as a matter of concern and worthy of the expenditure of health resources, since large numbers of people are affected. Therefore, the weight of the unsatisfactory conditions must be statistically significant on the value scale. Of course, it should be understood that any single cause, such as severe air pollution, can lead to a distribution of persons among many states of dysfunction, from very mild to severe.

(d) $F_J$, the functional weight of $S_J$ (coma), is close to $F_X$ (death), on
the ground that the functional difference between coma and death is insignificant. However, $S_x$ (death) has a zero transitional probability to a higher state, while $S_y$ (coma) has a nonzero transitional probability, which is dependent on the etiology of the coma. For instance, the coma of terminal cancer would have a transitional probability to a higher state of almost zero, while for a mild concussion it might be 0.95. Nevertheless, the functional weight $F_y$, for the duration of the coma, is very nearly equal to zero.

(e) Since function $(F)$ and dysfunction $(D)$ are complementary concepts, $D = 1 - F$.

Weighting through Equivalence in Time

We assume that a day in the life of a person has the same value as any other day in the life of this person, or any other member of the population.

![Diagram](image)

**Fig. 4.** Weighting the functional states through equivalence in time (group size is the same for all times).

Therefore, function-days can be said to be equivalent to each other, or 'traded-off' in time, if the amount of function lost by being in state $S_i$ for a length of time $T_i$ is equal to the function lost by being in state $S_j$ for a time $T_j$; i.e., if $D_iT_i = D_jT_j$. Thus, a dysfunctional weight of 0.5 for 1 day is equivalent to a dysfunctional weight of 0.25 for 2 days. In this trade-off procedure, there is a maximum value allowable for time $T$, since the standard life is $T_s = 90$ years $= 32,850$ days. This means that any values traded off that necessitate a time factor greater than 90 years are, a priori, unreasonable.

As a procedure for weighting the functional states, the following scenario becomes possible: Suppose there is available a limited amount of resources to be allocated, and there are two large and equal groups of people, one in state $S_i$, the other in state $S_j$. With the expenditure of these resources, the group in state $S_i$ would be in this state for a time $T_i$ and then made 'well,' i.e., go to state $S_A$ for their remaining lifetime. But if the resources
were expended on the group in state $S_i$ they would be in that state for a time $T_i$ before going to state $S_A$. The policy maker must decide the following: What should be the ratio $T_i/T_j$ so that the resources do the same 'good' in both cases; i.e., so that there is equivalence, or indifference, or a trade-off between the two groups? This scenario is illustrated in Fig. 4. By proceeding in this fashion, the relation between the weights assigned to each of the states can be determined. Since we assumed that $F_A = 1$, and $F_X = 0$, from the above argument we can transform the decisions of the policy maker to assigned numbers, or weights, to the states of function dysfunction $S$. Knowing the values of $D$, we of course know the values of $F$, from $F = 1 - D$.

**Weighting through Equivalence in Population**

It may be that the judges find it more natural to think in terms of numbers of persons, rather than of time. The question then becomes: suppose

![Figure 5](image_url)

*Fig. 5. Weighting the functional states through equivalence in population (time is the same for all groups).*

there are scarce resources to be allocated, and there are two large groups of people, one in state $S_i$, the other in state $S_j$. The resources, which must be assigned totally to one group or the other, would keep each group in their state the same length of time before making them well. What should be the ratio of the sizes of the groups, $N_i/N_j$, so that the same good is done in both cases?

Since $D_iN_i = D_jN_j$, therefore $D_i/D_j = N_j/N_i$. This is illustrated in Fig. 5.

The procedure otherwise is the same as before, and the weights of the states $S$ are calculated accordingly.

**Weighting through Equivalence in Dysfunctional History**

Another way of looking at these equivalences, or trade-offs, that seems reasonable is as follows: A group of people are in state $S_i$. Allocation of
scarce resources gives a choice between maintaining them in state $S_i$ for the duration of the standard life $T_s$; or being transferred to state $S_A$, i.e., making them well, but dying 'prematurely' by $T_i$ years. (Loosely speaking, this is saying that we make sick people well, at the expense of not using resources for people who have reached the age of $T_s - T_i$). Then $D_i T_s = 1(T_i)$; or $D_i = T_i / T_s$, as illustrated in Fig. 6.

**Illustration of a Health-Status Index**

As an initial attempt actually to assign numbers to the states of function/dysfunction, for illustrative purposes, we make the assumption that

![Diagram](image)

*Fig. 6. Weighting the functional states through equivalence in functional history (group size is constant).*

the dysfunction of any state is weighted twice as much as that of the preceding state. This leads to an exponential relation of the form:

$$D_i = D_1 2^{(i-1)};$$

where $i = 1, 2, \ldots, 10$, corresponding respectively to the subscripts $A, B, \ldots, J$ of the states $S_i$. If we regard $D_J$ as being close enough to one to be regarded as equal to one for the purposes of the example, $D_{10} = 1 = D_1 2^{(10-1)}$, whence $D_1 = 0.00195 = \frac{1}{2}$ and $D_i = 2^{(i-10)}$. Table I can then be constructed.

There are several ways to interpret this table to see if it expresses the values that administrators would wish to see assigned. For example, from column 4, with a fixed amount of health resources available for allocation, the health administrators see that with these resources they can keep 16 times as many people in state $S_H$ (disability, major) as in state $S_J$ (coma)
TABLE I
ILLUSTRATION OF A HEALTH-STATUS INDEX

<table>
<thead>
<tr>
<th>(1) Dysfunction</th>
<th>(2) State (S)</th>
<th>(3) Weights (D)</th>
<th>(4) Equivalents in people, or days</th>
<th>(5) Life-time equivalents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well-being</td>
<td>$S_A$</td>
<td>$0^+$</td>
<td>$1^-$</td>
<td></td>
</tr>
<tr>
<td>Dissatisfaction</td>
<td>$S_B$</td>
<td>0.0039</td>
<td>0.9961</td>
<td>265 (9 mo)</td>
</tr>
<tr>
<td>Discomfort</td>
<td>$S_C$</td>
<td>0.0078</td>
<td>0.9922</td>
<td>128 (4 mo)</td>
</tr>
<tr>
<td>Minor disabled</td>
<td>$S_D$</td>
<td>0.0156</td>
<td>0.9844</td>
<td>64 (2 mo)</td>
</tr>
<tr>
<td>Major disabled</td>
<td>$S_E$</td>
<td>0.0313</td>
<td>0.9687</td>
<td>32</td>
</tr>
<tr>
<td>Disabled</td>
<td>$S_F$</td>
<td>0.0625</td>
<td>0.9375</td>
<td>16</td>
</tr>
<tr>
<td>Confined</td>
<td>$S_G$</td>
<td>0.125</td>
<td>0.875</td>
<td>8</td>
</tr>
<tr>
<td>Bedridden</td>
<td>$S_H$</td>
<td>0.25</td>
<td>0.75</td>
<td>4</td>
</tr>
<tr>
<td>Isolated</td>
<td>$S_I$</td>
<td>0.5</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td>Coma</td>
<td>$S_J$</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Death</td>
<td>$S_K$</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

for the same duration. They all then become well, i.e., go to $S_A$. These are equivalent, or 'trade-off,' conditions. Put another way, the administrators see a trade-off between moving one group of people from $S_J$ to $S_A$, as compared to moving 16 times as many people from $S_E$ to $S_A$, all other conditions remaining the same. Furthermore, the same data can be read to mean that a group to be in $S_J$ for one day is equivalent to the same group being in $S_E$ for 16 days.

In similar fashion, each item in column 4 can be related to each other one.

![Diagram]

Fig. 7. Intuitive weighting through equivalence in functional history.

Column 5 also offers interesting information. It says that a health administrator sees a trade-off between using resources to maintain a group of people in state $S_E$ (major disability), for the entire 'standard' life of 90 years, as compared to maintaining the same group in state $S_A$ (well-being) for the 'standard' life less 2.8 years because of premature death. If put to a
layman, the question would be: how many years of your life would you be willing to give up so that instead of living with a major disability all your life, you would live without even dissatisfactions for the remainder of your life? He answers 2.8 years. This point is illustrated in Fig. 7.

In similar fashion, each item in column 5 can be related to each other one.

It should be noted that, as the various kinds of disability associated with each state are more completely defined, this process will assist the health administrator in adjusting the values until they are satisfactory and consistent.

For instance, it appeared to us that the values derived were, in general, too low. We therefore made intuitive adjustments to obtain a satisfactory

<table>
<thead>
<tr>
<th>(1) Dysfunction</th>
<th>(2) State (S)</th>
<th>(3) Weight</th>
<th>(4) Equivalent in people or days</th>
<th>(5) Equivalents in lost lifetime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Well-being</td>
<td>$S_A$</td>
<td>0</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Dissatisfaction</td>
<td>$S_B$</td>
<td>0.0039</td>
<td>0.9961</td>
<td>256 (9 mo)</td>
</tr>
<tr>
<td>Discomfort</td>
<td>$S_C$</td>
<td>0.0156</td>
<td>0.9844</td>
<td>64 (2 mo)</td>
</tr>
<tr>
<td>Minor disabled</td>
<td>$S_D$</td>
<td>0.0313</td>
<td>0.9687</td>
<td>32 (1 mo)</td>
</tr>
<tr>
<td>Major disabled</td>
<td>$S_E$</td>
<td>0.0625</td>
<td>0.9375</td>
<td>16</td>
</tr>
<tr>
<td>Disabled</td>
<td>$S_F$</td>
<td>0.125</td>
<td>0.875</td>
<td>8</td>
</tr>
<tr>
<td>Confined</td>
<td>$S_G$</td>
<td>0.25</td>
<td>0.75</td>
<td>4</td>
</tr>
<tr>
<td>Bedridden</td>
<td>$S_H$</td>
<td>0.50</td>
<td>0.50</td>
<td>2</td>
</tr>
<tr>
<td>Isolated</td>
<td>$S_I$</td>
<td>0.67</td>
<td>0.33</td>
<td>1.5</td>
</tr>
<tr>
<td>Coma</td>
<td>$S_J$</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Death</td>
<td>$S_K$</td>
<td>1</td>
<td></td>
<td>1</td>
</tr>
</tbody>
</table>
tive satisfaction (or dissatisfaction) associated with the states $S$. Satisfaction is an intrinsic value, i.e., a ground value accepted by society as a whole. The dissatisfaction stems from social dysfunction, i.e., restriction in usual daily physical and social activities. The description of the states $S$ is independent of the demographic characteristics of the population, or the cost to society or the health system in dealing with the dysfunction. It is making explicit an intuitively understood parameter so that it can be manipulated with other measurable factors (time, population, probability of transition) in formulas to assist policy-makers in their decisions.

6. DEFINITIONS OF OUTCOME CRITERIA

Output, Effectiveness, and Population Health-Status Index

Having defined the concepts of function/dysfunction, health status index, prognosis, target population, and standardized duration of life, we can now define the concept of health system output. From the viewpoint of the health services, the mission of any defined health system, or subsystem such as a health program, is to improve the health status of the population, or to reduce the severity of illness, as previously defined. Therefore, we define the output of a health program (or health system) as the change in the functional history of the target population resulting from the intervention of the health program (or health system).

Another useful concept is the level of performance of the system, i.e., the extent to which it achieves the conceived goal or objective. The objective is to achieve the ideal functional history, as shown in Fig. 2. The ideal output is therefore the change in functional history, because of health program intervention, if the ideal functional history is achieved. The effectiveness of the health program is then defined as the ratio of the actual output to the ideal output.

Definitions are, of course, a matter of judgment, and, in a sense, arbitrary. Some may argue that the ideal output is unrealistic, that, considering the state of medical knowledge, the best that one can hope for is the only practical ideal—and then proceed to describe the best functional history that one can hope for. On such a basis, we could define the effectiveness of the health program as the ratio of the output to the ‘best practical’ output just defined. The ratio of the ‘best practical’ output to the ‘ideal’ output could be called the level of feasibility.

To illustrate this discussion, let us assume that a program is being considered addressed to a disease for which the prognoses depend on age, race, and disease form (or patients in this disease category have different prognoses). Let us assume that there are five distinct disease forms, five age brackets, three races (back, white, other) and 11 distinct functional/
dysfunctional states, \( F/D \), from 0 to 1. We have thus defined a ‘cell’ as a quadruplet (disease form, age, race, function, weight), with the number of cells equal to \( 5 \times 5 \times 3 \times 11 \), or 825. For each cell there is a prognosis, both with and without the program; thus, there are 1650 prognoses.

At the time \( T_0 \) of initiation of the program, there are a certain number of people in each cell, which we can express as a fraction of the target population \( N \); that is, there is a distribution of the people as a function of the cells. If \( F_i \) is the functional weight and \( N_i \) the number of people for cell \( i \), then \( \bar{F}_0 = \sum_i F_i N_i \) is the mean value of the functional weight of the population at time \( T_0 \). It is important to note that \( \bar{F}_0 \) is an operational definition of the health-status index for the population at time \( T_0 \).

The variance \( V_0 \) is an indication of the spread of function among the population. Used in conjunction with the mean value, it provides additional information when making a comparative study among various populations (by analogy to personal income, if two populations have the same mean value but different variances, this fact is significant). The variance is given by \( V_0 = \sum_i (F_i - \bar{F}_0)^2 N_i \).

Now, as time increases, the distribution of the population among the cells will change. The prognoses \( p_i \) furnish the information necessary to compute the new distributions at each moment in time. We also note that, as people become older, then at certain times they change age bracket, and therefore their cell location changes. Knowing the distribution at any moment in time, we can compute the mean \( \bar{F} \) and variance \( V \) at that moment, in the same manner as described above for \( T_0 \). We visualize the results at different times as shown in Fig. 8. The area under the curve is the functional history of the target population. The unit of measure is function-years of the mean of the population. In a similar manner, one could plot the variance of the population as a function of time.

The above computations are done twice: first using the prognoses with-
out the program, secondly using prognoses with program intervention, with results, hopefully perhaps, as shown in Fig. 9.

We can now define the output of the program more precisely, as the area between the two curves, multiplied by the magnitude of the target population at time $T_0$; i.e.,

$$O = N(C_w - C_o),$$

where $O$ = the output of the program, $C_o$ = the area under the curve without program, $C_w$ = the area under the curve with program, and $N$ = the size of target population at time $T_0$. Then the effectiveness is given by

$$E = (C_w - C_o)/(T_s - C_o).$$

In Appendix A we have devised an illustration of the calculations involved, under the assumption that a stationary Markov process prevails.

In developing a measure of health-system output, the prognoses used had the appearance of forecasts. Actually, these are estimates based on statistical data and various health reports that have been gathered. This procedure is standard in the planning process, and represents no novel departure. It is also of interest to note that this method is applicable to programs that have been in operation for some time. The records would be our source for 'with-program' data. But estimates must still be made of 'without-program' data, in order to calculate program output.

Fig. 9. Functional history of the population mean with and without a program. Output/person = area between curves $C_w$ and $C_o$.

Output as a Stochastic Process

The definition of output that we have devised, as measured in function-years, or dysfunction-free-years, is based on a target population defined at time $T_0$. This is somewhat analogous to the economists' present-worth calculation, although the analogy is not strong, since discount rate has no meaning in terms of function/dysfunction. In reality, for most subsystems
of the health services, whether they be health programs or institutions, the
target population is not a fixed number. Rather, people enter the program
in a random fashion over time, while, similarly, others leave. This is to
say that the target population is a stochastic process \( N(t) \), which makes the
problem much more complex, and much research remains to be done. As
a step in this direction, we could define the people entering the program
during a specified time period, say one year, as a cohort. For this cohort, we
could compute the output precisely as described above. Then this output,
as a function of time, is reported annually, as illustrated, together with cost
and cost/output, in Fig. 10. The estimates of output are readily updated
as the actual functional histories of patients are compared with earlier
estimates.

We know that changes in the health status of the population depend,

\[
\begin{align*}
\text{Annual Target Population (N)} \\
\text{Annual Output (O)} \\
\text{Annual Output / Person (O/N)} \\
\text{Annual Cost (C)} \\
\text{Annual Cost/Output (C/O)}
\end{align*}
\]

Fig. 10. Illustration of output and other parameters as functions of time.

not only on the workings of the health services, but also on other socio-
economic factors, as well as ecological conditions generally. The correla-
tion between various causes and effects, where effects here are operationally
defined as outputs, becomes conceptually analyzable, albeit a large-scale
effort. This, however, is the kind of social reporting that is urgently re-
quired.\textsuperscript{[20]} We consider this discussion as a preliminary toward this task.

7. DECISION THEORY IN PROGRAM PLANNING

Health policy makers face the problem of constructing priorities among
the various health programs under consideration. They must decide what
importance they attach to each alternative in order to achieve their objec-
tives, including obtaining maximum improvement in the health status of a
growing population. The decision is a complex one, and involves, for each
program, not only an estimate of the output, but also an estimate of the
likelihood of success, the degree of relevancy, public acceptance, the ‘pres-
ent worth' of future benefits, manpower constraints, and many other factors. We have not attempted such a full analysis here. But one of the values of measuring health status in function-time is that it becomes possible to utilize it in decision theory, which provides a framework for aggregating these factors quantitatively.

Decision theory as a formal discipline is an area of active research. The basic decision model contains these variables: $S =$ states of nature, a row vector; $P =$ probability distribution for the states of nature; $A =$ alternative decisions, or policies; and $U =$ utility matrix; $u_{ij} =$ utility of outcome for $A_i$, given $S_j$.

The states of nature describe the environment that is not controllable by the decision maker, but affects the selection of alternative policies, and hence the outcomes. The environment includes not only physical, but social conditions, such as the budget level, demands for community control, influx of migrants with special diseases, etc. The alternatives include program mixes (each program requiring its own detailed description of resource needs).

The criteria for health-services outcome developed earlier can serve as the utility function for the decision theory model. The alternative $A^*$ is to be chosen that maximizes the expected value of outcome over all states of nature.

The decision model is useful because it makes visible in a precise way the factors that affect decision making. Unquestionably the demands that it makes on the decision maker to quantify his judgments are difficult to realize. If approximations can be made so that the model can be realized, then better decisions will be made, for the model brings clarity to a com-

"Fig. 11. The decision model."
plex situation by bringing into focus the pertinent factors. Much remains to be done in this area.

Special Decision Situations

Some situations are simple special cases of the above. Thus, if only one state of nature obtains, the matrix \( U \) reduces to a single column.

Budgetary considerations play a major role in most decisionmaking situations. It is useful, therefore, to consider the case where the states of nature are fixed, but the budget level is variable. Put another way, for any defined region (nation, state, or district), there is an allocation of resources (men, machines, materials, and money) that we describe as an input to the health system. Using dollar value as a common scale for all the resources, we can speak of the input cost to the system. The level of the cost may be fixed by budgetary considerations, or by a constraint such as scarce medical manpower. But for any selected level of input cost, we can ask the following question: What is the best distribution of the cost among the various programs so as to maximize the total output of the system? Under such a scheme, each program administrator would be motivated to operate his enterprise as efficiently as possible, so as to achieve the best figure of merit, the output/cost ratio, \( O/C \). Of course, in general, these figures of merit will vary from program to program.

If it were true that \( O/C \) is constant for all costs and all programs, then the answer to the question would be simple: ‘load’ all programs to their maximum input, in order of priority, as established by the figures of merit, until the selected level of input cost has been allocated. The calculations can be repeated for a whole range of selected levels of inputs. For each level, there is a corresponding output as defined previously. Good judgment may dictate that no health program be abandoned, that there is a minimum level for all programs. Then, in this case, all programs are loaded to their minimum level, and the above computations are done on an incremental basis, i.e., the difference between the selected level and the minimum requirements is distributed in the manner described above.

A more interesting case to consider, because it is more realistic, is the case where the figure of merit, \( O/C \), changes with input cost and program, usually decreasing (diminishing returns). Then it can be shown that the best allocation of input costs is such that for each program and its corresponding input cost, \( \frac{\partial O_i}{\partial C_i} = \mu \), is the same for all programs (see Appendix B).

8. A TUBERCULOSIS-PROGRAM ANALYSIS

We attempted a modest test of the validity of the concepts and methods proposed here; that is, we sought, in a real setting, to test whether the
method proposed "measures what it purports to measure" (reference 24, page 198). In choosing tuberculosis (TB) for analysis, we had in mind the availability of data. TB is a disease that has a long history of investigation by public-health professionals; and, by law, an up-to-date registry of cases is kept. While its characteristics were more complex than anticipated, it served to test the intuitive appeal of the proposed method.

To give the 'flavor' of the setting of the problem, we describe the scene as follows:

The population of a county in the state of New York is given as 1.1 million. The prime geographical area for TB is a slum and low-income area, 3 sq mi of one city. The city has a population of 0.5 million; the population of the prime area is 120,000. The rate in this prime area is 105/100,000 as compared to 12.3/100,000 in the remainder of the county. The TB problems in the prime area are complicated by low education, poor housing, and other disease conditions. For example, the syphilis rate here is 40/100,000 whereas it is 0.1/100,000 in the rest of the county. The gonorrhea rate is at the alarming figure of 1380/100,000, but low everywhere else. This data is for the year 1968.

The program has three main aspects: case-finding, then supervision and treatment of TB-active and inactive patients. Since TB is a communicable disease, the health services actively search out the patient. The purpose of testing is to find cases not entering the program otherwise. Thus case-finding is seen as a subprogram. The most effective case-finding method is a separate question, and will not be dealt with here.

We focused our attention on a section of the program that interested the county TB control director, called the "Child-Centered Tuberculin Testing Program." This section of TB control tests large numbers of school children, teachers, and other adults. The rationale for the program is to detect cases in their primary stage, and, by prophylactic treatment with isoniazid (INH), to prevent the development of active disease. However, this program, which absorbs as much as 20 per cent of the budget, has a low yield in terms of the number of TB cases found as a percentage of those tested, as shown by the data in Table III. For large-scale screening the Heaf test is used. This is a surface skin test, and based upon the configuration of the skin reaction, the registered nurse classifies them on a scale. Those on the doubtful end of the scale are retested with the Mantoux test, an intradermal test, for confirmation. All of the "positive" cases in Table III were confirmed as being TB infected, i.e., having a confirmed positive reaction. However, this is not the same as having TB disease (only about one in 20 infected persons eventually develops the disease). These positive reactors were further tested to find those with active TB disease, using X-rays and sputum tests as required. Four primary
active TB cases were found among the pupils, but none among the personnel.

For the purposes of prognosis, the various forms of the disease (Z) were classified as follows:

\[ Z_1 = \text{Primary inactive (positive reactor).} \]
\[ Z_2 = \text{Primary active.} \]
\[ Z_3 = \text{Pulmonary minimal.} \]
\[ Z_4 = \text{Pulmonary moderate.} \]
\[ Z_5 = \text{Pulmonary far advanced.} \]
\[ Z_6 = \text{Extrapulmonary.} \]
\[ Z_7 = \text{Primary inactive, with complicating factors.} \]

All the positive reactors are considered for drug treatment. The regime recommended depends on age, the form of the disease, existence of other complicating factors such as diabetes, etc. The 271 pupils and 35 school personnel who were put on drugs can be classified as shown in Table IV. While 858 personnel had inactive TB, only those were selected for

<table>
<thead>
<tr>
<th>TABLE III</th>
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<tbody>
<tr>
<td><strong>Tuberculosis Test Results</strong></td>
</tr>
<tr>
<td>No. of schools</td>
</tr>
<tr>
<td>----------------</td>
</tr>
<tr>
<td>Pupils tested</td>
</tr>
<tr>
<td>Personnel tested</td>
</tr>
<tr>
<td>Totals</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>TABLE IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pupils and School Personnel Put on Drugs Following the TB Tests</strong></td>
</tr>
</tbody>
</table>

**Pupils**

<table>
<thead>
<tr>
<th>Age 0-4</th>
<th>Age 5-14</th>
<th>Age 15-24</th>
</tr>
</thead>
<tbody>
<tr>
<td>Z=1</td>
<td>Z=2</td>
<td>Z=1</td>
</tr>
<tr>
<td>Ghetto</td>
<td></td>
<td></td>
</tr>
<tr>
<td>33</td>
<td>—</td>
<td>53</td>
</tr>
<tr>
<td>Nonghetto</td>
<td>—</td>
<td>35</td>
</tr>
</tbody>
</table>

**School personnel**

<table>
<thead>
<tr>
<th>Age 25-44</th>
<th>Age 45-64</th>
<th>Age 65-74</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of cases</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>9</td>
<td>3</td>
</tr>
</tbody>
</table>
drug treatment who had complicating factors (Z7). Not all the pupils were on drug treatment because of uncooperative parents, poor follow-up, etc. The statistics have been consolidated to display only the demographic characteristics needed for subsequent prognosis.

In terms of our method then, we put the question this way: If the impact of the school testing program is to give to the target population a certain amount of dysfunction-free time (DFT), how much of it would be lost by eliminating the school testing program? It was assumed that if the population became disabled later in life, they would be picked up by the health services, either by private physicians or clinics, in a worse state of dysfunction. In addition, it was assumed that the personnel released by the budget cut, particularly the public health nurses, are in demand for other health services (such as control of venereal diseases).

The pupils and school personnel tested by the school program constitute a cohort, processed through the TB control service. They are described as the number of people in each demographic-disease ‘cell,’ i.e., by the age bracket that they are in, their race and sex, the environment that they live in, and the form of the disease that they have. An additional parameter is the state of dysfunction that the members are in at the time that they enter the service for treatment. This is illustrated in Fig. 12. This information is required for the medical professional to be able to make a prognosis of the dysfunction history of the subcohort, i.e., the members of the cell, with and without treatment. For this study, the medical professionals made an estimate of the distribution of the population among five states of dysfunction, namely, asymptomatic (Sa), minor disability (Sd), ambulatory (Sb), confined (Sw), and death (Sd).

For a cell subcohort, with a specified state of dysfunction, the medical professional describes their dysfunction history, with and without treatment, and therefore the impact of the service on their history. Since the rationale for the service is that it improves the life pattern of the people served, it becomes necessary to forecast, or estimate, the future experience of the population. These estimates come from the accumulated experience of the director and his staff, the data available on the patients, as well as the extensive literature published on the subject. These prognoses, with and without treatment, as an estimated measure of the impact of the service, we call prognosis modules. Since we do this for each cell and state, we obtain a ‘library’ of these modules, for each of which we compute the dysfunction-free-years (DFY) contributed by the services. A typical prognosis module is shown in Fig. 13. We had 12 such modules.

From the library of prognosis modules we can compute the total DFY given to the cohort by the service as simply the sum of the DFY for each module, weighted by the number of people actually ‘passing through’ each module.
The computations were quite lengthy and will not be duplicated here for lack of space, since our focus is primarily on methodology. Admittedly, the ramifications of TB control are much wider than we describe here (epidemiologists have written extensively on the subject). But the fact remains that communication was possible with the medical professionals involved in the problem, so that their disease-oriented language could be translated into

\begin{itemize}
  \item \textbf{Cohort} = \text{N (ARXEZ)}
  \item \textbf{Age Bracket} (7)
  \item \textbf{Race} (2)
  \item \textbf{Sex} (2)
  \item \textbf{Environment} (3)
  \item \textbf{Disease Form-Z} (7)
  \item \textbf{State} (5)
\end{itemize}

\textbf{DFT} = \text{Dysfunction-Free Years}

\textbf{Fig. 12.} The prognosis module. Each module has a code \((A, R, X, E, Z)\).
our functional language. Furthermore, while the functional transitions could not be described as a Markov process, computations could still be made. We concluded that the DFY attributable to the "Child-Centered Tuberculin Testing Program" was quite small. In fact, while the patients

![Diagram](image)

**Fig. 13. A prognosis module: Z1, all environments, (15-24).**

were on the drug regime their functional state was lowered because of restrictions in daily activities. Under the given conditions, this reduced the attractiveness of the program still further. What with the demand elsewhere for skilled personnel, particularly the registered nurses, serious consideration was given to dropping the program.
9. CONCLUSIONS

We have attempted to show how a health-status index (HSI) can be used as a basis for quantifying the output of health services. Needless to say, no claim is being made that this measure is the measure; or even that only the indicators that are quantifiable are worthy of consideration. What is claimed is that by quantifying certain attributes or qualities, such as usual daily activities, more precise descriptions can be made, available mathematical techniques can be applied for purposes of verification, prediction, and explanation, and that this is useful for rational decision-making.

While we have attempted to demonstrate the limitations inherent in economic criteria for health planning, this does not mean that economic considerations are unimportant. The very term cost/effectiveness demonstrates this. In this connection, we would suggest for consideration a re-orientation of cost/benefit analyses. It is this: if economic analysis looks at the health system with an input from the economic system called cost, and an output back to the economic system from the health system called benefit, then the ‘charge’ (called cost in cost/effectiveness) to the health system should be cost minus benefit (theoretically, benefit could be greater than cost).

Underlying effectiveness is the concept of function/dysfunction that has been used as the ‘coin of the realm’ to find a common language for the various aspects of the delivery of health services. By extrapolation, one could search for a metalinguage that would compare the value of health with education and other social services in the competition for the allocation of scarce resources.

This study raises many basic questions calling for further research:

(a) The concept of a Health Status Index is central to the study. It requires careful examination by health and other administrators to see if it has intuitive appeal, based on their experience.

(b) The study tested a small section of a TB-control program. Clearly, further testing is called for on the whole range of prevention and medical care, to see if the concepts and methods are truly valid and reliable. This involves the translation of disease-oriented language to the function-oriented language described here.

(c) The data-gathering processes have to be examined and their results compiled in the light of the concepts and methods proposed here. This includes a linkage with other analyses, such as economic studies of health problems.

(d) Finally, there is the problem of correlating the health status of the population with socioeconomic and other environmental factors for the purpose of social reporting and planning for future needs, such as manpower
and physical facilities. This involves the problems of coordination with other social planners.

Comprehensive health planning has such broad implications that a study such as this can only be considered as a preliminary step in the direction of formulating the many complex problems that such planning involves. From our work it becomes clear that one of the important areas of research that must be investigated is the development of a meaningful systems model of health services in a pluralistic society, one that recognizes that there are multiple decision-making centers, with their own definitions of objectives, and loosely coupled together. A model that could show the relations in a quantitative way would center attention on the focal points, where, if pressure were properly applied, the system would move in the direction of the goals set by the planners. Such a model is difficult to construct. However, the sciences of cybernetics and general systems theory, and mathematical tools—such as the theory of stochastic processes, backed up by computer technology—give hope that meaningful progress can be made in this direction. The model could help visualize many types of interactions in the health system, primarily flows between agencies, programs, and institutions, whether of patients, manpower (doctors, nurses, etc.) material (drugs, supplies, equipment), or money—all as functions of time. Others are currently working on various aspects of such models.

APPENDIX A

SIMULATION OF A HEALTH PROGRAM

The purpose of this appendix is to illustrate the application of the mathematical model under idealized conditions, namely that the prognosis can be represented by a stationary Markov transitional-probability matrix, as an aid to visualize the concepts of output and effectiveness.

The following list gives the assumed input data and formulas used for the simulation:

1. The target population at time 0 is 1000, uniformly distributed from state $S_1$ (dissatisfaction) to $S_{10}$ (death). Since 100 died, 900 are candidates for a health program.

2. The 900 candidates are also uniformly distributed among the following 10 ages: 0 (infant), 5, 10, 15, ..., 45 yr. Each age group forms a cohort, and are carried in the calculation for the duration of their expected life span (ELS).

3. The 'standard life' is 90 years.

4. For each age, $ELS = 90 - age$. In the program, if a cohort dies before ELS, they are carried at $D = 1$ for the remainder of the ELS, and then dropped from the program calculation.

5. The prognosis for any cohort, at any time, depends upon: (a) whether the health program is or is not in operation; (b) what age bracket the cohort is in (in
the calculations at each year the age of the cohort is increased by 1); (c) the state $S_t$ that the member of the cohort is in at time $T_L$. For each age bracket there are two transitional probability matrices, one for 'with program,' the other for 'without program.' There are, altogether, 12 such matrices, each $10 \times 10$, or 1200 transitional probabilities. These were simulated on the basis of intuitive appeal and consistency. Space does not permit reproducing these numbers.

![Diagram](image)

**Fig. 14.** Estimated output and effectiveness of a simulated health program measured in dysfunction-free years.

6. There are 6 age brackets: (0–4), (5–14), (15–24), (25–44), (45–64), and (65–90).

7. The standard deviation, SD, is equal to $\sqrt{V}$. The computations are halted where SD $\leq 0.01$, with or without program. The 10 values of $D$ are: 0/0.00391/0.0156/0.0312/0.0624/0.125/0.500/0.670/1/1 (see Table II).
8. The output of the health program is given by $O = N(C_w - C_a)$. (See section 6.)

The results are presented in Fig. 14, and Fig. 15 shows the computer flow chart by which they were produced.

![Flow Chart](image)

**Fig. 15. Simulated health-program flow chart.**

**APPENDIX B**

**Optimum Program Mix for Different Inputs**

In a fixed environment, the health administrator operates a number of health programs. The output for each program, as defined in section 6, depends on the
allocation of resources to each program, defined as an input measured in dollars. The output is a continuous function of the input cost, a known function. For any given level of total resources available, what is the best allocation of resources among the programs so as to maximize the total output of all the programs?

Let \( O_i \) = the dysfunction-free-days (or years) achieved by program \( i \), \( C_i \) = the input cost of program \( i \), \( O = \sum_i O_i \) = dysfunction-free days achieved by all the programs, and \( C = \sum_i C_i \) = selected level of input.

We wish to maximize \( O \) for a given value of \( C \). Now \( O_i = f_i(C_i) \); i.e., \( O_i \) is a function of \( C_i \). Therefore \( O = \sum_i f_i(C_i) \). Using the Lagrange multiplier \( \mu \), we form the function \( L = \sum_i f_i(C_i) - \mu(\sum_i C_i - C) \). Then for an extremum (maximum or minimum), \( \partial L / \partial C_i = 0 = \partial f_i / \partial C_i - \mu \), for all values of \( i \). Therefore, \( \mu = \partial f_i / \partial C_i \), for all \( i \), as was to be shown.

**Fig. 16.** Output and rate of change of output as a function of cost.

In Fig. 16, the curve of \( O_i \) as a function of \( C_i \) is given data. The slope of the curve, \( \partial O_i / \partial C_i \), can thus be obtained and plotted as a function of \( C_i \). The efficient way to proceed with the computations is as follows: Select a value of \( \mu \), the Lagrange multiplier, equal to \( \partial O_i / \partial C_i \), for all \( i \). From the graphs, it is clear that this determines the value of \( C_i \) and \( O_i \), for all \( i \). Therefore \( O = \sum_i O_i \), the total output in dysfunction-free days, and \( C = \sum_i C_i \), the selected level of input, are determined. Thus the selection of different values of \( \mu \) determines a whole range of input costs. If, as indicated previously, there are minimum levels of operation of programs, this acts as a constraint. As long as the solution to the problem does not 'bump up' against a constraint, the above method from the classical calculus is valid. If the constraints must be considered, then the classical method fails, and one must resort to one of the modern mathematical techniques that in the litera-
ture goes under the heading of 'mathematical programming' (which includes linear and nonlinear programming). [17, 25]

ACKNOWLEDGMENT

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