SOCIAL INDICATORS FOR HEALTH BASED ON FUNCTION STATUS AND PROGNOSIS

J. W. Bush, M.D., M.P.H.
Milton M. Chen, Ph.D.
Donald L. Patrick, Ph.D.

1.0 INTRODUCTION

Widespread interest in social indicators has focussed attention and effort on various proposals for a general indicator of health status [Sanders, 1964; Chiang, 1965; Division of Indian Health, 1966; Sullivan, 1971; Gitter and Mostofsky, 1972]. Difficulties in developing such an indicator have led to several series of criteria for an ideal index, but many of the criteria overlap and conflict depending on the use conceived [Sullivan, 1966; Moriyama, 1968; WHO, 1971; Bush, et. al., 1972]; Goldsmith, 1972.

In our efforts to develop rational health planning models, we also recognized the need for a health index, but we have not previously offered a precise formulation of our model as a community-wide health indicator [Fanshel and Bush, 1970; Chen and Bush, 1971]. The purpose of this paper is to propose two indices, derived from a central concept of health, that we consider necessary to describe different aspects of community-wide health status.

Before presenting our two indices, we would like to review briefly some of the criteria and models that have been proposed. The strengths and weaknesses of the proposals can then be seen in sharper perspective.

1. The indicator should be of direct normative interest. Although this criterion has been criticized from different points of view [Sheldon, 1970; Land, 1972], we believe that the indicator should have a welfare orientation. This requires an implicit or explicit value component so that if the indicator improves, all other things being equal, society can be considered better off. Where only one number (indicator) is involved (mortality rate, bed-disability days, disease incidence rates), the value problem is rarely critical. But a complex social construct like health must certainly be represented by a weighted combination of many indicators, so that the weighting or social value problem becomes crucial. Most previous efforts to construct health indicators have tried to circumvent the value problem, and we believe that type of effort has led to many unsatisfying results.

2. The weighted index should be useful for priority setting, planning, and evaluation. Since the major point in collecting social statistics is to assist in policy-making, the index should be adaptable for social optimization. We should construct a health indicator in such a way that not only the direction but also the magnitude of the change in the indicator value is significant. With other relevant information on the component of the indicator responsible for the change, or estimates of the probable effect of some policy, the health indicator can then be used for priority setting and program planning.

We agree with Land [1972] that we should strive for indicators that fit meaningfully into larger social system models [Orcutt, 1960, 1970; Isard, 1969]. Within such models, even data that is not directly normative takes on meaning because it has a specified relation to other elements of the model. In health, this would be particularly helpful, since our abundant activity and utilization data can be given little normative interpretation without a larger model of health outcomes.

Adaptability for social optimization raises acutely the problem of constructing a social welfare function [Arrow, 1963; DeMeyer and Plott, 1971]. But refusing to construct a normative index does not make the problem disappear. It may be possible in the health field to mitigate some of the serious and thorny theoretical problems by the very process of index construction [Whitmore, 1972].

3. The indicator should permit study of the probable effects of different social policies. Admittedly the structural links between policies and indicators would be less developed in health than in economics, and the data to establish causal relations may be difficult to obtain, but the difficulty should not be overemphasized. If the links could be postulated theoretically, then they could be studied empirically--an almost inviolable methodological sequence in the cumulative sciences. Sheldon and Freeman's conclusion [1970:99] that it is impossible to use social indicators for setting priorities and developing a social balance sheet is probably overdrawn.

This does not mean that the health indicator should reflect policy directly or even be sensitive to a single change in policy. But the relation between the policy and the indicator should be specifiable, and the change (or lack of it) should be amenable to investigation.

Although we raise adaptability for social optimization as a desirable criterion for a health status index, here we will not discuss planning primarily, but will focus on methods for constructing objective health indices for time series and cross-sectional comparisons of total populations.

4. The health indicator should be useful for evaluative research. Although comparison of the health status of a given group over time is of great interest, comparison among different groups or subgroups at a given point in time gives important information for the public decision-making

process. Only rarely can a community-wide indicator give any indication of the impact of a policy change, but the follow-up of "treated" population subgroups in conjunction with control communities provides some evidence of causal relations [Campbell, 1969]. Such use of a social indicator for evaluative research is already in effect using our Index [Lawrence County Project, 1972].

5. The health indicator should be sufficiently sensitive to detect most of the significant changes in health status. The mortality rate and life expectancy are no longer adequate as indicators of health in western societies. A classification of multiple states of health must be developed that is refined enough to realistically reflect the array of conditions that afflict human populations, but it must be simple enough that data can be collected reliably without complex medical evaluation.

Furthermore, the set of weights reflecting the relative well-being of each of the states should not depend solely on criteria of economic productivity. Although the capacity to transform the Index values (or the underlying data) to economic criteria is desirable, earning capacity in itself is almost a dichotomous (work/no work) measure, and if systematically applied, would discriminate against many low or non-wage earning groups. It may be better to avoid the criterion at the outset than to try to retrench later from the socially unacceptable policy implications.

6. A community-wide health indicator should consist of "clearly defined component parts and each part should make an independent contribution to variations in the phenomenon being measured" [Moriyama, 1968:593]. A simple relation between the aggregated indicator and its parts will indicate what caused the change in the aggregate by locating the change in one of the component indicators. Component indicators may consist of the usual demographic subgroups, political jurisdictions (state, regional, local), or populations defined by other criteria.

7. An indicator of health should be derived from observable data and be easily reproduced. Ideally, the index should require no expensive new venture in data collection, but this case too should not be overstated. A social indicator for health that is intuitively acceptable and that satisfies the criteria outlined above would justify a significant new data collection effort. It may be possible to implement our suggestions without a drastic overhaul of current systems.

There may be other important criteria; this list is far from complete. Since few indicators will satisfy all the criteria, they must be judged as compromises among the different desirable properties. We will now compare several proposed indices with the above criteria.

Although Sanders [1964] discussed "effective life years", he did not make a concrete proposal for measuring community health levels. Operationally, his definitions lead to an economically productive man years index which is difficult to accept because of its insensitivity and the value judgements involved. Although computable from the life table, he did not propose a link to policy formulation.

Chiang [1965] proposed an index computed by the following formula:

$$H_x = 1 - \overline{N}_x \overline{T}_x - 1/2m_x \text{ where}$$

H_x = mean duration or average fraction of the year the individual is "healthy" in age group x

$\overline{N}_x$ = the average number of illnesses per person in [age group] x

$\overline{T}_x$ = the average duration of an illness for x

m_x = the age-specific death rate for the year.

The index can be computed from available data, but it is insensitive, since the single state of illness defined covers the entire range of illness conditions. Furthermore, death is weighted as equivalent to illness, a socially unacceptable value judgement. Finally, no method is defined for relating the index to policy decisions.

Although the Indian Health Service [1966] and the Pan American Health Organization [Ahumada, 1965] developed formulae for computing program priorities, their indices include terms related to reference populations or expert judgements of vulnerability, and are not well adapted to serve as direct indicators of health status in comparative and time series analysis.

The most intriguing recent proposal is Sullivan's "single index of morbidity and mortality", which is based on the concepts of "expectation of life free of disability" and "expectation of disability" [1971]. To compute the expectation of life free of disability, the conventional ${}_nL_x$ in the life table is weighted by a disability factor $I_x = 1 - \frac{W_x}{365}$ to obtain ${}_nL^*_x$ where W_x = number of days of disability per person per year in the interval beginning at age x. W_x is derived from health interview and institutional surveys. Values of T^*_x are computed in the same manner as the conventional life table. The resulting expectation of life free of disability, $\mathring{e}^*_x$, gives an appropriate index of health. The expectation of life free of disability for civilian white males for the U.S. in the mid-1960's was 62.5 years, and the expectation of disability was 5.3 years.

The model as proposed has several advantages: (1) it corresponds closely to a comprehensive quantification of the social construct of health; (2) it is related directly to hard, available data; (3) it bypasses many difficult value questions; (4) it could be augmented without major changes, and (5) it could be related indirectly to policy choices. We shall discuss the shortcomings of this index as well as its special meaning after presenting our own model.

2.0 HEALTH AND FUNCTION STATUS

2.1 Operational Definition of Health

Inherent in the social construct called "health" are two dimensions: (1) function level, an individual's level of function at a point in time, and (2) prognosis, his expected transitions to other levels, more or less favorable, at future times

(Fig. 1). For measurement purposes, these two dimensions require separate specification.

Function status is the primary value dimension of health. Optimum function is defined as conformity to society's standards of physical and mental well-being, including performance of the activities usual for a person's age and social role. As defined here, disturbances in function are not only social, but also include pain, and other physical and mental symptoms that are considered deviations from norms of well-being, even when there is no interference with social role performance. Such deviations from societal standards of well-being are value judgements. Standards of well-being can be defined and deviations can be classified into a series of function levels ranging from complete well-being through various levels of dysfunction to death. Social values can be measured for these function levels to produce a scale of well-being with a unit from 0 for death to 1 for complete well-being.

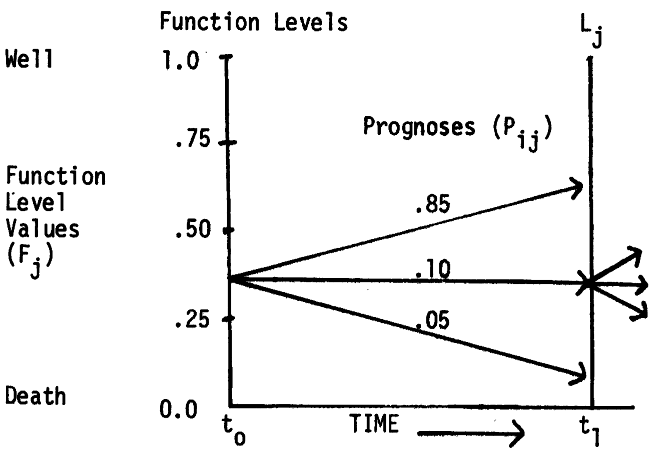

Figure 1. Function levels (L_j) represent states on the continuum from well-being to death. Function level values (F_j) are the social preferences representing the relative value of the levels between 0.0 and 1.0. Prognoses (P_{ij}) are the transitional probabilities for movement among the function levels over time.

Health status, on the other hand, is a composite of an individual's level of well-being at a point in time and his expected transition to other levels, more or less favorable, at future times. This view sharly distinguishes between the desirability of the immediate level of function and the probability of being in other levels as they change over time. These two dimensions, labelled function level and prognosis, have traditionally been confused in discussions of health and illness; both are necessary to describe the health status of an individual or population.

Treating the two variables as analytically distinct allows them to be quantified separately and to vary independently for different populations. Health status can then be described as a joint function of the two variables. Precisely stated, health status is the product (expected value) of the social preferences assigned to levels of function and the probabilities of transition among the levels over the remaining life of an individual

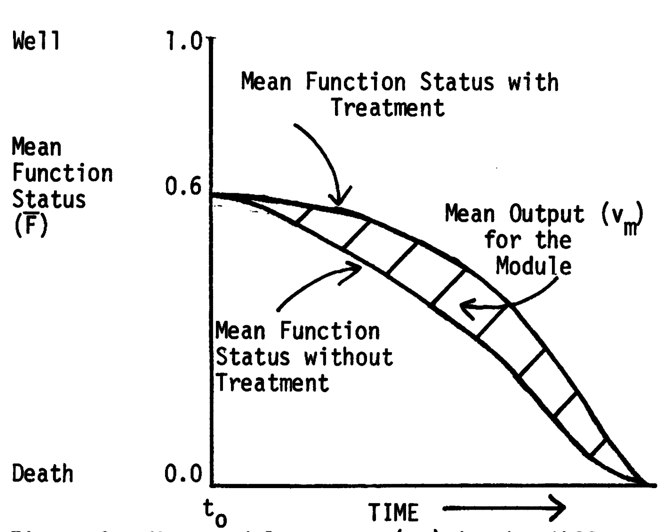

Figure 2. Mean module output (v_m) is the difference (ΔQ) between the quality adjusted life expectancy of the cohort with and without treatment.

or group. Conceptually, health status may be expressed as follows:

$$H = \frac{\Sigma F_j Y_j}{\Sigma Y_j} \quad \text{where}$$

H = health status of an individual or group

F_j = level of well-being (value, preference) that society assigns to function level j

j = index for function levels = 0, 1, 2, ..., 30

$Y_j = \sum_{t=1}^{k} \pi_{j,t}$ = total expected duration in function level j over all time periods

$\pi_{j,t}$ = proportion of time spent in level j between time periods t-1 and t, derived from the product (expected value) of the distributions and transition matrices for each time period

t = index of time periods = 0, 1, ..., k where k is the last time interval.

Given methods for incorporating various attributes of function, for measuring their values, and for incorporating the prognoses, we believe this formulation realistically incorporates the critical features of what society means by health [Patrick, et. al., 1972a]. From this conceptual definition, we shall derive formulae for quantifying the function and health status of a community that can be made operational with current data collection and value measurement techniques.

2.2 Operational Definition of Function Levels and Value Measurement

Using items from the Health Interview Survey of the National Center for Health Statistics, the Survey of the Disabled of the Social Security Administration, and several rehabilitation scales and ongoing community health surveys, we constructed three scales with mutually exclusive and collectively exhaustive steps to describe function status (Table 1). These different scales largely cover the spectrum of objective disturbances that diseases and disabilities can cause in role performance. Changes in these factors can occur not only because of physical disabilities, but also because of symptoms, sensory disturbances, mental retardation, and mental illness. These disturbances were summarized in an independent set of 42 symptom/problem complexes.

Combining different steps of the norms for social activity, mobility, and physical activity, and omitting rare or impossible combinations, 31 levels of function were created that can be used to describe the function status of an individual or

TABLE 1. SCALES AND DEFINITIONS FOR THE CLASSIFICATION OF FUNCTION LEVELS*

	SOCIAL ACTIVITY
A	Performed major and other activities
B	Performed major activity but limited in other activities
C	Performed major activity with limitations
D	Did not perform major activity but performed self-care activities
E	Required assistance with self-care activities
	MOBILITY SCALE
A	Travelled freely
B	Travelled with difficulty
C	In house
D	In hospital
E	In special unit
	PHYSICAL ACTIVITY SCALE
A	Walked freely
B	Walked with limitations
C	Moved independently in wheelchair
D	In bed or chair

*Definitions and sources of scale items available from the authors.

a population. Members of a population may fall in a particular level for a variety of reasons, all having in common the defining features of that level. A matrix bounded by the function levels, 5 age groups, and symptom/problem complexes generates a universe of function status descriptions, as follows:

Age 40-64.

Walked with limitations.

In hospital.

Did not perform major activity but performed self-care activities.

Had burn over large areas of face, body, or extremities.

Using a probability sample of such case descriptions to represent the function status universe, we have undertaken a series of studies to find optimum methods for measuring the social values or preferences associated with the function levels. Examples were derived from the rating of the 400 case descriptions by 62 graduate students and nurses using the method of equal-appearing intervals.

We have also compared the validity and reliability of category rating, magnitude estimation, and equivalence across different orders of method presentation, across individual and group testing situations, and across students and health leaders [Patrick, et. al., 1972b]. The results of the study indicate the feasibility of measuring levels of well-being that constitute a unidimensional, equal-interval preference continuum. The invariance of the values assigned to the function status conditions across the different judge groups provides evidence for the validity and reliability of the measurement methods. Along with this study, progress in the development of social value measurement techniques generally [Coombs, 1964; Stevens, 1966; Sellin and Wolfgang, 1964; Bock and Jones, 1968; Anderson, 1972] indicates that the previously immeasurable value dimension of health may be integrated into an empirically verifiable social indicator.

2.3 Function Status Index

Given a valid set of social values and the distribution of the population among the set of function levels from appropriate surveys, the distribution can be weighted by the values to summarize the function status of the population at a point in time in the Function Status Index.

Algebraically, the Function Status Index ($\overline{F}$) is expressed as:

$$\overline{F} = \frac{\sum_j N_j F_j}{N} \quad \text{where } 0 \le F \le 1 \text{ and}$$

N = total number of persons in a population

N_j = number of persons in function level j

F_j = weight or social preference for function level j

j = index for the function level = 0, 1, 2, ..., 30.

Table 2 illustrates a simple calculation of the function status index for a population at a given point in time.

If every member of the population were at the level of optimum function, then the function status index for the population would be 1.000.

Data from health surveys can be used to determine the function level distribution of a population. Then the FSI, an index that integrates prevalence data on disability levels of different social values, would have several advantages: (1) it gives a concise summary of the current level of physical and mental well-being in a community; (2) it is sensitive since multiple function levels are defined; (3) the data is observable and can be easily reproduced without spefial medical knowledge or memory; (4) each respondent is classified into one and only one level between death and well-being; (5) longitudinal studies of the same population can be used to construct time series; (6) different populations can be compared cross-sectionally (7) the Index can be disaggregated into component parts by subdividing the population to study different distributions, causes of dysfunction, or possibilities for intervention; (8) it can be related to respondent reportable causes of dysfunction (arthritis, shortness of breath, etc.) and to medical diagnosis by auxilary surveys; (9) mechanisms already exist in the National Health Survey for new data collection; and (10) treatment and control groups can be monitored over time with the FSI in evaluative research studies to determine if changes in function status are attributable to the program.

TABLE 2. ILLUSTRATIVE DISTRIBUTION OF PERSONS AMONG DIFFERENT FUNCTION LEVELS AND COMPUTATION OF THE FUNCTION STATUS INDEX

Function Level (L_j)	Number of Persons (N_j)	Function Level Values (F_j)	(F_jN_j)	$\bar{F} = \frac{\Sigma F_jN_j}{N}$
30	95,000	1.00	95,000	
27	3,000	.69	2,070	$\bar{F}= \frac{98,070}{100,000}$
17	1,000	.59	590	$\bar{F}=$ .9807
10	700	.44	308	
2	300	.34	102	
Total	100,000(=N)		98,070(=ΣF_jN_j)	

While the FSI provides a more clear-cut outcome indicator for evaluative research and makes it possible to integrate data on different function levels, it does little to resolve the difficult problems of research design that remain essential for establishing causal relations. Clearly the level of the FSI as a social indicator is affected by many intervening variables, and these must be disentangled in the usual ways, primarily by decomposing the indicator to isolate the contributing factors to the change, by establishing global correlations with other indicators (such as income, crowding, or housing quality) over long periods of time with many different populations, and by performing specific studies to choose among competing hypotheses.

For all its advantages, the FSI is an incomplete indicator, since it does not include the prognoses inherent in our concept of health and may be misleading about the overall health status of the community. For example, an increase in the mortality from function levels with low values would cause the FSI of the remaining living population to rise; on the other hand, an increased probability of survival in the same low levels would cause the FSI to fall.

Even among the living population, existing changes in transition probabilities may not be reflected in the population distribution among the function levels and the FSI for many time periods, perhaps several decades. This delay in the response of the FSI, despite changes that have already occured, may obscure both the magnitude and the direction of the change in health status. Although Sullivan's index avoids the paradoxical influence of mortality (and we could so supplement the FSI), the lag problem, common to practically all social indicators, is inherent in his use of currently observed distribution vectors. For a realistic view of the health of the population, we require a more sensitive, comprehensive, and dynamic indicator, an indicator that detects the changes currently in process.

3.0 VALUE ADJUSTED LIFE EXPECTANCY

3.1 Prognosis and Function Level Expectancy

In addition to function status, the concept of health incorporates prognosis, or the expected movement from one level to other levels over subsequent time intervals. This movement can be described as a probabilistic process, where the transition probabilities are the prognoses. The mortality rate is the probability of moving to death from any higher level.

We have used the medical term "prognosis" since it connotes the health-related meaning of the transitions among the function levels and disease states. From the definition of health status above, it is not the momentary level of function, but the outlook for the future that primarily determines what medical specialists and the public mean by "health" status. Diseases are "serious" or "not serious" depending on the associated probability of severe impairment or death, sometimes without much regard for the immediate comfort of the patient.

Like the mortality rate, the transitions among the other function levels should be determined empirically by population monitoring. If the transitions occuring within the memory span obtained on a single interview are not adequate for the computations, then interviews of the same sample will be required on at least two occasions to obtain reliable data. A few questions added to panel studies such as those of the Current Population Survey, would be more than adequate to produce the data without substantial new effort. From such data, transition rates among all the function levels can be computed and integrated with the mortality rate for each age and demographic subgroup.

These prognoses determine the time to be spent in each function level, or the function level expectancy. Analogous to life expectancy, tables can be constructed for populations with given demographic characteristics (modules) to determine the life time expected duration in each of the function levels. Function level expectancy is nothing more than the distribution of the life expectancy among the various function levels. Also, like the current life table, or more properly, the mortality experience table, the function level expectancy is not a projection, but a convenient summary statistic of actual data that treats the current transitions as if they were persistent over the life of a synthetic cohort.

This strategy permits us to define a series of function level expectancies that, like the life table, are independent of the age structure of the population described and facilitates population comparisons. In the model of function level expectancy outlined here, population subgroups can be defined by any relevant demographic or disease characteristics for which data are available, including mental health.

We believe that the controversy over positive versus negative measures of health rests partly on the confusion between prognosis and level of function. For many years, some groups have argued that positive mental health is not simply the absence of disease or symptoms, but the possession of certain attributes associated with high function level expectancies, and that only a subset of the total population enjoys such "positive" health.

We believe that subgroups can be reliably defined that possess not only physical attributes, but also personality characteristics, that are associated with longer expectancies in high levels of function. Such population groups would indeed have a higher value-adjusted life expectancy as computed below. The terms "positive" and "negative" in which the controversy has been couched cannot be given mathematical specificity and should be superseded by the more precise and flexible terminology of prognoses, transition probabilities, and function level expectancies, where the function levels are defined to include the presence or absence of anxiety, depression, and other emotional disturbances.

Many concepts and methods developed in the life table are relevant in the construction of a function level expectancy table. Because of the multiple levels involved, however, the process is more complicated than the usual multiple decrement table, and resort to a refined stochastic model may be necessary. Essentially, the life table constitutes a synthesis of many Markov processes with a separate matrix applied to each age group.

We may define as many levels or states as we find useful and can reliably distinguish. As outlined previously, we now identify 30 levels, but these should be consolidated into a shorter list on the basis of further value studies. Since Markovian states will be defined by additional criteria in further computations, we shall regularly refer to this basic list as function "levels" rather than as states.

If we standardize the age intervals as, say, one year, and define each Markovian state by both age group and function level characteristics, we can construct a grand matrix that will encompass all the age specific transition matrices. As an illustration, we may specify four function levels: A = well, B = non-bed disability, C = bed disability, D = death. A person in age group 1 in disability level A will be denoted as A_1, etc. Thus formulated, transfers would occur only from one age group to the next age group. The transition matrix would appear as follows:

	A_1	B_1	C_1	D_1	A_2	B_2	C_2	D_2	. . .
A_1	0	0	0	0	X	X	X	X	. . .
B_1	0	0	0	0	X	X	X	X	. . .
C_1	0	0	0	0	X	X	X	X	. . .
D_1	0	0	0	0	0	0	0	1	. . .
A_2	0	0	0	0	0	0	0	0	. . .
B_2	0	0	0	0	0	0	0	0	. . .
C_2	0	0	0	0	0	0	0	0	. . .
D_2	0	0	0	0	0	0	0	0	. . .
.	.	.	.	.	.	.	.	.	. . .
.	.	.	.	.	.	.	.	.	. . .
.	.	.	.	.	.	.	.	.	. . .

X represents the transition probability with $0 \le X \le 1$. Persons remain identified in the death state by age permitting us to integrate morbidity with mortality. The process under this formulation becomes a Markov chain.

A realistic and sensitive index of health status requires that we determine the P_{ij}, i.e., the transition rates among all the Markov states jointly defined by function level and age group. We must ascertain where each respondent has transferred from, or follow him to determine where he transfers to, in order to complete each cell of the transition matrix. This matrix gives us knowledge of the process that is currently operating.

Moreover, the equilibrium distribution vector Y^*, that is expected from continued operation of the P_{ij}, gives a unique and superior indication of health status over single distribution vectors observed at arbitrary points in time. Even a drastic change in P_{ij} might not have its full effect for many time intervals, and we cannot know whether the observed distribution vector at a given point (as in Sullivan's model) represents the equilibrium distribution or not.

In fact, the observed vector might be quite different from Y^*, especially if the process is in its early phase of development. An indicator based on current distribution vectors is insensitive to changes that are already emerging under the operation of P_{ij}. The equilibrium distribution vector of the matrix P_{ij} is analogous to the stable population of the life table, since it points to the steady state of the process if the transition probabilities persist. But the matrix specified earlier does not have the properties required to produce the equilibrium distribution that can be interpreted as the expected duration of stay in each of the Markovian states.

To converge to an equilibrium vector when raised to successively higher powers, a stationary transition matrix must be irreducible and aperiodic [Hillier and Lieberman, 1968; Parzen, 1962]. A matrix is irreducible if and only if all states communicate with each other, i.e., any state can be reached from any other state. An irreducible chain may not converge to a unique equilibrium distribution unless at least one of the states in the system is aperiodic. An arbitrary state is said to have period s (s>1) if $P_{ij}^t = 0$ whenever t is not divisible by s and s is the smallest integer having this property. If a state can be entered only at time intervals 0, 2, 4, ..., then that state has a period of 2. On the other hand, if a state can be entered for two successive time intervals, then that state has a period of 1 and is aperiodic. If any state i in a set is aperiodic, then all states in the set will be aperiodic and the matrix derived from the set will be aperiodic [Bush, et. al., 1971].

To assure the irreducibility and the aperiodicity of the chain, we can artificially create a reservoir state (S_0) that is analogous to the assumption of a constantly renewed population in life table construction. If we assume a dummy entry rate from the reservoir state to the initial state A_0, and if, at the end of the last age interval, every member is transferred back to the reservoir state, then we can treat the problem of entry and exit under a closed system. In this way, all the states will communicate with a periodicity of 1. Since the reservoir state is a dummy device, it can be deleted from the equilibrium vector. The transition matrix would now appear as follows:

	S_0	A_0	A_1	B_1	C_1	D_1	A_2	B_2	C_2	D_2	. . .	A_{n-1}	B_{n-1}	C_{n-1}	D_{n-1}	D_n
S_0	X	X	0	0	0	0	0	0	0	0	. . .	0	0	0	0	0
A_0	0	0	X	X	X	X	0	0	0	0	. . .	0	0	0	0	0
A_1	0	0	0	0	0	0	X	X	X	X	. . .	0	0	0	0	0
B_1	0	0	0	0	0	0	X	X	X	X	. . .	0	0	0	0	0
C_1	0	0	0	0	0	0	X	X	X	X	. . .	0	0	0	0	0
D_1	0	0	0	0	0	0	0	0	0	1	. . .	0	0	0	0	0
A_2	0	0	0	0	0	0	0	0	0	0	. . .	0	0	0	0	0
B_2	0	0	0	0	0	0	0	0	0	0	. . .	0	0	0	0	0
C_2	0	0	0	0	0	0	0	0	0	0	. . .	0	0	0	0	0
D_2	0	0	0	0	0	0	0	0	0	0	. . .	0	0	0	0	0
.	.	.	.	.	.	.	.	.	.	.	. . .	.	.	.	.	.
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.	.	.	.	.	.	.	.	.	.	.	. . .	.	.	.	.	.
A_{n-1}	0	0	0	0	0	0	0	0	0	0	. . .	0	0	0	0	1
B_{n-1}	0	0	0	0	0	0	0	0	0	0	. . .	0	0	0	0	1
C_{n-1}	0	0	0	0	0	0	0	0	0	0	. . .	0	0	0	0	1
D_{n-1}	0	0	0	0	0	0	0	0	0	0	. . .	0	0	0	0	1
D_n	1	0	0	0	0	0	0	0	0	0	. . .	0	0	0	0	0

where

S_0 = reservoir state

A_0 = entry state of the system

n-1 = last age interval

As an illustration, we constructed a grand transition matrix from the mortality rate and hypothetical transition rates among the other levels. We computed the equilibrium distribution vector by raising the power of the matrix, deleted the dummy states S_0, A_0, and D_n, and aggregated the proportions for the function levels A, B, C, and D offer the age intervals to yield an equilibrium vector of $\pi^* = [\pi_A^*, \pi_B^*, \pi_C^*, \pi_D^*]$ = [.72413 .04985 .02134 .20468]. Since we used a total of 9 ten-year age intervals, the total of age intervals I = 90 years. The equilibrium function level expectancies are computed as follows:

$$Y^* = I\pi^* = 90\ [.72413\ \ .04985\ \ .02134\ \ .20468]$$
$$= [65.17\ \ 4.49\ \ 1.92\ \ 18.42]$$

Subtracting the 18.42 years duration in the death states, we obtain the life expectancy:

$$Y_A^* + Y_B^* + Y_C^* = 65.17 + 4.49 + 1.92$$
$$= 71.58 \text{ (years)}.$$

As indicated earlier, this equilibrium distribution vector Y^* is a unique summary of the process represented by the current transition matrices and provides a statistically reproducible estimate of the function level expectancies required for computing the Value-Adjusted Life Expectancy (Q^*).

An index based on Y^* will detect changes in health status that are ignored in the life table. Given the same mortality, different rates of transfer among levels A, B, and C represent significant differences in health status. In the life table, all such changes are disregarded. In fact, even small changes in rates for a single age group will change the equilibrium distribution vector.

Our notion of function level expectancies is similar to Sullivan's expected disability and disability free years. The disability and disability free states correspond roughly to our function levels. But Sullivan's computation of the disability expectations are not derived from the transition matrices, P_{ij}, carried to equilibrium; they are cumulated across all the age groups from currently observed distribution vectors, π_j, from household and institutional surveys.

Thus, Sullivan's disability and disability free life expectancies may be different from the equilibrium distribution of Y_j^*. For instance, from our hypothetical data, if the distributions were observed at the 8th period, the resulting estimate of the function level expectancy under Sullivan's model would be [70.654 4.023 1.650]. This distribution vector is different from the long-run equilibrium distribution, and gives no indication of the

TABLE 3. FUNCTION LEVEL EXPECTANCIES CONSTRUCTED FROM NATIONAL DATA [SULLIVAN, 1971]

Function Level L_j	Function Level Expectancies Y_j
Disability free	64.9
Non-Bed Disability	3.3
Bed Disability	2.0
Live Expectancy	70.0 (years).

direction or magnitude of the changes already in process. The advantage of Sullivan's index is that it can be computed using currently available data, and it intuitively provides an estimate of the Y_j in our framework, as illustrated in Table 4.

3.2 Value-Adjusted Life Expectancy and the Health Status Index

By applying the function weights to the function level expectancies, we obtain the value-adjusted life expectancy. This can be accomplished with a standardized set of weights by the operation

$$Q^* = \Sigma F_j Y_j^* \quad \text{where}$$

Q^* = the value-adjusted life expectancy.

Table 5 illustrates the computation by applying a set of values to the previously computed distribution vector.

TABLE 5. ILLUSTRATIVE COMPUTATION OF VALUE-ADJUSTED LIFE EXPECTANCY

Function Level Expectancies Y_j^*	Function Level Values F_j	$Y_j^* F_j$
65.17	1.00	65.17
4.49	.59	2.65
1.92	.34	.65
Value-Adjusted Life Expectancy (Q^*)		68.47

The value-adjusted life expectancy (Q^*) may be regarded as the equivalent of expected dysfunction free years of life or the expected quality adjusted years of life. This value-adjusted life expectancy can be used as a health indicator for comparing: (1) population groups of all ages cross-sectionally, (2) the health status of the same population over time. For example, Q^* for the U.S. resident in 1970 might be Q^*_{70} = 68.000 years, whereas the same figure for 1960 might have been Q_{60} = 67.527 years; the difference would be a precise composite expression for the total change in the population's health status. Even better than the Function Status Index, Q^* could be monitored over time as a social indicator that incorporates the dynamic aspects of health status, and could be correlated with other social indicators for social systems models and analyses.

For most purposes, Q^* is the best indicator of the health status of total populations. Since it is constructed from the same types of data and values as the Function Status Index (F), it has all the previously outlined uses and advantages. But Q^* remedies the major difficiency of the FSI and Sullivan's expectation of disability free life; it reflects immediately changes in prognoses, and yet is observable without medical diagnosis. It also corrects the insensitivity of current life expectancy measures, since it integrates multiple levels of function with mortality and is not subject to paradoxical change as other morbidity indicators have been. Furthermore, Q^* may be computed for age-specific comparisons.

Q is transformed to the 0-1 scale by the ratio to the sum of the remaining time intervals during which transitions might occur. If this standard life (S) is defined as 100 years, then at birth (Age 0) health status is the decimal transform of Q, as follows:

$$H = \frac{\Sigma F_j Y_j}{\Sigma Y_j} = \frac{Q}{S-A} = \frac{68.47}{100-0} = .6847$$

As age increases, however, H becomes increasingly sensitive to incremental changes, and it is not clear that these changes correspond to any clear interpretation of health status. Using the age-specific life expectancy in the denominator does not completely resolve the problem. Further study may permit us to devise a more meaningful ratio for comparisons between age groups.

The value-adjusted life expectancy is not very helpful in evaluation research, since cohorts under various treatments can rarely be followed over their life expectancy. Where the Markovian states are also defined by disease forms, however, the total disease history may be synthesized from currently observed transitions in a further expansion of the stochastic process outlined above [Bush, et. al., 1971].

A major advantage of Q^* is that it combines morbidity with mortality in a single number that is independent of both age and medical diagnoses. It can be determined using currently available survey and value measurement techniques, and replicated from year to year and from one population to another. Although more complex models may be possible, the discrete Markov model captures the important transitions of the life table for all the function levels, permits us to incorporate a standardized set of social values, and summarizes them in a unique scalar value for time series and cross-sectional comparisons, the major function of a social indicator.

3.3 Health Planning and Program Analyses

An ideal social indicator should be useful not only for monitoring but also for social decision-making. One of the most powerful uses of Q^* comes in planning and program analysis, where we project the probable impact of our policies on health status. It is the potential or expected difference in the value of Q^*, with and without the program, that drives the health system, and makes society willing to allocate resources to health services.

The output (value or benefit) of a health program can be defined as the increment of value-adjusted years of life (ΔQ) added to a target population by the program's intervention (Fig. 2). Different subgroups of the target population are affected differently by interventions. To accurately describe the different effects, we must disaggregate the target population into modules, that is, into subgroups that are homogenous with respect to prognoses and expected function status. The average value of treating the members of a particular module, m, is given by the difference in their expected value-adjusted years of life with and without the treatment ($v_m = \Delta Q$).

The total output of an entire program is the sum of the outputs of the individual modules, a linear function of the numbers of persons serviced, a function that can be maximized across multiple disease and population subgroups, as follows:

$$V = v_1 n_1 + v_2 n_2 \dots v_m n_m \dots v_z n_z \quad \text{where}$$

V = total program output

$v_m = \Delta Q$ = mean value of treating a member of module m

v_m = number of persons serviced in module m

z = index of the final module.

With the appropriate estimates of v_m, this model directly relates activity data about the numbers of patients treated to a meaningful output estimate, and provides a number with the required mathematical properties for use in cost/effectiveness and mathematical programming models. It is also amenable to relating resource inputs for defined services to a measure of output through production functions where the treatment of n_m is a function of the numbers of physicians, nurses, other technical personnel, drugs, laboratory equipment, space, and resources consumed.

The fact that the same basic concepts can be used both as a social indicator and as a planning model means that we can quantitatively analyze the contribution of one health program to the social indicator (Q^*) through its target population. Although we can never assert definitively that an observed change in Q^* for a population is entirely due to a particular program, we can investigate quantitatively the probable effects of the program to see if they could account for the change. Similarly, we can examine other possible causes of the change, such as demographic shifts. An examination of the precise number and composition of the program target populations, their expected health status without a program, and the time lag before the treatments take effect, make immediately evident why the effects of most health programs are not detectable in most social indicators for health.

From a theoretical standpoint, it should be possible to construct a macromodel of the health system using the concepts of health output described here. Overlaps in programs would be handled by creating new cells for the intersections of two or more target groups. Certainly it would be informative to examine the effects of eradicating various categories of diseases both on the expected value-adjusted years of life and on resource utilization. An analytical framework that connects a comprehensive social indicator for health status with a production function for health services will make it possible to examine such questions in detail.

CONCLUSION

We have proposed a Function Status Index ($\overline{F}$) that could be constructed using current data collection mechanisms and feasible value studies that would significantly augment our knowledge of the level of well-being of the population and facilitate cross-sectional and time series comparisons.

The Value-Adjusted Life Expectancy (Q^*) would give a reasonable approximation of an ideal health status index, but would require collecting new kinds of data on the function level transitions on a community or nation wide basis. Such data would be transformed into a single comprehensive index of physical and mental health status that incorporates both its value and prognostic dimensions. Such an index would be constructed from empirically determined components that would be replicable over time and among different population groups. In addition, the model provides criteria for evaluative research and an analytical framework for estimating the output and contribution of health programs to the health status of the population. We believe that methodological research should be intensified to make this measure a practical social indicator for health.

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