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TABLE OF CONTENTS

LIST OF TABLES

LIST OF ILLUSTRATIONS

A PHYSIOLOGICAL APPROACH TO HEALTH MEASUREMENT

CHAPTER I

INTRODUCTION

Over the past several decades, numerous attempts have been made to measure the collective health of nations or other populations. Such a measure is commonly referred to as a health index. As the American health care system has grown into an industry in itself, the need for such an index has become imperative. American industry has always been interested in various indices that reflect the impact of its goods upon the target populations. Without these indicators, decisions regarding the optimum allocation of resources would be impossible.

Traditionally, health workers have had to rely primarily upon mortality, and sometimes morbidity rates, as their source of information for planning and evaluative purposes. In recent years more sophisticated attempts have been made to measure the health of populations, but do not seem to have been well accepted. One factor that seems to confuse the issue is an apparent shift in emphasis by Federal and many private health agencies from programs primarily concerned with specific health problems such as venereal disease, or tuberculosis, to programs that attempt to provide total or comprehensive health care.

The earliest attempt to measure health in terms of variables other than mortality seems to have been made by Stouman and Falk (1939) in the 1930's. Working under a commission from the League of Nations they developed quantitative indices in the following three areas: vitality and health, environment, and public health activity. From 1943 to 1952, The Registrar General of Great Britain (1957) compiled periodic reports from their Sickness Survey which gave detailed tables on various aspects of morbidity, however, no attempt was made to summarize the data into what could be called an index of health.

A more comprehensive approach was taken in the early 1950's by the United Nations (1954) Committee of Experts in attempting to present statistical indicators of a nation's level of living. The committee recommended that health be included as one of 12 areas to be considered in the level of living. A study group subsequently appointed to develop measures of health agreed upon three general indicators. They were: expectation of life at birth and at one year of age, crude death rate, and the proportional mortality ratio. The study group recognized the limited nature of these measures and recommended further studies where the data were available.

Reduction of the broad notion of health into a set of measurable criteria has been attempted more than once by the U. S. National Committee on Vital and Health Statistics (1960). No specific recommendations were made, due to their inability to settle upon an operational definition of health, a stumbling block that still plagues workers in this area. There are many definitions of health currently in use but most, if not all, are of dubious scientific value. After reviewing an extensive list of such definitions, Goldsmith (1972) asked the following questions: "... how does one translate into operational language such terms as 'social well-being', 'cheerful acceptance', 'rhythm', 'continuing adjustment', fruitful creative living', 'balance appropriate', or 'gross dissatisfaction'?" These are terms used in current definitions of health and it is easily seen that such terms do not lend themselves to scientific inquiry.

Realizing these difficulties, researchers in the 1960's began searching for more indirect measures that would reflect the outcome of health or ill health. Sanders (1964) recommended measure of "functional adequacy" which he defines as the number of days during a year an individual is able to fulfill a social role appropriate to his age and sex. Using this data in combination with mortality rates, a modified life table is built that gives "effective" life years as the measure of health. The problems in defining such a social role, using only the variables of age and sex, are obvious. A particular deficiency in an individual's health may have no effect on his ability to fulfill his usual social role; whereas, the same deficiency in another individual may destroy his means of livelihood.

In attempting to limit himself to variables more amenable to estimation by survey techniques, Chiang (National Center for Health Statistics, 1965) developed a general index which was a probabilistic model incorporating measures of incidence and duration of disease in addition to mortality. Chiang's index was widely criticized because of his assumption of independence of incidence and duration of disease and for not considering the relative severity of the diseases.

Chronologically, the next major contribution was made by

Sullivan (1966) in a review and commentary of health indices developed prior to 1966. This paper seems to have had a significant impact on subsequent work in the field and deserves some attention. Sullivan's discussion centered around indices that could be used to measure trends in the health of the U. S. population. As such, he defines two requirements that an index must fulfill:

(1) It should show changes over time in significant aspects of health of the living as well as in mortality.

(2) It should be subject to analysis into components which provide a useful description of health problems underlying index values.

He reviews the indices that had been proposed, along with different variables that could be incorporated into an index to satisfy these requirements, concluding the following: "A concept of morbidity defined in terms of the disabling consequences of disease and injury seemed both measurable and pertinent to the proposed use of a health index."

Apparently following this suggestion, Bush and Fanshel (1970) have developed an index based on functional disability. They defined eleven states of disability ranging from well-being to death, with appropriate classification schemes for each state. Assuming that health includes not only the present state, but also the probability of transition to another state in the future, they have proposed a stochastic model for describing health. Their ultimate measure, called the Health Status Index (HSI) is the mean value of weights assigned to the eleven functional states. The weights are found by arbitrarily assigning zero to the death state and one to the well-being state, with a panel of expert judges supplying the intermediate values. As Chen (1972) points out, modifications of these weights according to expert prognosis and expected benefits from health program intervention, results in the HSI no longer being an invariant measure of health. If an index is to be used to compare different populations, or the same population over time, invariance is an absolute necessity.

In spite of the proliferous definitions of health, those workers interested in its measurement, consistently return to either direct or indirect measures of morbidity and mortality. In the previously mentioned paper by Sullivan (1966), he delineates the following three measures of morbidity: (1) clinical evidence, (2) subjective evidence, and (3) behavioral evidence. Clinical evidence includes "... signs, symptoms, laboratory test results, and observations of tissue pathology which have been evaluated by a physician and organized according to diagnostic categories or syndromes." Sullivan suggests that the sources of bias, including different methods of classification, results in the fact that this type of evidence "... cannot be safely taken as measures of conditions as they occur in the population." Apparently the author is thinking of clinical evidence as it relates to diagnosis of a specific disease, rather than evidence of morbidity in general.

Subjective evidence of morbidity refers to indications such as an individual's report of symptoms or feelings or his opinion of his health status. This type of information is important to the clinician in his diagnosis; however, since the factors influencing the expression of verbal complaints are so poorly understood, this type of evidence has received little consideration.

Behavioral evidence seems to be the most popular form of data for population-based measures of morbidity. It includes such indications as absenteeism, restriction of specified activities, medical expenditures, seeking medical care, or institutional confinement. This type of information is collected on a routine basis by many institutions, both public and private, and is usually available for health workers. Data of this type are also amenable to collection by survey techniques as exemplified by the Health Interview Survey. The forms of disability incorporated in the HSI would be included in this category. The Q index of health status developed by Miller, Berg, Bates (1968) is essentially an attempt to combine mortality data with behavioral evidence of morbidity. The actual variables included in the computations include time lost due to death, time in the hospital, time in outpatient visits and time in restricted activity. The Q index was developed for use by the Public Health Service, Division of Indian Health, and has apparently met with some success in that setting, in terms of ordering priorities and for allocation of resources. However, due to the variables measured, Q is an indicator of the utilization of facilities and it is not clear what relationship this has to the evaluation of health.

The varied approaches and attitudes evidenced by the work outlined so far would lead one to conclude that there is not now, nor will there ever be, a single "index of health." An index, like any other measuring device must be tailored to the specific application. One thing that seems to be universally accepted is that health is multidimensional, regardless of what definition one cares to adopt. Even if one limits his attention to measures of mortality and morbidity, there remains considerable work to be done.

If, in Sullivan's definition of clinical evidence, one were to leave off the phrase "... which have been evaluated by a physician and organized according to diagnostic categories and syndromes.", the result would be a kind of clinical evidence of morbidity that seems not to have been considered in the measurement of population health. The set of clinical and laboratory observations taken on an individual are basically measures of the functional capacity of the different organ systems in the human body.

It would seem reasonable to attempt to measure health in terms of the physiological functions of the human organism. The classic concept of disease is a deviation, from the usual ability to function, of one or more of the organ systems of the body. If health were measured in terms of these functions, the problems of bias due to different systems of classification and diagnosis would be circumvented. Granted that medical technology is not able to completely evaluate an individual's functional capacity, the evaluation of the health of populations does not necessarily need to be as sensitive. With a fairly limited set of observations, the physician is able to make a reasonably good judgement as to the general physical condition of an individual. Note that there was no mention of diagnosis in the above statement. Hypertension is one measure of impaired functional capacity which can influence or be influenced by many things, each categorized as a different disease. If health were measured on the basis of variables such as hypertension rather than a specific disease associated with it, the ability to diagnose would not enter into the picture.

To continue with this example, it should be obvious that hypertension would not have the same effect on the health of all individuals so afflicted and so for this reason hypertension would not be an appropriate measure of the health of an individual. However, it is entirely possible that within any two communities the broad spectrum of responses to hypertension would be represented, i.e., the individual differences would tend to average out when the relative health of populations is considered.

To this date, the measurement of health utilizing clinical and laboratory measurements has not received much attention, primarily because of the technical and financial restrictions involved. In recent years development of automated laboratory analysis has reduced the cost of laboratory tests to such an extent that the clinician is able to obtain a wide variety of tests that can be used to give a reasonably adequate profile of a substantial number of organ functions.

An index based upon physical measurements would necessarily use information on a multidimensional scale. The general procedure of measuring health on a multidimensional scale has been suggested by Chen (1972). In his paper, Chen made no attempt to derive an actual index but rather considered the theoretical development of the algebra involved and the philosophical justification for the approach. Chen points out that establishing an "ideal" normal is not necessarily the same as our usual concept of normal, i.e., average. For example, he notes that ideal weights in our affluent society are somewhat less than average. One problem not discussed by Dr. Chen, which is of prime importance, is in the estimation of variances and covariances. It is obvious that the parameters involved in the evaluation of physical function are not independent; however, a brief examination of the literature of clinical chemistry, pathology, and laboratory medicine seems to indicate that independence of most of these variables, at least in the healthy state, is assumed. With multiple clinical testing becoming a more integral part of modern medicine, it is imperative that these correlations be better understood.

Sources of data for these estimates are generally based on relatively small samples from select groups. There are, however, a few exceptions. Reed, et al. (1972) has done a study of normal blood values on 1,419 clinically normal adults. Craig and Bartholomew (1969) studied the effects of age on blood profiles from 7,337 male workers and Bunow (1969) investigated ethnic differences in the blood profiles of 21,000 California cannery workers. These studies are very useful for ascertaining normal or expected values of the various physiological parameters; however, little attention was given to cumulative effects or correlations between the measurements.

The general area of work classified under the heading of health indices is extensively represented in the literature and obviously not covered in this brief review. Because of the complexity of the problem and lack of data, most authors have preferred to limit their work to either specific health problems such as tuberculosis or to specific populations such as a hospital ward. These studies provide valuable information for a better understanding of natural phenomenon; however, papers were selected for this review whose purposes more nearly paralleled those of this work in the development of a "general" index for a "general" population. The purpose of this dissertation is essentially twofold: first, to propose the use of a well known statistical technique in the relatively new area of health measurement, and secondly, to demonstrate its application and discuss the types of problems encountered with a real population.

With continuous increases in both variety and versatility of instrumentation,automated laboratory analysis has become so common that it is now the rule rather than the exception. For example, the Technicon Corporation markets a twelve channel autoanalyzer commonly called the SMA 12/60 which simultaneously analyzes twelve different constituents of blood. The autoanalyzer can be programmed to measure different blood components, but there is a standard set that most laboratories use. The following is a list of the variables that the SMA 12/60 is normally used to monitor:

1. Total Bilirubin
2. Calcium
3. Cholesterol
4. Glucose
5. Albumin
6. Lactate Dehydrogenase, (LDH)
7. Alkaline Phosphatase
8. Inorganic Phosphorous
9. Total Protein
10. Transaminase, (SGOT)
11. Blood Urea Nitrogen, (BUN)
12. Uric Acid

Another machine commonly used in modern laboratories is the SMA 7 which measures the following variables:

1. Red Blood Cells
2. White Blood Cells
3. Hematocrit
4. Hemoglobin
5. MCV
6. MCH
7. MCHC

A third group of tests commonly utilized are known collectively as the urinalysis (U/A). Although these tests are not generally automated, they are done as a group by most laboratories. Some of these tests are not quantitative, but the following are the tests commonly included in the U/A that are to some degree quantitative:

1. Specific Gravity
2. Glucose
3. Albumin
4. Blood
5. Ketone
6. Bilirubin
7. Casts and Crystals

The laboratory tests mentioned so far can be used to detect a wide variety of physiological malfunctions and some may in fact be repetitious or too specific for the purposes of this work. There are several other important measurements that can be taken at the clinical level that would seem essential in the evaluation of health. Roughly they would be as follows:

1. Height

2. Weight
3. Temperature
4. Blood Pressure
5. Pulse
6. Chest X-Ray
7. Spirometry

Since in many cases the foregoing measurements are taken at the same time on an individual, multivariate analytical techniques are very natural tools to be used in their analysis. Data for this investigation have been provided from existing medical records by the Medical Services Division of the Tennessee Valley Authority (TVA). Obviously when a study of this magnitude is undertaken with the restrictions of resources and manpower necessarily imposed, decisions must be made at least partially on the basis of convenience rather than the altruistic foundations normally desired. The ideal procedure would be to design this study and sample from appropriate populations, taking all the measurements deemed important. The alternative, as is the case here, is to find a population which has been sampled and measured, and design the study to fit the data. This approach is justifiably subject to much criticism when undue inferences are drawn; however, there is a great deal of information to be obtained in this manner and to ignore the potential gain would indeed be nescient. Obviously an attempt will be made to choose variables and make other decisions with at least some intuitive justification in terms of the ultimate success of the proposed index; however, it must be kept in mind that the important contribution of this work is in terms of the methodology and the approach to the problem rather than a choice of the best set of health parameters. In other words, the population of employees of the TVA is a select population in virtually all demographic characteristics so that an index built for application to or for this group can be generalized only in terms of its method of construction.

The overall purpose of this dissertation is an attempt to devise a procedure whereby an index of health may be derived that can, with relative ease, be applied to populations or communities. Other indices have been developed that incorporate such variables as incidence, duration, and severity of disease as well as mortality, to name a few. Many of these variables are difficult to define, have no realistic optimum levels, and in fact may not be measurable. It is the intention here to measure health in terms of well-defined clinical and laboratory indicators of physiological functions. In this manner, acceptable, or normal values for each measurement may be obtained in order to give a baseline with which to compare different populations by means of the Mahalanobis D^2.

CHAPTER II

METHODS

Data Base Source

Data for this investigation have been provided by the Division of Medical Services of the Tennessee Valley Authority (TVA) in Chattanooga, Tennessee. The TVA was established by act of Congress in 1933 to develop the vast natural resources of the Tennessee Valley. Due to the remote locations of TVA projects, a medical program was initiated the following year to provide medical services to its employees. The activities of the Medical Division have evolved over the years into an excellent occupational health program utilizing such modern facilities as an automated medical laboratory, an automated information system, computerized electrocardiography and multiphasic health testing as well as mobile and permanently located medical clinics. Under this system, health care is provided for about 24,000 employees over an area of approximately 80,000 square miles.

Complete medical examinations are given to employees at the time of employment and at regular intervals of one to three years depending upon the worker's classification. In addition to an extensive clinical examination and medical history, various laboratory procedures are utilized which include urinalysis, blood analysis on SMA 12 and SMA 7 analyzers, spirometry, and electrocardiogram among others.

Computerization of TVA medical information was initiated July 1, 1971, and since that time the medical records of over 27,000 employees have been stored on tape. It is with these records, covering the period of July 1, 1971, through March, 1973, that this investigation will be concerned.

The medical record of each employee contains coded information on that individual's history, clinical examination, laboratory results, diagnosis, and possible work restrictions that are imposed as a result of the physician's examination. The exact information recorded at any one clinic visit depends upon the purpose of the visit. Thus, an attempt will be made to use primarily initial employment and periodic examinations as they are, in general, the most complete. Since many of the employees will have more than one complete exam in their records, the earliest one will be chosen in those cases. This will be done for the sake of uniformity and to insure that no person is included more than once in the analysis. Insistence upon a complete examination as a criterion for entrance into the study will facilitate the use of clinical and laboratory observations that were taken at the same point in time. This of course, will be necessary if the two are to be used in conjunction in the study.

Diagnosis is recorded by ICDA number, using the eighth revision. Associated with each diagnosis is a two digit code which indicates the current status of that particular infirmity, i.e., whether it is better or worse, receiving treatment or not, or if this is a new or old diagnosis. The physician also makes note if he feels any follow-up action is desired and if so the patient is automatically notified at the appropriate time. Figure 1 shows the options that can be taken in these fields and is fairly self-explanatory. The physician is authorized to impose any of a host of work restrictions on the employee to insure that the health of the employee or his co-workers will not be endangered by any observed physical or mental impairments. This information will be utilized in the construction and testing of the index.

Measurement Parameters

The set of clinical and laboratory measurements utilized in this dissertation will be referred to as the measurement vector (MV). An attempt will be made to narrow the MV as much as possible by using elements that are common to as many diseases as possible. For example, overweight either influences or is influenced by diabetes, hypertension, gout and arteriosclerotic heart disease, to name a few. Since overweight is common to so many diseases, it serves as an excellent example of the type of variable desired as an element of MV. The initial version of MV will be composed of tests that generally indicate the functioning of the major organ systems of the body. Due to the overlap in information provided by several of these tests, it is anticipated that the final MV will be somewhat shorter.

The discussion so far has assumed that all variables desired could be included in the analysis; however, a more pragmatic look at the data required some alterations. Choice of the elements of inclusion was based upon (a) the principle of widest manifestation, as mentioned earlier with, say, overweight, (b) consistency of collection, and (c) validity of measure, not necessarily in that order. Decisions were made not so much on the basis of compliance with the above criteria, but

	Required Treatment	Not Required Treatment	Unchanged	Improved	Cured or Dropped	Worse
Definite new diagnosis previously unknown by TVA and negative medical history	11	12				
Definite previously known diagnosis			23	24	25	26
Tentative or suspicious Diagnosis	31	32	33	34	35	36

Figure 1--CURRENT STATUS CODES used in the Tennessee Valley Authority automated medical record system.

rather variables were simply accepted if they did not fail to comply. This is a small distinction, but one which the author feels obligated to make. Examples of variables rejected and the reasons would be tonometry because of (a), spirometry because of (b), and microscopic urine exam because of (c). Another variable that deserves special attention here is the measure of overweight. There are two ways this element could be treated. The first and possibly the best would be to find the ideal weight for a given height and build and then use as a measure, the difference in observed and ideal. An alternate procedure would be to express height and weight as one number that would reflect both elements and be somewhat standardized. The latter alternative will be taken here and the measure will be what is known as the ponderal index. The ponderal index is recognized as a somewhat crude but acceptable measure of obesity and is defined as $\sqrt[3]{\frac{\text{weight X 100}}{\text{height}}}$.

For the purposes of summarization, the following is a complete enumeration of the initial MV in the order to be used:

SMA 12

1. Total Bilirubin
2. Calcium
3. Cholesterol
4. Glucose
5. Albumin
6. Lactate Dehydrogenase, (LDH)
7. Alkaline Phosphatase
8. Inorganic Phosphorous

9. Total Protein
10. Transaminase, (SGOT)
11. Blood Urea Nitrogen, (BUN)
12. Uric Acid

SMA 7

1. Red Blood Cells
2. White Blood Cells
3. Hematocrit
4. Hemoglobin
5. MCV
6. MCH
7. MCHC

Urinalysis

1. Albumin
2. Sugar
3. Ketone
4. Bilirubin
5. Blood

Miscellaneous

1. Ponderal Index
2. Temperature
3. Pulse
4. Blood Pressure
5. Chest X-Ray

Partitioning of the Population

The above mentioned variables will form the basic or initial MV. It is easily shown that many of these measurements are directly related to one or more of the factors age, race, and sex. For this reason the present study will be limited to white males because the remaining race and sex categories will not contain sufficient numbers for a detailed analysis. An ideal MV will then be derived for each age category. The ultimate measurement to be taken on each individual will be a measure of how far his observed MV is from the ideal MV appropriate for his particular age.

In order to derive the so-called ideal vector, the records of the healthiest of the subjects will be used to define the ideal vectors and to estimate the associated covariance matrices. For the purposes of this discussion, let X_{ij} denote the vector of measurements for the j^{th} person in the i^{th} age group from the healthiest of the employees. Then

$$\frac{1}{n_i} \sum_{j=1}^{n_i} X_{ij} = \overline{X}_i ,$$

which will represent the vector of ideal values for the i^{th} category. The estimated covariance matrix associated with each $\overline{X}_i$ will be

$$S_i = \frac{1}{n_i} \sum_{j=1}^{n_i} (X_{ij} - \overline{X}_i)(X_{ij} - \overline{X}_i)'.$$

There is now an "ideal" measurement vector $\overline{X}_i$, and covariance matrix S_i which will be used in the evaluation of the remainder of the employees in the i^{th} age group.

Testing of this index will require adequate sampling from populations whose relative health we can to some extent predict. To this end the population of employees eligible for inclusion in this study will be divided into three groups in the following manner. Those subjects considered to be in the best of health by virtue of not having any recognized disease or disability at the time of examination will be separated and referred to as group I. This group will provide baseline data with which to define optimum values. After these optimum values have been derived for all ages, group I will be returned to the eligible population which will then be randomly divided into groups II and III of equivalent sizes. The index will then be built and refined on group II, and tested on group III. Refinement and testing of the index will require the subdivision of groups II and III into different categories based upon a subjective evaluation of their health. Previously, reference was made to a current status and follow-up code being associated with each diagnosis as well as a work restriction code. This information will be used to classify the subjects into categories of health. Admittedly, any ordering of health status using these criteria is going to be crude at least; so it would seem wise to develop several somewhat independent categorizations with relatively wide groupings so that success or failure will not depend on a single scheme of ordering. The categorization schemes to be used are as follows:

A. Number of Diagnoses - This scheme will separate the subjects on the basis of whether they had 0, 1, 2, 3, or 4+ separate problems diagnosed.

B. Current Status - Using the codes in Figure 1, the subjects will be separated into the following groups:

1. No diagnosis
2. Current status codes 24, 25, 34, 35
3. Current status codes 12, 23, 32, 33
4. Current status codes 11, 31, 26, 36

For those subjects with multiple diagnoses, the diagnosis with the highest code (worst) according to the above order will be used.

C. Follow-up - Subjects will be separated on the basis of:

1. No diagnosis
2. Diagnosis but no follow-up required
3. Follow-up in twelve months
4. Follow-up in three months
5. Follow-up in one month

D. Work Restrictions - Work restrictions are coded according to environmental conditions, physical requirements of the job, and physical limitations of the individual. Work restrictions are grouped into the following major headings:

1. No work restrictions
2. Restrictions due to vision, hearing, dental, or miscellaneous impairments
3. Chemical irritants
4. Restricted lifting
5. Mental or emotional problems
6. Length of workday
7. Dexterity
8. Operation of powered machinery

9. Limited exertion or working environment

Because of the arbitrary nature of these classifications, it is anticipated that during the refinement stage of the analysis, these classification schemes might be combined or otherwise altered if evidence of the need to do so arises.

Construction and Testing of the Index

At this point the analysis is in what has been called the refinement stage and the data from group II will be utilized to make those refinements. There are two areas that this refinement stage will concentrate on: (1) reduction of the MV to a minimal set, and (2) verification or improvement of the subjective definitions of categories of health. Reduction of MV will be accomplished by means of a stepwise discriminant analysis with two groups. This analysis will be done by machine using program number BMD07M from the BMD program series, Dixon (1970). The two groups representing the most divergent levels of health in the first categorization scheme will be utilized for the discrimination. Note that this is not the usual application of a discriminant analysis in that the end product of this type of analysis is normally a linear discriminant function to be applied to the observed vectors to maximize the ability to discriminate. The linear discriminant function is essentially a set of weights that give more emphasis to those elements of the observation vector that are most different in the groups to be discriminated. Realistically this would tailor the proposed index to this particular population which is contrary to the original purpose of this dissertation. The assumption here is that the TVA population of white males has the same diseases as their counterparts in other U.S.

populations in general, but there is no reason to believe that those diseases would be in the same ratios. The discriminant analysis here will simply be used to pick out any elements of the MV that contribute no additional information not contained elsewhere in the vector. Realizing the universal fact that different age groups encounter different problems, the discriminant analysis will be applied separately to each age group, which may or may not result in different vectors for different ages.

The index value will then be computed for each subject by the following procedure. Let Y_{ij} be the j^{th} person in the i^{th} age category in group I. Then $(Y_{ij} - \overline{X}_i)' S_i^{-1} (Y_{ij} - \overline{X}_i) = D^2_{ij}$, which will be recognized as the Mahalanobis D^2 in terms of the "ideal" variance-covariance matrix. D^2_{ij} is simply an expression of distance between the vectors Y_{ij} and $\overline{X}_i$. The index of health for any population group would simply be the group's average D^2. To verify whether or not $\overline{D}^2$ actually reflects levels of health, is not a straightforward task. Since there is not at present an accepted quantification of health, less esoteric methods must be employed. The subjective levels of health described earlier will now be used for this purpose.

Group II will be categorized according to the schemes outlined and mean D^2's will be found for each health category. This point in the study has been reserved for making any small adjustments that may be called for. For example, the mean D^2's for group II may indicate that the groupings used in the Current Status categorization scheme are not adequate to produce sufficient sample sizes at each of the intuitive levels of health. If this is the case, and corrections can be made without destroying the legitimacy of the results, then this will be the place to make such corrections. The resultant categorizations will then be applied to the remaining subjects, group III, for the final test of the index. If in fact, the $\bar{D}^2$ reflects the health of populations, then the mean values for the health categories will be in the same order as the health categories themselves. In other words, if the categories were ordered from best to worst, then the associated $\bar{D}^2$'s should be automatically ordered from smallest to largest.

The final application of the index to group III may be viewed as a simulation of the case where it is desired to apply the index to N independent populations whose relative levels of health have been pre-determined in order to ascertain whether or not the $\bar{D}^2$ results in a utile health ranking.

CHAPTER III

RESULTS

Table 1 shows the age, sex, and race distributions of the TVA employees who have had laboratory studies done. It is easily seen that non-whites and females are not present in large enough numbers to facilitate a detailed analysis. The 17,314 white males will form the basic population for this study. Of these records, 9,074 were eliminated because they did not fulfill the requirements for a complete examination as discussed in CHAPTER II. One final screening procedure was used which cost another 1,120 subjects. This last criteria was concerned with the condition of the blood sample at the time it was received in the lab. If any sample was not listed as having been in good condition, it was not used in this study. This resulted in a total study population of 7,349 white males. The age distribution of these remaining subjects is shown in Table 2.

The first step in the analysis was the identification of the healthy employees and establishment of normal or baseline values. The healthy group of employees was defined as those individuals who had no known diagnosis at the time of examination. For this and subsequent uses of the ICDA codes in this study, codes with a Y prefix were ignored. The ICDA system provides Y codes to be used for special conditions and examinations without sickness. For the purposes of this study, exclusion

TABLE 1

DISTRIBUTION BY AGE, SEX, AND RACE, OF TVA EMPLOYEES THAT RECEIVED SMA-7 BLOOD ANALYSIS DURING THE STUDY PERIOD

	MALES		FEMALES	
Age	White	Non-White	White	Non-White
0-19	282	90	108	60
20-29	4713	465	420	114
30-39	3617	182	218	24
40-49	4249	256	312	19
50-59	3535	239	278	15
60+	918	38	62	5
TOTAL	17314	1270	1398	237

TABLE 2

AGE DISTRIBUTION OF FINAL WHITE MALE STUDY POPULATION

Age	Sample Size
<20	67
20-29	2011
30-39	1670
40-49	1729
50-59	1409
≥60	463
TOTAL	7349

of Y codes would, it seems, make the fact of, and number of diagnoses, a more meaningful concept. The age distribution of the 3,913 healthy subjects is shown in Table 3.

TABLE 3

DISTRIBUTION OF HEALTHY SUBJECTS BY AGE AND DATE OF EXAMINATION

Age	Examined Before 7/11/72	Examined on or After 7/11/72	Total
≤19	42	16	58
20-29	917	510	1427
30-39	684	334	1018
40-49	496	278	774
50-59	320	189	509
≥60	85	50	135
			3913

It is necessary to digress a bit here and discuss one of the difficulties encountered at this point in the study. The urinalysis and chest X-ray present a unique problem by virtue of being coded or "semi" quantitative measures. The actual codes are integer values 1, 2, or 3 depending on whether the test is normal, questionable or abnormal. It was found that so rarely were these tests coded as other than normal, the variance of the codes was so close to zero that correlations could not be computed within machine tolerances. As a result, the decision was made to eliminate these six variables from the analysis.

Also, an attempt was made to simplify the use of blood pressure by combining the systolic and diastolic components into a single number. The two most common single expressions of blood pressure in the current literature seem to be the average, (systolic + diastolic)/2 and the difference, (systolic-diastolic). No attempt was made to derive another expression for blood pressure as this could in itself be a very respectable task and outside the scope of this study. The difference and the average blood pressure were then included along with the individual systolic and diastolic measurements in the MV. Since the purpose here was other than to diagnose specific diseases, there would have been an obvious advantage to using as small a set of measurements as possible; this was seen as a possible place to eliminate some measurements. Neither of the combinations seemed to contribute any additional information to the study and were therefore dropped as will be explained shortly.

An example of the baseline information obtained from the healthy population is presented in the APPENDIX. After this baseline information was extracted, these "healthy" subjects were returned to the subject population which was then randomly divided into two groups of equal size which have been referred to as groups II and III. Group II was then used for what follows. Three subpopulations were chosen from group II and subjected to a Stepwise Discriminant Analysis which attempted to discriminate those individuals with no diagnosis from those with two or more diagnoses. As was discussed in CHAPTER II, this procedure was utilized simply in an attempt to eliminate any variables that did not seem to contribute to the pool of useful information. The subpopulations used were the pre and post July 11, 1972 30's decade and the pre July 11, 1972 40's decade. On this date, July 11, 1972, the TVA medical laboratory changed the procedure for measuring uric acid, LDH and SGOT, which requires separate handling for the data collected before and after this date. The results of the discriminant analysis indicated that neither of the combined expressions of blood pressure mentioned earlier were sufficient to make any meaningful addition to the discrimination process. It was also felt that the discriminant analysis might demonstrate the need for different sets of elements in the MV for different age groups; however this was not shown to be the case. Thus a uniform set of elements was maintained for all age groups.

Elimination of the two combinations of blood pressure shortened the MV to a length of 24 elements which formed the basis for the D^2 calculations on group II. Using the mean vector and covariance matrix appropriate for the individual's age and exam date, a D^2 value was computed for each subject in group II. After this calculation, age and exam date distinctions were ignored and mean D^2 values were computed for the different health categorization schemes as discussed in CHAPTER II.

One problem of minor significance arose at this point which was made evident by the D^2 values. Since the teenage group of the healthy subjects contained only 16 people, their resulting covariance matrix was singular so that a valid inverse could not be computed. This necessitated the elimination of this group from the analysis; however, the teen group was so small, it was not felt that the overall results would be affected either way.

Results of the D^2 calculations on group II are shown in Table 4. The first three categorization schemes generally present the continuum of values that would be expected under the assumption that both the intuitive schemes and the mean D^2 values are both measures of health. In interpreting these results it might be more appropriate not to consider the

TABLE 4

SUMMARY STATISTICS OF THE INDEX CALCULATIONS ON GROUP II
FOR ALL FOUR HEALTH CATEGORIZATION SCHEMES

Number of Diagnoses	Mean D^2	Standard Deviation	Standard Error	Sample Size
		NUMBER OF DIAGNOSES		
0	23.55	15.79	.36	1896
1	32.33	47.39	1.59	894
2	38.46	71.57	3.45	430
3	38.01	38.09	2.46	240
4+	45.13	63.93	4.89	171
		CURRENT STATUS		
Status Code				
1	23.55	15.79	.36	1896
2	26.22	11.26	1.38	67
3	34.53	54.44	1.48	1350
4	43.74	62.51	3.51	318
		FOLLOW-UP TIME		
Follow-up Code				
1	23.55	15.79	.36	1896
2	31.33	47.82	1.56	934
3	37.70	58.81	2.83	431
4	44.20	65.22	3.49	349
5	63.90	75.08	16.38	21
		WORK RESTRICTIONS		
Restriction Code				
1	27.73	31.78	.58	2974
2	36.18	77.62	4.51	296
3	27.30	12.48	3.94	10
4	36.03	53.15	4.14	165
5	0	0	0	0
6	22.57	7.16	3.20	5
7	21.81	4.46	2.23	4
8	54.28	0	0	1
9	38.48	43.62	3.29	176

first category (the healthy group) since they represent the population used to construct the model. The D^2's increase monotonically as the number of diagnoses increase, with the exception of the group with three diagnoses. This failure of category 3 (or 2, depending upon ones' viewpoint) to align itself as predicted is not seen as particularly detrimental to the hypothesis. It simply means that at this time the measure is not sensitive enough to distinguish between the population with two diagnoses and the population with 3 diagnoses. The more important point is that both of these category means are higher than the mean of the population with either no diagnosis or one diagnosis, and smaller than the population with four or more diagnoses, thus preserving the direction of the measure. The standard errors show the same pattern as the means while the standard deviations illustrate the high degree of overlap between the categories.

The scheme utilizing current status for population groupings seems to give better results than did the number of diagnoses. The monotonic increase is seen not only with the values of D^2 but also with the standard errors. The size of the group assigned current status code 2 was rather small (N=67) but the standard error seems to indicate that the sample size is sufficient to allow legitimate comparison with the other categories.

The best correlation between the proposed index and an intuitive ordering appears to result when the intuitive ordering is based upon the length of time specified for follow-up of observed problems. Once again a decrease in the level of health results in an increase in the mean D^2. The same increase is also observed in the standard deviation and the standard errors. The standard deviations are still quite large; however, the standard errors are small enough that they will allow a distance of at least one standard error between each of the means. Since the proposal is to use the mean D^2 values as the population measure, the standard error would be a more appropriate indication of the degree of separation.

The fact that the variance estimates of the D^2's increase even faster than the means, would at first seem to be a troublesome result; however, a little reflection will demonstrate that it should, in fact, be expected. The proposed index is essentially a measure of abnormalities, and the range of abnormalities is, by definition, greater than the range of normal values. In other words, as a population becomes less healthy, the number of abnormalities increases, which in turn expands the potential range of physiological measurements, thus increasing the variance of D^2.

The last scheme, (work restrictions) gives erratic results in terms of both the $\bar{D}^2$ and the sample sizes. This is the type of situation referred to earlier that might require some re-combination of categories before proceeding to the final test of the index on group III. However, since two-thirds of the group have no work restrictions placed upon them, (work restriction code 1) there does not appear to be an alternate scheme short of gerrymandering the categories. This could actually be construed as a favorable result. If the arbitrary ordering of work restrictions is not an ordering according to health status, and assuming that $\bar{D}^2$ does measure health, then an erratic pattern of $\bar{D}^2$ values would be expected. Since the work restriction categorization scheme was the most arbitrary of the four, the foregoing seems to be a plausible explanation of the results. Therefore, the schemes will be left intact for the test of the index on group III.

The final application of the index to the individuals in group III is shown in Table 5. Once again it can be seen that the index seems to reflect the intuitive levels of health as defined. The progression of means in the first scheme (number of diagnoses) is less uniform than had been expected and raises an interesting question. The fact that both applications of the index resulted in a better continuum on the current status and follow-up schemes than on number of diagnoses was not anticipated. While the number of diagnoses is a measure of quantity of disease, it could be argued that current status and follow-up are measures of quality or severity of disease. It may very well be that the D^2 is a combination of both, considering both quantity and quality in its measure of health. Nevertheless, the results have repeated themselves, even in the erratic nature of the fourth scheme (work restrictions), lending support to the hypothesis that the D^2 is an index of health.

In order to illustrate the distributional properties of the index, groups II and III were combined, giving the total study population. Figures 2 through 7 show percentage densities and distributions, respectively, for the schemes representing number of diagnoses, current status, and follow-up time. All three schemes show the gradual shifting of the curves to the right although more pronounced in the follow-up scheme. The summary statistics for this combined tabulation are presented in Table 6. The increase in sample sizes afforded by this

TABLE 5

SUMMARY STATISTICS OF THE INDEX CALCULATIONS ON GROUP III
FOR ALL FOUR HEALTH CATEGORIZATION SCHEMES

Number of Diagnoses	Mean D^2	Standard Deviation	Standard Error	Sample Size
		NUMBER OF DIAGNOSES		
0	24.31	22.42	.51	1967
1	30.76	38.11	1.30	856
2	30.99	24.07	1.16	430
3	37.75	48.66	3.30	217
4+	37.01	32.06	2.41	177
		CURRENT STATUS		
Status Code				
1	24.31	22.42	.51	1967
2	26.28	13.81	1.83	57
3	31.25	33.20	.92	1314
4	38.35	48.45	2.76	309
		FOLLOW-UP TIME		
Follow-up Code				
1	24.31	22.42	.51	1967
2	29.20	32.69	1.08	921
3	34.95	40.20	1.99	409
4	36.08	32.88	1.82	328
5	62.91	88.08	18.78	22
		WORK RESTRICTIONS		
Restriction Code				
1	26.83	24.76	.45	3026
2	31.71	43.14	2.57	281
3	26.32	12.64	3.81	11
4	27.73	14.77	1.19	155
5	0	0	0	0
6	28.62	16.95	9.79	3
7	22.75	10.27	5.93	3
8	22.10	8.74	6.18	2
9	44.06	68.83	5.34	166

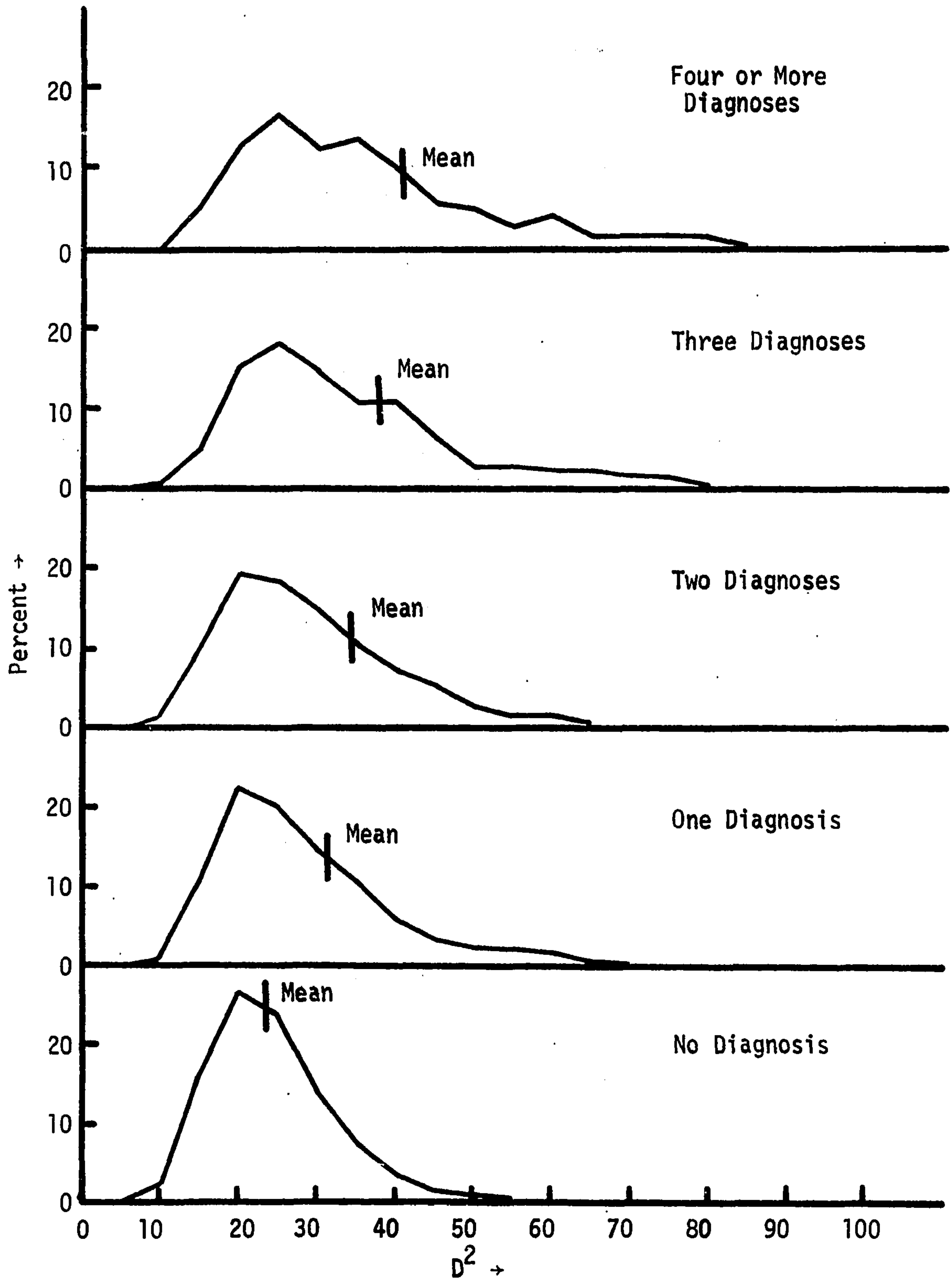

Figure 2--Densities of D^2 by number of diagnoses for total study population.

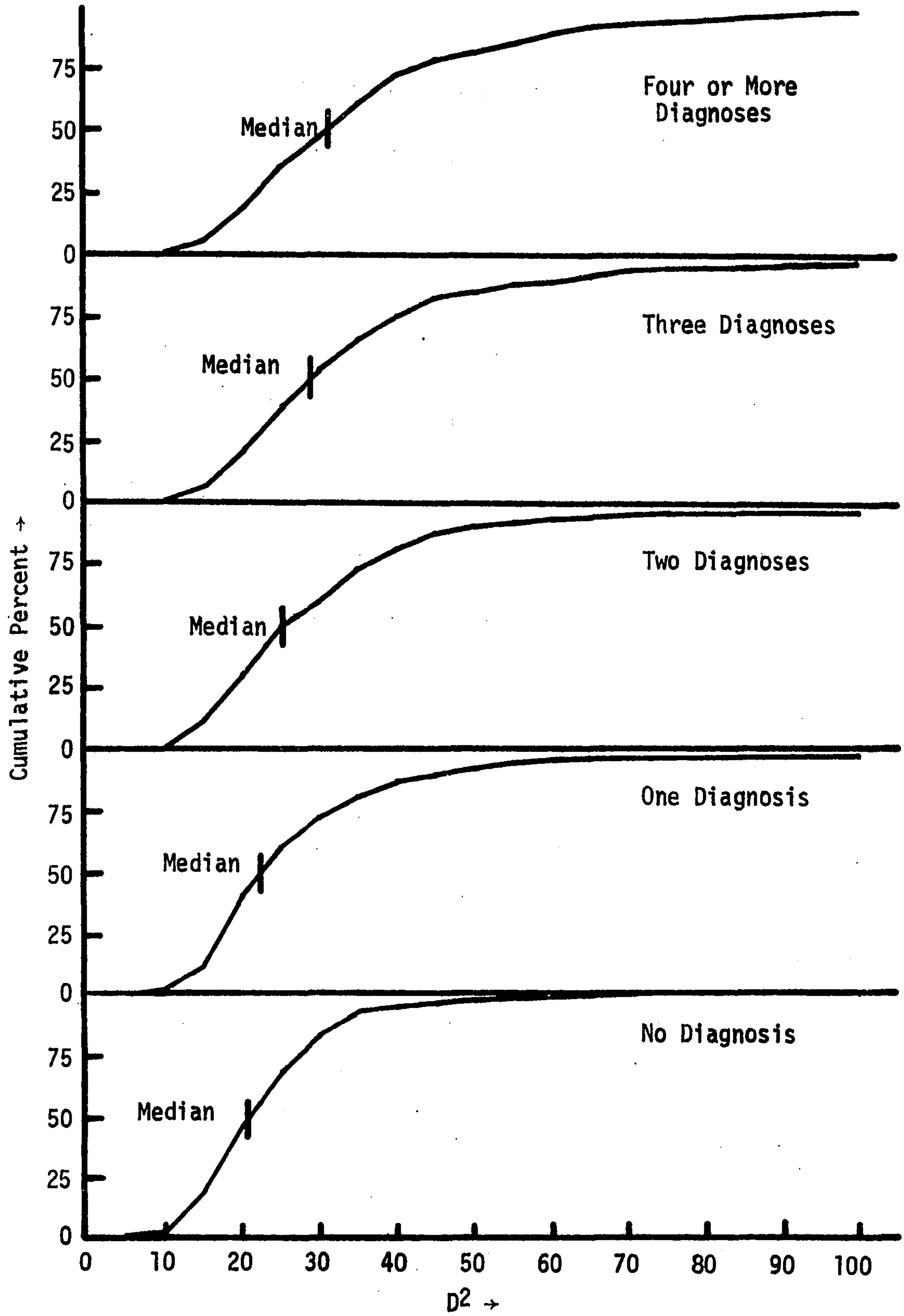

Figure 3--Distributions of D^2 by number of diagnoses for total study population.

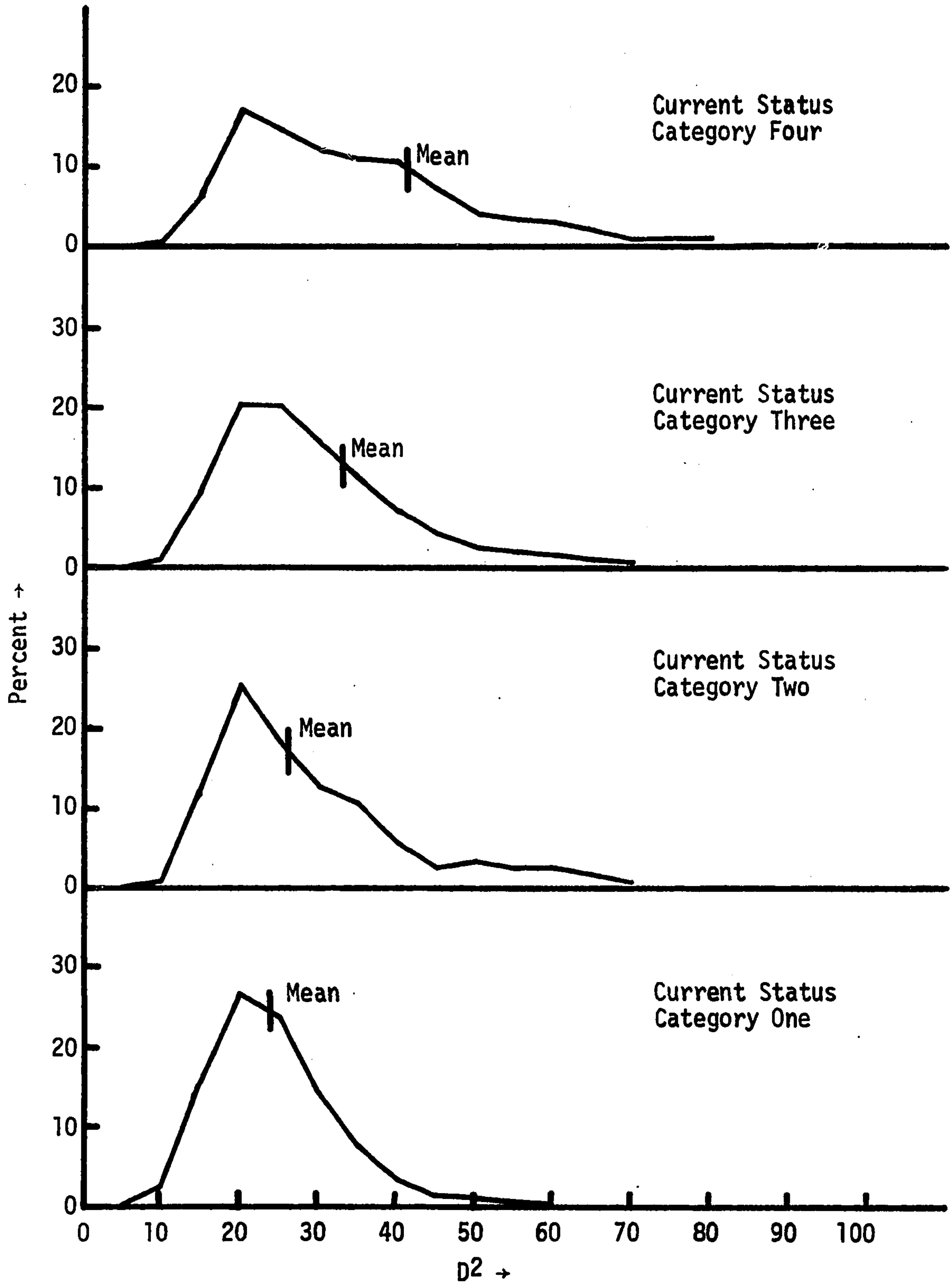

Figure 4--Densities of D^2 by current status category for total study population.

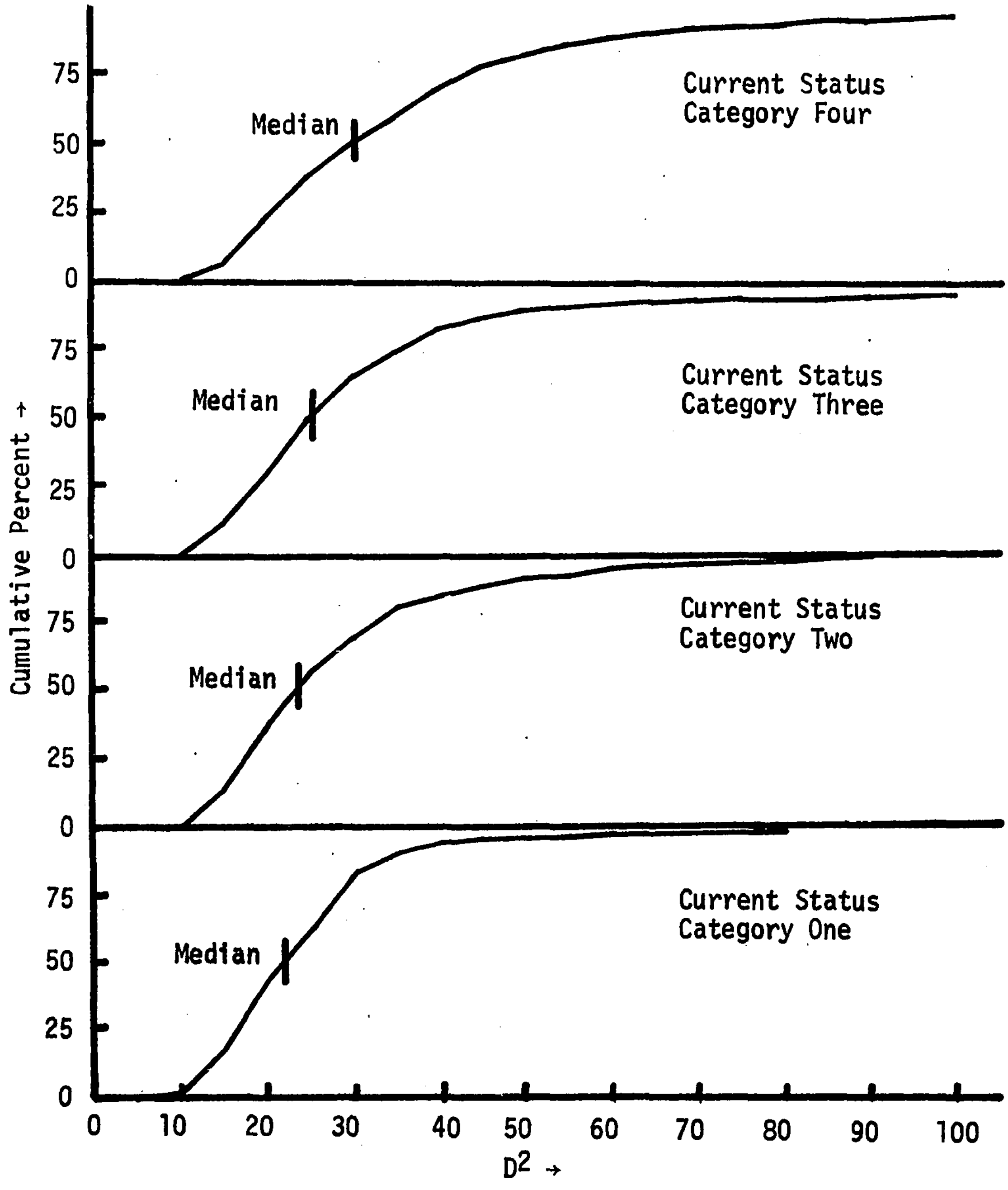

Figure 5--Distributions of D^2 by current status category for total study population.

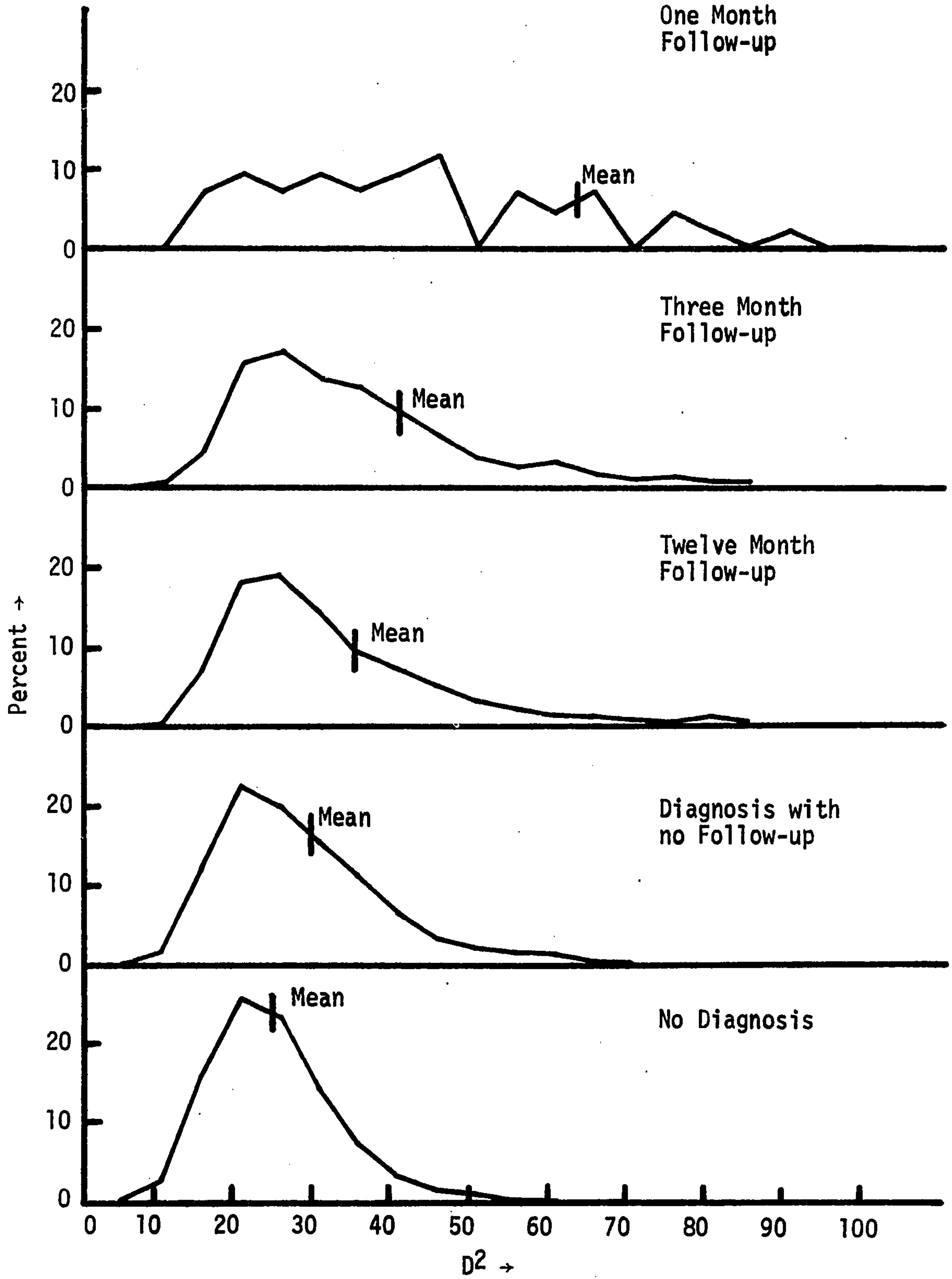

Figure 6--Densities of D^2 by follow-up time for total study population.

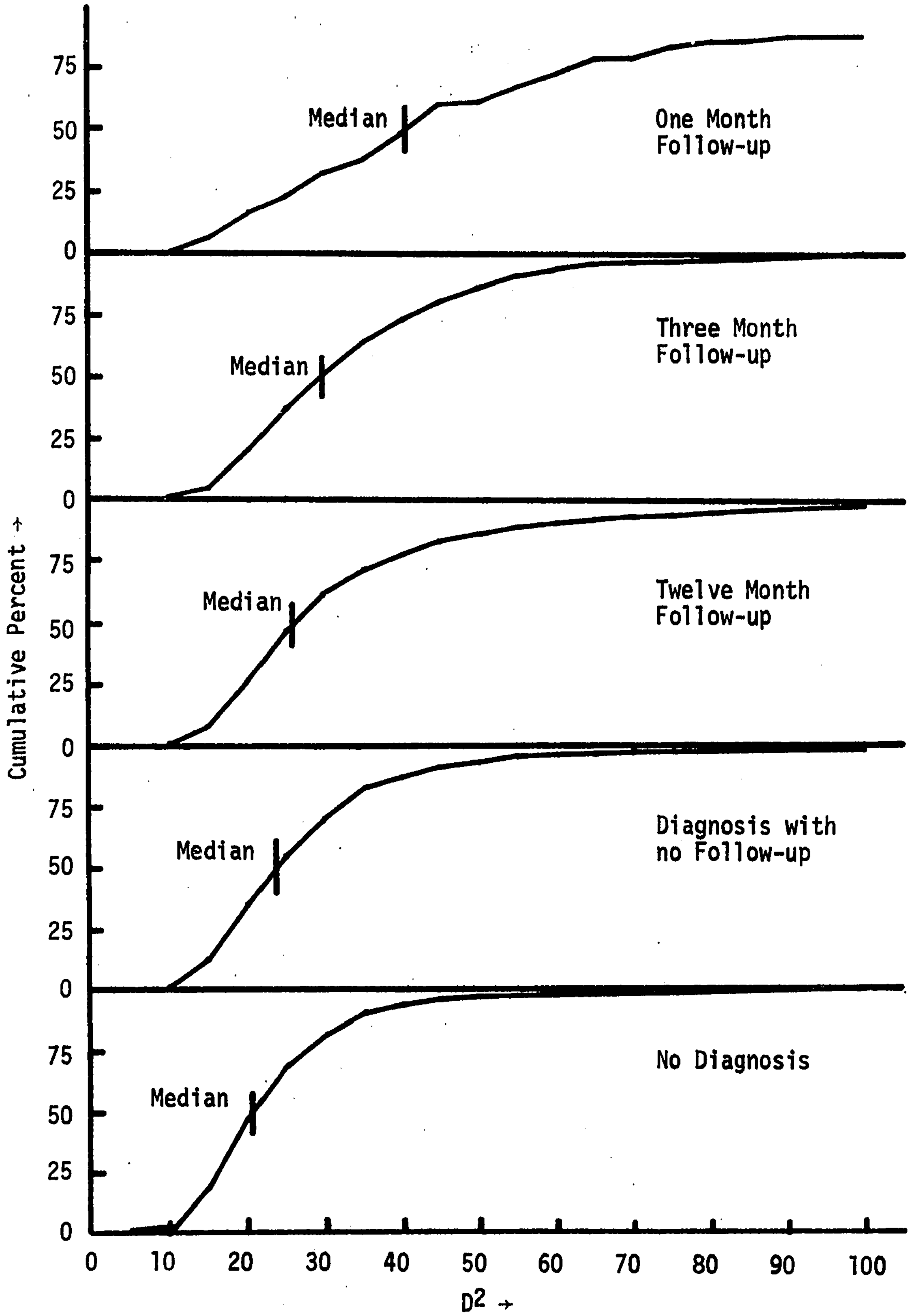

Figure 7--Distributions of D^2 by follow-up time for total study population.

TABLE 6

SUMMARY STATISTICS OF THE INDEX CALCULATIONS ON THE TOTAL STUDY POPULATION FOR ALL FOUR HEALTH CATEGORIZATION SCHEMES

		NUMBER OF DIAGNOSES		
Number of Diagnoses	Mean D^2	Standard Deviation	Standard Error	Sample Size
0	23.93	19.46	.31	3863
1	31.56	43.10	1.03	1750
2	34.73	53.49	1.82	860
3	37.89	43.38	2.03	457
4+	41.00	50.40	2.70	348
		CURRENT STATUS		
Status Code				
1	23.93	19.46	.31	3863
2	26.25	12.44	1.12	124
3	32.90	45.26	.88	2664
4	41.08	56.05	2.24	627
		FOLLOW-UP TIME		
Follow-up Code				
1	23.93	19.46	.31	3863
2	30.27	41.01	.95	1855
3	36.36	50.60	1.75	840
4	40.27	52.24	2.01	677
5	63.39	81.02	12.36	43
		WORK RESTRICTIONS		
Restriction Code				
1	27.27	28.47	.37	6000
2	34.00	63.21	2.63	577
3	26.79	12.25	2.67	21
4	32.01	39.69	2.22	320
5	0	0	0	0
6	24.84	11.01	3.89	8
7	22.21	6.74	2.55	7
8	195.69	300.73	173.62	3
9	41.18	57.24	3.10	342

combination of groups has apparently provided an element of stability to the index. The ordering scheme based upon number of diagnoses has mean D^2 values that not only are increasing monotonically but almost uniformly. Current status and follow-up time exhibit the same supportive patterns as before, while work restrictions still seem to contribute little useful information.

CHAPTER IV

CONCLUSIONS

If one accepts the hypothesis that any or all of the three primary intuitive categorization schemes reflect changing levels of health, then the proposed index does seem to provide a rudimentary quantification of different levels of health. This dissertation offers an alternate approach and methodology to the construction of a health index.

Little effort has been made toward optimization of the set of measurements. Obviously this would have to be done before any practical application of this procedure could be realized. Optimization would require not only a more representative population, but some general agreement on what constitutes an acceptable index. In this work, an acceptable index has been implicitly defined as one that would mirror, (independently) the intuitive levels of health. The problem is, of course, that until a generally acceptable definition of health is coined, researchers will continue to work with intuitive classifications of an intuitive concept.

Another major problem with this approach is with the definition of normal or baseline values with which to compare the populations. In this area consideration must be given, not only to philosophical discussions of normal and ideal, but also to biologic, geographic, and laboratory variation. The author proposes that the need for a "national clearinghouse" for clinical and laboratory measurements is indeed critical and should be given immediate attention.

Even with these shortcomings, this procedure for the measurement of health seems to be very promising. Application of this methodology to large populations would obviously require very sophisticated sampling procedures and substantial resources; however, this type of involvement has already been supported as evidenced by such projects as the National Health Examination Survey. It would be a simple matter, once normals are defined, to apply this type of index in smaller studies such as hospital surveys. In such situations, the manpower, equipment, and possibly the data are available.

An index constructed in this manner meets most of the proposed requirements for an acceptable index. With the possible exception of gradual genetic changes, it would be invariant over time - the first requirement that Sullivan (1966) imposed. It would also fulfill his second requirement, that it be subject to analysis into components. It would not be affected by socio-economic factors or availability of health services, as is the case with such indicators as physician visits, hospital days, disability days, etc. It does not at present include a measure of mortality; however, the completeness and quality of the mortality reporting system would be difficult to improve upon. In other words, new measures of mortality seem to represent a futile effort at this time.

Lastly, this type of index has obvious applications to population simulation research. The data quite possibly exist to construct a model population with these kinds of physical parameters. If such a model existed, it would then be a simple matter to simulate the introduction of, on the one hand, a disease epidemic, or, on the other hand, increased health services, thus providing an insight into the interactive effects of the various health parameters not presently available.

Most indices of health have failed to utilize the continuing advances being made in either statistical methodology or medical technology. It is hoped that this work will play some small part in remedying that situation.

CHAPTER V

SUMMARY

A great deal of effort has been expended in an effort to derive quantitative measures of health. Advances in medicine have triggered an evolution in emphasis from merely preventing early death to improving the quality of life. Whereas in the past, measures of mortality have been sufficient to evaluate needs and services, the complexity of today's health care system demands more sophisticated measures. A major problem encountered by those concerned with measurement and evaluation has been the lack of any widely accepted definition of what is to be measured. The concept of health is a very complex entity when one attempts to coin an operational definition. It is suggested that perhaps total understanding would be advanced if attempts at measurement were focused on the more elementary aspects of health. It cannot be argued that freedom from disease is at least a part of whatever constitutes health; and whatever the outcome of the philosophical discussions, it will always require attention. Therefore this dissertation has been concerned with the measurement of health in terms of freedom from disease.

The classic concept of disease is the inability of one or more of the organ systems of the body to function in a normal manner. Measures of disease have included such parameters as morbidity rates, physician visits, days of hospital utilization, disability days, and mortality rates to name a few. The problems in the collection of data to construct such indicators and the interpretation of the resultant measures are many. Diversity in type, need, and availability of health care render invalid comparisons made between populations based upon most existing indices.

It would seem safe to say that most Americans, at least, function with the same basic set of organ systems and that deviations in the capacity of these systems to operate, constitute a majority of what is referred to as disease. If, therefore, a measure of physiological function could be derived, it would in effect, measure disease. Evaluation of the functional capacity of an individual obviously requires a great deal of physician time in order to evaluate the pertinent data. However, if the emphasis is upon the identification of the presence of disease rather than the natural but more time-consuming diagnosis, then extended individual attention might be avoided. It has been the purpose of this dissertation to illustrate the development of an index of health utilizing accepted quantifiable indicators of physiological function.

Using the medical records of a large occupational medical program, a list of clinical and laboratory measurements was derived which are used in the evaluation of employee health. This list included such parameters as temperature, overweight, blood pressure and blood chemistry analysis. These parameters, referred to collectively as the measurement vector, (MV) were used as the basis for the quantification of health and were twenty-four in number.

Returning to the medical records, information on those employees that were free from clinically recognized disease or impairment was abstracted and these individuals were defined as "healthy" subjects. Since the population distributions of the parameters used are so dependent upon the factors age, sex, and race; the study was limited to white males and they were stratified by age. Records of the healthy subjects were then used to derive a mean MV for each age decade in the study population. Because of the fact that these mean MV's had been derived from a population that enjoyed above average health by virtue of being, for all practical purposes, disease-free, they were referred to as "ideal" vectors.

The hypothesis, then, was that a measure of the general health of a population could be arrived at through a comparison with that population's ideal MV, accounting, of course, for the appropriate demographic variables such as age and sex. The choice of the best method of making this comparison is not obvious. Due to the multivariate nature of the problem, the choice here has been a multidimensional measure of distance known as the Mahalanobis D^2. The basic idea was that each age group of the healthy subjects would generate a mean vector and covariance matrix, forming a vector space. The measure of health would then be equivalent to a measure of how far the observed MV is from the ideal MV in the vector space, relative to the variability of the data. As a measure of the health of a population, the proposal is to use a simple mean of the individual D^2's.

Several attempts were made to decrease the number of parameters included in the MV. The methods used for this reduction ranged from an attempt to combine the two measures of blood pressure to the use of a stepwise discriminant analysis to see if different parameters should be used for different age groups. It was felt that since different age groups do not experience the same health problems, it would be inappropriate to utilize the same parameters for all ages. Results of the discriminant analysis did not support this hypothesis; however, this should not be construed as being conclusive. The procedure was to subject a known healthy population and a relatively less healthy population to the discriminant analysis and to repeat the procedure varying the age of the populations. The problem is that this particular analysis uses a covariance matrix which is pooled from both populations. Since the covariance estimates used in the proposed index are taken entirely from the healthy population, it is not clear what interpretation should be given to the results of the stepwise discriminant analysis. In any case, a uniform set of parameters was retained for all age groups.

Verification that the index was actually measuring ill-health was a relatively complicated process. Included in the medical record of each employee is information regarding not only the fact of illness, but also information on how the illness is progressing, how long the attending physician is willing to wait before he requires a re-evaluation of the situation, and whether or not limitations should be placed upon the duties the employee is required to perform. This information was used to define several classification systems, each of which was an intuitive ordering of levels of health. For example, it was assumed that a population wherein every member had been evaluated by a physician and found to be free of disease, was in general, healthier than a population wherein every member had been diagnosed as having, say, two clinically recognized impairments.

The subject population was then partitioned according to these intuitive classification schemes in an attempt to simulate a test of the index on several populations whose relative health was a priori known. Results of this test support the hypothesis that an index constructed in this manner is, in fact, a measure of the general health of a population.

The advantage of this approach is that with appropriate choice of the ideal measurement vectors, valid comparisons can be made irrespective of time, geography, program intervention or a host of other complicating factors.

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APPENDICES

APPENDIX A

MEAN VECTOR FOR THE PRE-JULY 11, 1972 THIRTIES DECADE, CONSISTING OF 684-SUBJECTS

VARIABLE	ABBREVIATION	MEAN VALUE
TEMPERATURE	(TEMP)	98.37
PULSE	(PUL)	78.66
SYSTOLIC BLOOD PRESSURE	(SYBP)	126.6
DIASTOLIC BLOOD PRESSURE	(PIBP)	81.43
WHITE BLOOD CELL COUNT	(WBC)	73.69
HEMATOCRIT	(HEMA)	48.12
HEMOGLOBIN	(HEMO)	15.93
RED BLOOD CELL COUNT	(RBO)	53.99
MEAN CORPUSCULAR VOLUME	(MCV)	89.29
MEAN CORPUSCULAR HEMOGLOBIN	(MCH)	29.61
MEAN CORPUSCULAR HEMOGLOBIN CONCENTRATION	(MCHC)	33.08
SERUM CALCIUM	(CACC)	9.614
INORGANIC PHOSPHOROUS	(PHOS)	3.318
SERUM GLUCOSE	(GLUC)	107.2
BLOOD UREA NITROGEN	(BUN)	13.74
URIC ACID	(URAC)	6.026
SERUM CHOLESTEROL	(CHOL)	218.7
TOTAL SERUM PROTEIN	T-PR	7.459
ALBUMIN	(ALBU)	4.982
TOTAL BILIRUBIN	T-BI	.5418
ALKALINE PHOSPHOTASE	(ALPH)	67.35
LACTATE DEHYDROGENASE	(LDH)	151.8
SERUM GLUTAMIC - OXALACETIC TRANSAMINASE	(SGOT)	39.75
PONDERAL INDEX	(POND)	7.956

APPENDIX B

GUIDE TO INTERPRETING TABLES OF VARIANCE - COVARIANCE
AND CORRELATION ESTIMATES

	PART I						PART II					
	TEMP	PUL	SYBP	DIBP ...	MCHC	CAL	PHOS	GLUC ...	ALPH	LDH	SGOT	POND
TEMP	—											
PUL		—										
SYBP			—									
DIBP				—								
.												
.												
.												
ALPH									—			
LDH										—		
SGOT											—	
POND												—

VARIANCE ESTIMATES UNDERLINED ON THE DIAGONAL WITH CORRELATION ESTIMATES ABOVE

CORRELATION ESTIMATES BELOW THE DIAGONAL

APPENDIX C

VARIANCE - COVARIANCE AND CORRELATION ESTIMATES FOR THE PRE JULY 11, 1972 THIRTIES DECADE - PART I

	TEMP	PUL	SYBP	DIBP	WBC	HEMA
TEMP	.3103	1.956	1.021	.6830	1.435	.1029
PUL	.3103	128.0	22.75	19.58	40.16	4.625
SYBP	.1499	.1645	149.5	68.58	11.21	3.614
DIBP	.1330	.1878	.6086	84.94	-.1840	5.618
WBC	.1120	.1543	.0398	-.0009	529.2	18.85
HEMA	.0649	.1435	.1038	.2140	.2877	8.113
HEMO	.0498	.1298	.0844	.1865	.1871	.8270
RBC	.0093	.1171	.0865	.1164	.1012	.5545
MCV	.0477	-.0004	-.0244	.0397	.1649	.2327
MCH	.0434	-.0083	-.0423	.0372	.0764	.1529
MCHL	-.0148	-.0206	-.0363	-.0162	-.1734	-.1912
CALC	.1394	.1030	.1377	.2165	.0521	.2867
PHOS	.0138	.0378	-.0730	-.0312	.0447	-.0765
GLUC	.2737	.2328	.1645	.1081	.0035	.0178
BUN	-.0553	-.1333	-.0332	-.0111	-.1166	-.0389
URAC	.0159	.0267	.2211	.2840	-.0203	.0083
CHOL	.0397	.1111	.0153	.0290	.1244	.2150
T-PR	.1874	.1108	.1620	.2570	-.0020	.1982
ALBU	.0097	-.0232	.0681	.0744	-.0338	.1783
T-BI	-.0451	-.0594	.0107	.0580	-.1910	.0240
ALPH	.1208	.1008	.1024	.1172	.1948	.2148
LDH	.1088	.1155	.1650	.1805	.0993	.1238
SGOT	.1432	.1374	.1868	.2299	-.0048	.1550
POND	.1284	-.0091	.1932	.3134	.0279	.0254

PART I--Continued

HEMO	RBC	MCV	MCH	MCHC	CALC
.0264	.0203	.1501	.0432	-.0102	.0286
1.397	5.224	-.0287	-.1674	-.2882	.4296
.9823	4.172	-1.688	-.9250	-.5472	.6209
1.635	4.231	2.068	.6138	-.1844	.7359
4.094	9.179	21.44	3.147	-4.923	.4422
2.241	6.227	3.746	.7793	-.6724	.3011
.9051	2.267	.0733	.4033	.3624	.0914
.6044	15.54	-14.02	-4.077	.5775	.2798
.0136	-.6290	31.95	8.390	-1.689	.0806
.2369	-.5777	.8292	3.204	.5014	.0161
.3086	.1187	.2678	.2269	1.524	-.0175
.2607	.1925	.0387	.0244	-.0385	.1360
-.0629	-.0404	-.0071	-.0019	.0376	.0939
.0088	-.0069	.0271	.0262	.0321	.1065
.0029	.0341	-.0733	-.0318	.0920	.0747
.0908	.0551	-.0677	.0131	.1294	.1645
.1444	.0826	.0933	.0305	-.0873	.1862
.1280	.1512	.0322	-.0282	-.0818	.5139
.1339	.1147	.0240	.0012	.0223	.4338
.1415	.1274	-.1010	.0032	.2137	.1527
.1186	.0080	.1958	.1235	-.0967	.1255
.0356	-.0118	.1406	.0738	-.0789	.0780
.0953	-.0215	.1696	.1238	-.0649	.1295
.0685	.0609	-.0729	-.0236	.0760	.0127

VARIANCE - COVARIANCE AND CORRELATION ESTIMATES FOR THE
PRE JULY 11, 1972 THIRTIES DECADE - PART II

	PHOS	GLUC	BUN	URAC	CHOL	T-PR
TEMP	.0050	3.072	-.1070	.0106	.9250	.0418
PUL	.2784	53.06	-5.241	.3618	52.61	.5024
SYBP	-.5808	40.52	-1.412	3.243	7.798	.7942
DIBP	-.1862	20.06	-.3564	3.139	11.18	.9497
WBC	.6692	1.637	-9.320	-.5589	119.7	-.0182
HEMA	-.1417	1.023	-.3851	.0282	25.61	.2264
HEMO	-.0389	.1686	.0095	.1037	5.745	.0488
RBC	-.1037	-.5486	.4677	.2609	13.62	.2389
MCV	-.0263	3.089	-1.441	-.4591	22.04	.0730
MCH	-.0022	.9454	-.1981	.0281	2.282	-.0202
MCHC	.0302	-.7985	.3949	.1917	-4.506	-.0405
CALC	.0225	.7916	.0958	.0728	2.871	.0760
PHOS	<u>.4231</u>	1.460	-.0423	.0521	1.017	.0317
GLUC	.1114	<u>406.0</u>	1.293	1.884	24.18	1.453
BUN	-.0187	.0185	<u>12.08</u>	.1415	2.870	.0670
URAC	.0668	.0779	.0339	<u>1.439</u>	1.015	.0820
CHOL	.0374	.0287	.0197	.0202	<u>1749.</u>	2.658
T-PR	.1215	.1799	.0481	.1704	.1586	<u>.1607</u>
ALBU	-.0454	-.0248	.0059	.1064	.0501	.2880
T-BI	.0465	.0869	.1580	.1808	-.0821	.2017
ALPH	-.0670	.0515	-.0715	.0485	.1529	.1119
LDH	.0451	.0642	-.0469	.1549	.1131	.1411
SGOT	.1063	.1266	-.0941	.2525	.0626	.2266
POND	-.0186	.0752	.0834	.3265	.0715	.0033

PART II--Continued

ALBU	T-BI	ALPH	LDH	SGOT	POND
.0017	-.0072	1.461	1.572	1.455	.0250
-.0834	-.1930	24.77	33.90	28.35	-.0361
.2651	.0377	27.19	52.33	41.65	.8244
.2183	.1535	23.45	43.16	38.64	1.008
-.2474	-1.263	97.28	59.29	-1.998	.2241
.1616	.0196	13.28	9.152	8.055	.0252
.0405	.0387	2.450	.8776	1.654	.0227
.1439	.1443	.6839	-1.203	-1.547	.0838
.0432	-.1640	24.02	20.62	17.49	-.1438
.0007	.0017	4.799	3.428	4.043	-.0148
-.0087	.0758	-2.592	-2.528	-1.462	.0328
.0509	.0162	1.005	.7467	.8707	.0016
-.0094	.0087	-.9468	.7606	1.261	-.0042
-.1587	.5031	22.54	33.54	46.54	.5290
.0066	.1578	05.396	-4.227	-5.966	.1012
.0406	.0623	1.262	4.822	5.523	.1367
.6665	-.9870	138.8	122.7	47.75	1.044
.0367	.0232	.9740	1.468	1.657	.0005
_.1013_	.0114	-.6356	.3365	.0012	-.0074
.1248	_.0826_	-.5599	.0932	.5325	-.0016
-.0920	-.0898	_471.4_	85.29	86.38	.6314
.0408	.0125	.1514	_673.2_	199.5	1.490
.0002	.1016	.2181	.4216	_332.6_	1.080
-.0670	-.0160	.0833	.1645	.1697	_.1218_