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**VITAL and HEALTH STATISTICS**

DATA EVALUATION AND METHODS RESEARCH

# **Methods for Measuring Population Change**

## **A Systems Analysis Summary**

An introductory study of varying requirements of data for the measurement of population change, and of the alternative methods which are available to obtain these data, using a systems analysis approach. Data requirements are grouped into four categories, and seven major statistical methods are explored and rated in terms of their usefulness in furnishing each type of data.

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*With increasing concern about rapid growth of the population, in this country as well as in many less developed countries, and with the widespread adoption of family planning programs, there is a growing need for methods of measuring population change. Considerable resources have been and will be expended in the collection of data to measure population change. A systems analysis approach is described which, by examining different methods of measurement in relation to the varying types of data required, would lay the foundation for decisions on where additional theoretical methodological research should be concentrated to improve the adequacy and precision of existing methods and to identify methodological gaps for which new methods are required.*

*The four broad classes of population data requirements are summarized under four headings: (1) data content requirements, (2) population composition requirements, (3) geographic area requirements, and (4) time requirements.*

*The armamentarium of statistical methods available to meet these requirements is then explored. The statistical methods are considered under seven major headings: (1) the conventional population census, (2) the conventional vital registration system, (3) continuous population registers, (4) sample registration systems, (5) sample interview surveys, (6) panel longitudinal studies or repetitive cross-section surveys, and (7) a combination of methods in "demographic measurement laboratories."*

*After a brief description of each method, the methods are then examined, taking each one separately, as to their suitability with regard to the four groups of data requirements. Each method is rated for each of the data requirements on a judgmental scale of strong, medium, and weak. These evaluations are summarized in table A (p. 10).*

# METHODS FOR MEASURING POPULATION CHANGE

## A SYSTEMS ANALYSIS SUMMARY

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### 1. INTRODUCTION

The world is now in a period of extremely rapid population growth. This is a continuing process of growth that started in the far past with a slower rate and smaller absolute increments but is now growing at a faster rate with rapidly increasing absolute increments.

Examining official and unofficial estimates of past and future world population totals,<sup>b</sup> the following first order differences for successive 50-year intervals can be seen:

Between 1750-1800, increased	187,000,000
Between 1800-1850, increased	284,000,000
Between 1850-1900, increased	388,000,000
Between 1900-1950, increased	865,000,000
Between 1950-2000, will increase	3,615,000,000.

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<sup>a</sup>Forrest E. Linder is Professor of Biostatistics at the School of Public Health of the University of North Carolina, Associate Director of the Carolina Population Center, and consultant to the National Center for Health Statistics international statistical program. This study was supported entirely by PHS Research Grant No. HD03441 from the National Institute of Child Health and Human Development to the University of North Carolina.

<sup>b</sup>Many differing population estimates are available, but within narrow limits determined by different assumptions and methods of calculation, the same broad interpretation emerges. The above figures are derived from the U.N. World Population Prospects<sup>1</sup> and Durand<sup>2</sup>.

The impact of these rapid increases does not fall equally on every country of the world. The increases are generally proportionally larger in the less developed countries of the world and many of these have adopted national policies and instituted specific programs designed to slow the rate of national population growth. It is estimated that more than half the people of the less developed nations now live in more than 25 countries with policies and programs to reduce birth rates by family planning.<sup>3</sup>

The population problem is not limited to countries in the early stages of economic development. It is true that for many Americans the population question is generally viewed as a world problem, and one removed from day-to-day living in the United States. But the United States also has a domestic population problem although it is of a different type than the global problem.

On a global basis and in the less developed countries, there are immediate warnings of extensive starvation with continuing social and political unrest. In the United States there is no foreseeable danger of wide-spread malnutrition due to an overall shortage of food. On a global basis there can be valid concern in many areas that the population is rapidly approaching a magnitude where the land-space is inadequate to permit an acceptable mode of life considering the probability of slow economic and social development. The United States, at least in the near future, does not face this desperate space problem.

However, the American people are used to an extremely high level of living in terms of open space and the domestic population pressure may therefore be rapidly approaching unacceptability. There is considerable doubt that Americans will be willing to gracefully accept drastic changes in their accustomed mode of living, and yet U.S. population growth is forcing such changes.

These considerations, together with the fact that in the United States the deleterious effects of population growth are concentrated in the less affluent sectors of the population, have led to a positive U.S. population policy and programs to make family planning information available to all who desire it.<sup>4,5</sup> Appropriations specifically earmarked for population programs by the U.S. Congress for research, domestic action programs, and for foreign assistance have rapidly increased for the fiscal years 1967, 1968, and 1969.

It is easy to recognize that a population problem does exist. The crudest type of existing statistical data make this evident. But to measure more subtle population changes; to evaluate the social, economic, and cultural factors that facilitate population change or create barriers to it, requires more sophisticated measurement instruments. Programs for the modulation of population growth will be extremely costly, will extend over long periods of time, and may produce results that will be obscure in the initial phases. Many false starts will be made, many programs will fail to penetrate to the population sectors most concerned, and some approaches may have a negative rather than the expected positive effect.

The timely evaluation of these programs will require effective, sensitive, and relatively inexpensive measurement tools capable not only of giving an early indication of changes in vital rates but of revealing significant factors related to such changes. The statistician concerned with such measurement problems has at his disposal a considerable array of measurement methods or tools, but each of these methods has certain intrinsic limitations as well as varying technical and administrative difficulties or defects. A review of these tools, first in relation to their suitability to meet the broad needs for population change measurement instruments, and

then, in more depth, with regard to the special technical power of each, will be of value in selecting operating methods to be used in the field as well as in identifying basic and operations research which may be needed to improve the existing methodology.

## 2. THE SYSTEMS ANALYSIS APPROACH<sup>c</sup>

An organized analysis of the attributes of statistical methods in relation to the measurement of population change is justified because of the extensive resources that are being and will continue to be put into data-collection activities. It cannot be assumed that all of these methods will be successful and there is substantial evidence, using the criteria of the amount of valid data produced on changing vital rates, that there is substantial waste effort. The conventional census procedure produces no direct data on change of vital rates, and the validity of survey methods at their present level of technical development has serious defects.<sup>d</sup> In spite of such defects the needs for data are so great that survey activity for collecting new data on fertility topics will continue to increase. A committee of the International Union for the Scientific Study of Population has published an extensive list of recommended topics for fertility studies.<sup>14</sup> The Population Council has published a valuable collection of questionnaires on KAP (knowledge, attitude, and practice) surveys<sup>15</sup> and is preparing a standard operating manual. The U.S. Bureau of the Census is recommending to countries a comprehensive package of survey proposals including suggested methods for measuring vital

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<sup>c</sup>The definitions and concept of "systems analysis" differ greatly but generally "the systems approach involves identifying a problem, defining the objectives which must be achieved to solve it, considering alternative methods for meeting these objectives, and choosing the most attractive alternative by rigid cost-effectiveness analysis, by intuition and judgment, or by something in between,"<sup>6,7</sup>

<sup>d</sup>Som and others have written on nonsampling errors and biases in retrospective demographic inquiries.<sup>8-13</sup> The National Center for Health Statistics has published a number of studies on survey response error in *Vital and Health Statistics*, Series 2.

rates.<sup>16</sup> There is a substantial possibility that these types of recommendations will encourage expanded data-collection activities without a critical appraisal of the validity of the data collected. The likelihood of waste effort and invalid results are particularly great in reference to ad hoc fertility surveys. The conventional census and vital statistics systems have deficiencies but at least these methods have the benefit of over 100 years of international study and the cooperative formulation of recommendations, so that the subject coverage has been reduced to the most manageable and important topics and the nature of the deficiencies is well known.<sup>9</sup> Although experience is now being rapidly accumulated, this "shakedown" process has barely started for fertility surveys.

A systems analysis of existing methods in relation to present requirements is only an initial step in developing a theory of measurement of population change. And even a detailed systems analysis cannot be definitive since a systems analysis is an iterative process leading to different conclusions as requirements and methods change and as more precise information on the short-comings and strengths of the different methods is known.

The first step in a systems analysis of population change measurement methods would be an examination of the broad requirements or uses that any system of measurement methods must satisfy. These are more complex and inter-related than may seem at first glance and it is certain that no one statistical procedure will meet all of the requirements. The next step is to identify and clearly define the armamentarium of statistical tools or methods that can be used to deal with the measurement of population change. An examination of the attributes of the various methods in relation to the broad requirements would then lay the foundation for decisions on where additional theoretical methodological research should be concentrated to improve the adequacy and precision of existing methods and to identify methodological gaps for which new methods are required.

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<sup>9</sup>For the latest formulation of these international recommendations see United Nations Recommendations. 17,18

In examining the extent to which statistical methods satisfy the stated requirements it will be difficult to separate characteristics of each method which are to some degree intrinsic to the method from characteristics which are merely a consequence of the available resources or of good or bad administrative or operational practice.

The different methods do require different types of field organization, different types of specialized personnel, and different levels of financial expenditure. If these factors are substantially changed, then a method as defined here becomes almost a different method. It is conceivable that almost any deficiency of any method could be reduced or eliminated by an adequate infusion of operating resources and by superior administrative conditions. Inversely, of course, even the best technical methods can be vitiated by insufficient resources or operational incompetence. In spite of this, *considering the pattern within which the different methods are in fact usually used*, the methods have intrinsic limitations and advantages which may be considered in relation to different measurement requirements. This discussion is concerned primarily with these intrinsic limitations and advantages rather than with the characteristics most susceptible to administrative change.

The broad analysis suggested above should then be followed by a detailed study of each defined method. These following studies should consider each method in detail, carefully identifying the technical character of each method, the administrative requirements in terms of organization, personnel and budget, synthesizing practical experience that has accumulated, and revealing important technical problems which require new basic or operational research.

It is the purpose of this paper to attempt only the initial broad analysis of requirements and methods. A detailed examination of the attributes of each statistical tool can then follow with the benefit of some overall reference framework within which each method can be oriented.

For either the broad analysis or the detailed examination of an individual method it is important to have a practical judgment of how much precision is really required to serve the pur-



poses for which the data are collected. Perfect data are seldom if ever necessary. Even approximate data may be sufficient to indicate a general course of action and rough data may be sufficient to permit an administrative judgment as to whether that course of action needs to be changed. With regard to the soundness of their statistical bases, many public health programs have proceeded on a philosophy of "as if" and with regard to population action programs many different types of considerations other than those based on statistical fact may determine their direction, thrust, and velocity. Nevertheless, it can scarcely be denied that accurate data can be used to avoid tremendous waste in planning and evaluating administrative operations and in general, more precision makes possible more rational program administration.

It is also necessary to define the boundaries within which the systems analysis is to be undertaken. The concept of a systems analysis is broad in scope and, without definite boundaries, the analysis could tend to range in a too amorphous manner over the entire field of statistical method. There are numerous requirements and subrequirements for data and numerous minute features of the different methods. These are interrelated to form a complex too broad for a single treatment. There is, of course, a vast literature dealing with the mathematical or analytical adjustment, graduation, subtabulation and computational treatment of defective data, and with extracting estimates of vital rates from partial information. Some of these methods and new techniques are summarized in various sessions of professional conferences.<sup>19</sup> The United Nations has also published a detailed manual on these methods.<sup>20</sup> This article is not intended to deal with this class of method but rather to be directed to the problems of obtaining more adequate data in the first place.

Even in the area of original data collection there are certain types of problems which will not be considered. In general, consideration will be limited to those methods most directly applicable to the measurement of the net effects of programs intended to achieve some reduction in the rate of population growth. Within these terms of reference there are some statistical problems and methods which are not studied. Some of these

are methods relating to administrative evaluation of operating programs, the collection of service statistics,<sup>21</sup> and the use of microsimulation schemes to estimate vital rate changes.<sup>22</sup>

### 3. MATRIX OF REQUIRED MEASUREMENT FACTORS

The required factors or attributes that any measurement system should have depends upon the broad purpose that the system is designed to serve.<sup>23</sup> Some statistical systems are designed to serve a number of different purposes, and the methods used evolve into a compromise procedure which is thought appropriate to balance its suitability to these various purposes. The intent here, however, is not to examine the major statistical data-collection methods from the point of view of their adequacy in meeting several general needs, but to examine in a more limited way their adequacy in meeting the specialized purposes as measuring tools to detect the end results of programs directed at the reduction of the rate of population growth—that is, the measurement of changes in vital rates (birth and death rates) or the measurement of the net results of such changes.

The variety and pioneering character of the population modulation programs that are being initiated in various countries of the world is evidence that even within the limits of the purpose stated above, measurement methods must be designed that will satisfy a number of distinct requirements. It is obvious that one single method or procedure will not suffice. In brief, the requirements that must be met can be grouped into four broad classes: (1) data content/requirements, (2) population composition requirements, (3) geographic area requirements, and (4) time requirements. The optimum satisfaction of only one of each of these requirements might result in the selection of a statistical method that would be entirely inadequate in relation to the other groups of requirements. But since these groups of needs are all interrelated and must all be satisfied to some extent, they constitute a matrix of requirements. In effect this matrix becomes a multidimensional mold which partially defines the desired measurement tools. It is clear that the matrix described for dis-

cussion is not a complete matrix for evaluation purposes, since the choice of a measurement method to be used may depend upon factors not considered in detail here such as cost requirements, needs for specialized personnel, specifications for minimum sampling errors, and so forth. It is hoped that factors such as these will be considered in more detail in subsequent analysis of the methods.

### **Data Content Requirements**

If the primary purpose under consideration here is the measurement of changes in vital rates, the main requirement with regard to data content is that the method include information on the number of births and deaths together with any additional information which is necessary to convert such gross numbers to rates. While this is the obvious major requirement, it is by no means sufficient, since the appraisal of the effects and causes of population control programs requires knowledge of many factors related to the manner and rapidity of population change as well as the range of variables which may affect, in a positive or negative way, the design and operation of the population programs themselves. The International Union for the Scientific Study of Population<sup>14</sup> as well as other agencies has made recommendations for items for such related variables.

No doubt some of the many items suggested have little or marginal value and in time a more concise list of essential and tested items will emerge. However, there is no doubt that any completely satisfactory statistical procedure must be capable of coping with the collection, processing, and analysis of a wide variety of substantive items. It does not follow, of course, that any single statistical tool must encompass the whole range of substantive topics, but the available armamentarium of tools must meet the needs for many different types of data.

### **Population Composition Requirements**

The substantive items referred to above are in many cases of little value unless they can be expressed as rates by reference to an appropriate population base. This obviously requires that the

total population serve as a base but it is also essential that the various strata or elements that makeup the composition of the total population serve as bases. The population of any nation is not usually spread evenly over all population composition elements and population action programs must be designed to differentially relate to these elements. For example, in some countries the population problem may be more or less acute among the different economic classes. In some instances, the more affluent economic classes may already have easy access to family planning information with the resultant birth rates reflecting their desired family-size norms. In the United States this is the case and accordingly the thrust of the official programs is to bring this same knowledge to the less affluent sectors of the population. In other countries the population problem may be primarily the problem of the predominantly rural areas.

For such reasons, the whole necessary analysis of the changes of population may depend upon a differential study of numerous sectors of the population—by social and economic variables, by education, by demographic variables such as age, by urban-rural sectors of the populations, and by various religious, ethnic, and nationality groups. The point is not only whether these data can be collected in relation to the data-content items discussed above but whether a population base for rate computation can be also compiled and classified according to these variables. Some survey designs and other data-collection systems may produce the numerator information for rate calculation but fail to produce the denominator population base classified by the required categories.

### **Geographic Area Requirements**

The geographic area requirements for adequate measurement of population change are perhaps the most difficult to meet. For certain important purposes, such as national economic planning, a nationwide measure of change in vital rates is most essential, since these rates determine the gross rate of population growth and this in turn defines an important aspect of a national plan for economic and social progress. However, action population programs are not

necessarily administered in a uniform way from a national center and, even if they were, the problems and results vary by geographic areas as well as by population composition factors. In large federated countries, program administration may be a responsibility of state or provincial administrations with great variation in the program design, available resources, and efficiency of administration. This creates a demand for population growth data not only for the national totals, but for subnational geographic or political divisions such as states, cities, and minor civil divisions. Since family planning programs are still in an experimental stage of development there may also be a need for precise data for large program developmental regions or areas and even for small experimental units established to evaluate different program designs.

From a theoretical point of view it is conceivable that an ideal statistical method could be designed and successfully applied to the smallest geographic area required and that this method could then be expanded to larger and larger geographic units until the total national area was covered. However the resource and logistic demands of this approach for most if not all of the methods considered here would seem to rule it out as a practical approach for the near future.

#### Time Requirements

Family planning programs are difficult to organize and are extremely expensive in terms of budget and manpower. Such programs are designed in various ways based on differing premises and differing strategies of program operation. To prevent enormous waste effort it is essential that some method of appraising the effective results of such programs be used which can detect changes in population growth rates over relatively short time periods. For more classical types of demographic analysis or for historical demography such long-interval statistical procedures such as the traditional census may be adequate. It was from the analysis of decennial census data that the world has been brought to an appreciation of the urgency and magnitude of the world population problem. However, for program evaluation a decade-interval is much too

long as a statistical measure of population change. In addition to the needs for evaluation of population action programs, the study of short-term changes in vital rates, such as those related to economic fluctuations, war activities, and poor agricultural seasons, require at least a year-to-year measure of changes in vital rates, and for some purposes an even more current index.

## 4. THE ARMAMENTARIUM OF STATISTICAL METHODS

It will be clear that to meet the specifications of the matrix of required measurement factors a variety of statistical methods may have to be employed. Broadly speaking the statistical methods which are available as data-collection procedures may be considered under seven major headings: (1) the conventional population census, (2) the conventional vital registration system, (3) continuous population registers, (4) sample registration system, (5) sample interview surveys, (6) panel longitudinal studies or repetitive cross-section surveys, and (7) a combination of methods which might be called "demographic measurement laboratories." The total statistical program in any country directed at measuring population changes and carried on by official and unofficial data-collecting and research agencies will probably comprise some combination of all of these methods. Yet, a careful examination of each major method in relation to the matrix of requirements will permit the development of an eclectic compilation and research program of maximum utility.

Among the seven major groups of statistical methods listed, the conventional population census and the conventional vital registration system have rather clear internationally accepted definitions.<sup>17,18,24,25</sup> The other methods require some additional degree of definition and description before they can be evaluated in terms of the general requirements that have been set up. Even for the census and the vital registration system it may be worthwhile to reemphasize some of their essential attributes in the same manner as for the other methods, so that the different methods as defined and discussed in this article are clearly differentiated.

## Conventional Population Census

The concept of the conventional population census is generally well understood, but the term is sometimes used also to refer to a variety of data collection procedures which are not "population censuses" in the more precise meaning of the term. The examination of the census in this paper refers to the method defined by the United Nations<sup>25</sup> in these terms: "A census of population may be defined as the total process of collecting, compiling and publishing demographic, economic and social data pertaining at a specified time or times, to all persons in a country or delimited area." The United Nations source lists some of the essential features of a national census as: (1) must be officially sponsored or carried out by a national government, (2) must relate to a precisely defined area, (3) must be universal in the sense of covering all persons within the defined scope of the census, (4) must be a total enumeration referring to a well-defined point in time, (5) must be a collection of separate data for each individual and not merely some process of aggregating group totals, and (6) must be carried through to the compilation and publication of data by geographic areas and by basic demographic variables.

## Conventional Vital Registration System

Some form of legal provision and permanent organization for the continuous registration of vital events exists in practically every nation of the world. The United Nations *Handbook of Vital Statistics Methods*<sup>24</sup> defines this process as follows: ". . . a vital statistics system can be defined as including the legal registration, statistical recording and reporting of the occurrence of, and the collection, compilation, analysis, presentation, and distribution of statistics pertaining to 'vital events', which in turn include live births, deaths, fetal deaths, marriages, divorces, adoptions, legitimations, recognitions, annulments, and legal separations." The registration method is defined as ". . . the continuous and permanent, compulsory recording of the occurrence and the characteristics of vital events primarily for their value as legal documents as provided by law and secondarily for their usefulness as a source of statistics . . ."

Obviously the vital statistics systems of most countries fall short of this comprehensive definition in one way or another, either by not covering all of the different vital events specified or by operational deficiencies in covering completely the types of events specified by the national legal basis of the system. In this paper the primary concern is with the system as the source of statistics on births and deaths although the other vital events are also of interest as factors indirectly related to population growth.

## Continuous Population Register

The continuous population register starts with a base of census-type information to which continuous corrections and additions are made with an input of data derived from a vital registration system and other administrative reports. Because of the necessity to make change-of-residence corrections the record systems are typically maintained at a local level. The method of extracting statistical information from a large number of local registers and consolidating it for national totals varies from system to system. Population register systems are theoretically attractive because the same system produces data on the number of births and deaths as well as the corresponding population base. However, the systems are highly sophisticated in that they require very precise input data, a disciplined and literate population to report regularly changes in demographic status, and accurate procedures for matching records and compiling data from them.

The concept of a continuous population register is not uniquely defined. Many variations in the design and the purposes of the systems exist.<sup>26</sup> The best known systems are those in several north European countries and the Japanese Koseki system. In most instances the systems have not been established for the purpose of creating statistics but for other administrative objectives and in general the statistical output from the systems has been disappointing, although increasing attention has been given to this statistical byproduct of the systems.<sup>27</sup>

## Sample Registration System

The conventional registration system fails to serve its purposes in many situations because

the technical manpower and financial resources are inadequate to produce vital statistics at a useful level of quality. The concept of a sample vital statistics system is that available resources could be concentrated on the administration of vital registration in a limited group of geographic areas selected as an adequate sample of the whole country or some subnational major civil division and in this way produce an acceptably accurate estimate of birth and death rates for that political geographic unit. Earlier descriptions of the sample registration concept<sup>28</sup> visualized the sample registration units as reenforced units of the already existing national registration system so that the number of sample units could be gradually increased resulting ultimately in an improved nationwide conventional vital registration system. Since a vital registration system does not in itself produce the population base figures necessary for the computation of vital rates, most experimental efforts to establish a sample vital registration system have included an overlay of sample interview surveys partly to estimate the population of the sample area and partly to yield an independent report of births and deaths based on retrospective responses of the interviewees. A rather wide variety of designs have been tried, some in which the registration element of the system is quite independent of the official registration organization, some in which elaborate matching between the individual records of the registration and survey is attempted, and some in which the method is essentially a sequence of surveys with less emphasis on the continuous registration process. Some of these variations in method are described in a number of papers.<sup>29-34</sup>

### Sample Interview Survey

In some respects the sample interview survey method resembles the census technique except that with the advance in the theory and practice of population sampling these surveys can be conducted on a smaller number of respondents—a fact which permits many changes in data collecting techniques. Sample surveys for demographic purposes may be conducted with sample units consisting of individuals, households, or defined geographic areas. The items of data collected may be items of current fact (e.g., present

marital status) or retrospective items (e.g., total number of children ever born). Surveys can be designed to produce estimates of a wide variety of items and at the same time population estimates in the required detail to convert the gross estimates of the variables to demographic ratios or rates. Sample surveys have almost unlimited flexibility as to the scope of their subject matter and geographic coverage, but their wide potential and relative economy tends to encourage their use without due attention to the many technical problems of survey design and administration and without a critical evaluation of the validity of the data collected for newer and untested topics. Nevertheless the power and the adaptability of the sample interview survey assure it a role of increasing prominence as a method of collecting data on factors related to population change.

### Panel Longitudinal Studies

The concept of the panel longitudinal followup method of studying population change is simply that of selecting an initial panel of persons, according to criteria determined by the purposes of the study, and making periodic observations on this group by repeated interview surveys and the collection of other records so as to create a complete history of the changing facts which are pertinent to the study for each person in the panel. Unfortunately the needs and requirements for this method of study have not been clearly analyzed and they are generally difficult from an administrative as well as an analytical point of view.<sup>35</sup> The term "longitudinal" study is applied to a number of quite different study designs, and for some of these designs, even if data are collected longitudinally, the analysis is basically little more than a series of cross-section studies. Longitudinal studies are essential where a variable must in some sense be integrated over a time period for each individual or where the outcome of a particular act is being studied. While important for medical studies, longitudinal types of investigation would seem to have fewer advantages for general studies of population change. Studies of this type require perhaps more sophistication and data collecting precision than population register systems, but are more feasible because the number of persons in a panel is usually quite small.

## Demographic Measurement Laboratories

The concept of a demographic measurement laboratory is a relatively new concept for demographic studies, but is a long established method for the study of health conditions of a population and for developing improved methods for measuring such attributes. The Eastern Health District of Baltimore established in the 1930's by Johns Hopkins School of Hygiene, the Hagerstown area administered by the U.S. Public Health Service, the Tecumseh area in Michigan designed by the Michigan School of Public Health, the Arsenal Health district in Pennsylvania established by the Pittsburgh School of Public Health, and the California Population Laboratory under the direction of the California State Health Department are varying examples of this general concept as applied to problems of population health and medical care. These different study areas have produced a great wealth of published data on health and health measurement methodology, but unfortunately there seems to be no general review article which examines the general concept as a statistical method.

The concept as applied to population<sup>f</sup> is simply that of defining a fixed geographic area and using all available continuous and ad hoc statistical procedures for collecting the maximum amount of information for that area that pertains to the topics under study. Since many different types of data can be collected and all available methods can be used, the total pool of data which becomes available has much greater analytical potential than if the same data collection efforts were dispersed over different population areas. Further, since a great deal becomes known about the population of the area, it forms an ideal situation in which to test the validity of new measurement methods.

The demographic measurement laboratory concept permits a variable design, but ideally the laboratory should include a specific geo-

graphic area, for which maps and a house numbering system are maintained, a periodic population census taken, an upgraded sample or complete vital registration system established, and a permanent central office where data from these continuing processes as well as from ad hoc surveys and studies can be collated, linked, and analyzed. The data obtained from a limited geographic area of this type may have validity for that area, but the extent to which they can be given a broader generality depends upon the extent to which the laboratory population can be considered to represent a broader group.

## 5. RATINGS OF MEASUREMENT METHODS

Table A gives the results of an examination of each method defined above in terms of the degree to which the method seems to satisfy the broad measurement requirements with which this particular analysis is concerned. The ratings or evaluations are on a rough judgmental scale of *strong*, *medium*, and *weak*. It is recognized that these summary ratings are judgmental in character but they do depend on an examination of essential attributes of the method itself modified by knowledge of the experience with these methods as they have been actually applied and administered in various countries throughout the world. Because of the qualitative nature of the evaluations or ratings, it is expected that other investigators might give somewhat differing weights to various attributes of each method and would have differing appraisals of the accumulated experience on their use. The ratings assigned by the author are supported to some extent by the detailed notes given in the appendix. For convenience in reference the paragraph numbers in the notes correspond to the numbers of the entries in table A so that ready reference can be made from the table to the corresponding comment. The comments or notes given in the appendix for each rating in table A, by no means, constitute a complete justification or defense of the ratings, but they do indicate some of the factors and the line of thought that lead to the evaluation. It would be differences of opinion in the selection and evaluation of these factors that would result in different ratings.

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<sup>f</sup>As stated above, the laboratory concept has not yet been developed in detail for the study of population or population measurement methods. However, the studies carried on in the Gandigram area of Madras State, India and intensive area studies such as those of Singur, West Bengal, India are examples of early applications of this approach.

Table A. VARIOUS METHODS OF MEASURING CHANGE RATED ACCORDING TO THE DEGREE TO WHICH THEY SATISFY BROAD MEASUREMENT REQUIREMENTS

[The numbers in each cell of the table correspond to paragraph numbers in the appendix, which is a justification of the ratings given]

STATISTICAL METHODS FOR MEASURING POPULATION CHANGE	REQUIRED MEASUREMENT FACTORS			
	Subject Content	Geographic Area	Population Composition	Time
Conventional population census-----	1. weak	2. strong	3. strong	4. weak
Conventional vital registration system-----	5. weak	6. strong	7. weak	8. medium
Continuous population register-----	9. medium	10. strong	11. weak	12. strong
Sample registration system-----	13. medium	14. medium	15. weak	16. strong
Sample interview system-----	17. strong	18. medium	19. strong	20. strong
Panel longitudinal follow-up-----	21. medium	22. weak	23. weak	24. medium
Demographic laboratory-----	25. strong	26. weak	27. strong	28. strong

Such differences in ratings would not, however, destroy the value of table A since even allowing for variation some observations can emerge and these will be a useful guide to the selection of methods that have the greatest potential of satisfying the general requirements for measuring current population change. It is immediately obvious from table A that no one method alone will meet all of the basic needs of a country for essential population data and the ratings in table A can serve as a guide in designing the overall measurement system, with each method playing a proportionate part so that the total effective result is maximized.

This summary systems analysis of the broad characteristics of population measurement methods is also intended to focus attention on the soft or weak features of each to assist in the focusing of future methodological research. For example, the conventional population census is the most fundamental and universally used method of collecting data on population and related characteristics. Yet the procedure is weak as regards the "time" requirement. There is typically a long delay between the population enumeration and the date when the tabulated results become available, and there is generally a 10-year interval between censuses. Yet it may be possible to improve on both of these features. Continued research on character-reading methods of data processing, computer tabulation, and the introduction of sampling methods at various stages of census processing may appreciably improve the rapidity with which census results are obtained. The increasing practice of taking quinquennial censuses will cut the intercensal interval in half.

On the other hand, the weakness of the census method with regard to subject content pertinent to measuring population change is likely to be

more intractable. As a major national statistical collection method the general census must serve many purposes and the cost of a total census is so large that there must necessarily be a tight restriction on the number of items included. It is hardly conceivable that a population census could ever give the subject coverage required for KAP studies or could cover any large number of the items recommended for fertility surveys by the International Union for the Scientific Study of Population.

Each method can be examined carefully not only to determine its defects as the method is now usually used but to probe for features that can most feasibly be improved. A concentration of theoretical and applied research on such features may more rapidly develop the method so that it is more efficient in meeting the types of requirements described in this paper.

However, the summary analysis presented here cannot serve fully as a basis for either designing the overall national measurement system or identifying completely the areas of needed methodological research. These objectives require a more detailed and comprehensive systems analysis of each method for which this summary analysis can serve as a framework or background. Such a more detailed analysis for each method should go beyond consideration of the broad measurement factors considered here, and examine the available evidence as to the technical validity of the method as well as to survey more completely the administrative experience that has been obtained for each method. Such studies would then identify in detail the needed theoretical and operations research which could lead to the design of more adequate methods to meet the urgent needs outlined in the first part of this paper.



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## APPENDIX

### DETAILED NOTES ON RATINGS IN TABLE A

Table A. Various methods of measuring population change rated according to the degree to which they satisfy broad measurement requirements

[The numbers in each cell of the table correspond to paragraph numbers in this appendix, which is a justification of the ratings given]

Statistical methods for measuring population change	Required measurement factors			
	Subject content	Geographic area	Population composition	Time
Conventional population census-----	1. weak	2. strong	3. strong	4. weak
Conventional vital registration system-----	5. weak	6. strong	7. weak	8. medium
Continuous population register-----	9. medium	10. strong	11. weak	12. strong
Sample registration system-----	13. medium	14. medium	15. weak	16. strong
Sample interview system-----	17. strong	18. medium	19. strong	20. strong
Panel longitudinal follow-up-----	21. medium	22. weak	23. weak	24. medium
Demographic laboratory-----	25. strong	26. weak	27. strong	28. strong

1. *Census - content (weak)*: The subject-matter content of the traditional population census is limited by the large cost of collecting data on many variables for a total population. The fact that most censuses are taken as official governmental projects under penalties for nonresponse, tends also to restrict the census content to those few items which the government is willing to consider so important as to justify a mandatory response. The census, as United Nations recommendations for the 1970 World Census<sup>17</sup> show, is typically designed as a multipurpose statistical instrument, providing most essential national data on a variety of subject topics. The content coverage in terms of the number of items included for any one topic (e.g., fertility) is therefore quite restricted. The newer census practices of covering the total population with only a few basic items and expanding the subject coverage, utilizing subsamples of the population, greatly increase the scope of the census. Censuses of this design might be considered as "medium" with regard to coverage.

2. *Census - area (strong)*: The area coverage of the census is its strongest characteristic. By definition the term "census" connotes a national census and this is universally true except insofar as a few censuses in special cases may omit by design some relatively minor sector of the national territory because of rea-

sons such as inaccessibility. Since by definition a "census" covers 100 percent of the population<sup>8</sup> the volume of data is adequate to permit tabulation and detailed cross-tabulation of items for major and minor civil divisions. Census data is almost universally tabulated in some detail for states or provinces, subnational regions, individual large cities, counties, and sometimes even for smaller geographic units, such as census tracts. If the subject-matter scope of a census is increased through the use of population subsamples, the validity of tabulating these items for smaller geographic areas is weakened.

3. *Census - composition (strong)*: Since one of the primary purposes of the census is to determine the composition of the population this is one of the census' strong attributes. Many of the census items relate to the economic, social, and educational status of the population. To the extent that the census also includes items of more formal demographic interest (age structure, marital history, and fertility history) the census provides an extremely rich source of data for demographic analysis. Again, as in the case of tabulation

<sup>8</sup>Based on the U.N. definition of a census, the term "sample census" is really a contradiction of terms.

by areas, the large volume of census data permits tabulation and cross-tabulation of demographic variables in great detail according to the population composition groups.

4. *Census - time (weak)*: As a statistical tool for measuring population change the census is weak in two ways regarding the time factor. As a major and expensive nationwide statistical effort the usual practice is to take a census at 10-year intervals. While a sequence of decennial censuses provides an excellent base for long-range studies of historical demography and perhaps the most complete base for analyzing changes over the past decades, the long interval between censuses does not provide a sensitive method of measuring current population change which is required to evaluate population action programs. The decennial census interval is also too long for the effective use of census data for other national purposes and consequently more and more countries are establishing a tradition of quinquennial censuses. However, for measurement of current population change a 5-year interval is also too long. The second time defect of the nationwide census arises from the bulk of data processing required with the result that in ordinary circumstances census tabulations, except for a few total figures, are typically not available for 2 to 3 years after the date of the enumeration. In many cases the publication of the census results extends over a longer time span. This means that the most recent available decennial census data are usually 3 to 13 years old. With an increasing pattern of quinquennial censuses and the use of electronic computers, the conventional national census procedure is being greatly improved, but even so, the census is not an adequate statistical method from the standpoint of the time variable for measuring current population change.

5. *Vital registration - content (weak)*: The vital registration system exists originally and primarily as an official method of establishing the legal fact of birth and death. The statistical uses of the system are secondary byproducts. Accordingly many items on the registration document are for the purpose of establishing identity and family relationship and other legal characteristics of the vital event and have little or no value as analytical variables in studying population change. This priority of items, in combination with the necessity for administrative reasons to keep the total number of items limited, results in a registration document with a paucity of information relating to factors affecting population change. Those demographic items which are included are usually highly relevant to the analysis of population change and, of course, the fact of birth or death established by a registration system is the datum of greatest importance to this question. Nevertheless, the statistical content of the vital registration system is one of its weak aspects.

6. *Vital registration - area (strong)*: As with the census, the area factor of the registration system is a strong point. A registration system, presumably covering all of the population of a nation, can be the source of birth and death information for every civil subdivision even to the smallest village. This strong feature of the registration system—the ability to provide data on vital events for subnational geographic areas—is somewhat dampened because the gross number of births and deaths for an area has little meaning unless it can be related in the form of rates to the populations from which the births and deaths arise (the population exposed to risk). Because many births or deaths occur in areas other than those in which the principals concerned usually reside, it is difficult in many cases to tabulate the data so that there is a correct relationship between the population exposed to risk and the vital events. This factor is negligible for data tabulated for national totals but becomes more and more serious as the geographic tabulation unit becomes smaller and smaller. It is, of course, particularly serious in the case of small geographic units containing medical facilities that attract births and deaths across boundary lines from adjacent geographic units. Most modern vital statistics systems attempt to correct this defect by a reallocation of nonresidents.

7. *Vital registration - composition (weak)*: National vital registration systems are usually weak insofar as information on the registration record which would permit compilation of the data according to the economic, social, and demographic composition of the population. The latest draft of United Nations recommendations<sup>18</sup> for the contents of the birth record include only a few priority factors of this kind. Typically vital statistics are not available by income, occupation, education, literacy, and other important variables corresponding to population composition groups.

8. *Vital registration - time (medium)*: Since the registration system operates continuously it does not suffer from the same time deficiencies as the periodic census. Also since the total volume of individual records for births and deaths to be processed in any 1 year would be only about 2.5 percent to 7.0 percent of the volume of census records the system potentially could produce annual reports on the number of vital events with an acceptable timelag in tabulation and publication. Provisional totals are sometimes available on a monthly or quarterly basis with a timelag of only 3 to 4 months. With a periodic census as a base, current birth and death data permit the continuous calculation of a national population total, assuming international migration is negligible or, as is usually the case, its net effect is known.

The census and the registration system, if both are accurate and timely, thus provide a strong up-to-the-

minute measure of overall population change for a country as a whole. This strong time factor largely disappears for the estimation of vital rates or net rates of population change for subnational areas since in most cases, internal migration is not negligible nor is its net magnitude known in post-census periods. Therefore, for other than national totals, the vital statistics system inherits the time deficiency of the periodic census. In certain countries there is another serious time-defect in the registration system. In these countries vital events are tabulated not according to the month or year in which they occurred but according to the month or year in which they were registered. Since substantial numbers of births may be registered years after the events took place, this method of compilation may conceal a significant trend in the rate.

9. *Continuous population register - content (medium)*: The continuous national population register based on some form of a national census, continuously updated by an input of information from a registration system and periodically verified by a census check, would be expected to be more complete in terms of content than either of the two systems which support it. In general, these registers include clear information on the fact of a vital event, on the geographic movement of people from residence in one geographic civil division to another, and, in some cases, on a few census-type variables relating to population composition. If the registers are maintained on a family basis, many other items of demographic interest, such as marital history and fertility history, can be derived from the information on the record. Because of this linking of discrete items of information the population register can be richer in content than either of its supporting systems. In spite of such technical advantages it may be noted that the United Nations statistical commission has expressed a rather negative opinion of population registers as a statistical data collecting method.<sup>36</sup>

10. *Continuous population register - area (strong)*: One of the original and primary purposes of the population register is to establish a population figure (or even a roster) for small geographic civil administrative units. For this reason the fact of change of residence from one local jurisdiction to another is currently noted. Hence data on vital events, together with figures on the corresponding base population is potentially available for cities and small geographic areas. Population registers are often stronger in providing data for local areas than in methods for collating such data, except for a few summary figures, into totals for more and more comprehensive subnational or national figures.

11. *Continuous population register - composition (weak)*: Since population registers are periodically revised or verified by some form of population census, they could have the same strength relative to data on

population composition as the census itself. However, the current input information from the registration system is weak on this type of information and as a consequence the continuous register will rapidly deteriorate with reference to its accuracy on these variables as the original or revised census data become obsolete. Furthermore, the population register collates input data relating to the base census information, the current registration information, and reported information on migration. The necessity for economical and efficient procedures for recording these data tends to eliminate from the population registers variables which were not essential to their original purpose. As stated, these purposes usually have been more closely concerned with local administrative problems than compiling useful national or subnational statistics.

12. *Continuous population register - time (strong)*: The continuous population register has all of the advantages of the vital registration system with regard to the time factor, and because the base population is continuously updated, the system overcomes the disadvantages relating to time which are suffered by the periodic census. Therefore from the standpoint of measuring current population changes and current changes in vital rates, the population register has outstanding advantages particularly since this time advantage is accompanied by an equally strong area advantage. These strong points would seem to indicate that the population register method approaches an ideal system for measuring current population change. However, the method is highly sophisticated and serious defects in the system arise from a complex of technical and administration problems. The detailed consideration of these problems requires a separate analysis of the operational requirements of population register systems.

13. *Sample registration system - content (medium)*: As has been stated above in connection with the definition of the statistical methods considered here, the concept of the sample registration system is not yet precisely defined. If the sample registration system is, in effect, an integral part of the regular nationwide legal registration system then it tends to be limited in content to the same items that are included in the regular system. Some new experimental data-collection procedures which are sometimes referred to as sample registration schemes are more in the nature of a series of successive interview surveys of the same sample areas. To the extent that this is so, the procedures can have a wider content scope than the conventional registration system. Because it is on a sample basis and therefore more economical than a complete system, there is no intrinsic reason why a sample registration system could not expand its content coverage to some extent even if the system is closely related to the regular registration organization.

14. *Sample registration system - area (medium):*

The sample registration system is appropriate either for collecting data for a small defined area, such as a minor civil administrative unit, or for larger geographic areas such as states or provinces or for the territorial expanse of a whole country. For example, the Indian sample registration scheme<sup>34</sup> is planned for the whole country, but it is initially being put into operation in only some of the states and within some of these states it has also been operating on a more intensive basis than in others with increased sample sizes in selected regions.

A sample registration system, whether it covers only a small local area or the total country, is of course based on data collected from a number of small geographic sample units. This exposes the system to some technical and administrative problems related to reallocation of data on a residence basis. Another problem arises in the assumption that there is correspondence between the population in an area and the vital events recorded in the area.

15. *Sample registration system - composition (weak):* The sample registration system suffers from the same limitations as the conventional registration system in the restriction of the number and scope of items on the registration document that permit an analysis of the information on vital events according to composition groups of the population. Unless established as an independent and duplicating system in addition to the regular system in the sample areas, the sample system will be constrained somewhat by the underlying legal orientation of the conventional system.

16. *Sample registration system - time (strong):*

Since under a registration system the data are collected currently and since under a sample system the total volume of data need not be large, the time aspect of the sample registration scheme is one of its strong factors. However, the gross number of vital events becomes meaningful as a measure of population change only when it is converted into rates by being related to a correct population base. Therefore a sample registration system, by itself, has some of the same time deficiencies as the conventional registration system. That is, it is most valuable at the time of, or for a short period after, the regular census. However, if the primary purpose of the sample registration system is to provide a current measure of change in birth and death rates it need only cover a population of sufficient size to bring the sampling errors down to a size consonant with the magnitude of the rate changes it is desired to detect. Under this sampling scheme, it therefore becomes administratively feasible to take ad hoc or regular periodic censuses of the sample areas as frequently as required to establish a satisfactorily accurate population base.

17. *Sample interview survey - content (strong):*

The feasible content coverage of the sample interview survey as a method of measuring population change and related factors is one of its strong aspects. Since it is on a sample basis, the volume of field and processing work may be held at a manageable level so that there is no intrinsic limit to the scope of items determined by work volume considerations. Usually there are no legal or policy considerations, as in the case of the census or the vital registration system, that restrict the scope of the items included. In this type of data-collection process it is so easy to add items that this may turn into somewhat of a disadvantage rather than an advantage. The Population Council has recently compiled a collection of fertility survey schedules<sup>15</sup> that contain a bewildering array of topics. In an attempt to introduce some order and standardization into fertility survey practice the International Union for the Scientific Study of Population has prepared several recommended lists of topics but even the recommended core list contains over 80 items and subitems. The census and the vital statistics system may be too weak on item coverage but the items that are included in these official procedures have had the advantage of many decades of appraisal, testing, and international recommendation.<sup>h</sup> This sifting process has barely begun for items included in fertility surveys.

18. *Sample interview surveys - area (medium):*

With regard to area coverage, sample surveys may be considered to have medium or variable strength. The sample investigation can be focused on any defined small area that may be of interest in evaluating population action programs or, as in the case of the Indian National Sample Survey,<sup>37</sup> the area coverage may be nationwide. While adjustable in this way, surveys in practice have one feature that usually limits their utility for area analysis. If designed for nationwide coverage, a sample survey cannot be designed to also yield estimates for states or provinces without substantially increased costs. If designed to produce estimates for a single state or province, the survey cannot yield estimates for subprovincial units without large increased costs. Theoretically, of course, a nationwide survey could be designed to produce national, state, and local estimates, but in this case the operation would become so massive that it would approach census-like magnitude and would necessarily take on some of the census deficiencies with regard to content coverage, time required to produce results, and the gap between successive surveys as dictated by budget considerations.

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<sup>h</sup>Work on international standards for mortality classification was initiated at the first International Statistical Congress in 1853. The first international recommendations for a population census were adopted by the International Statistical Institute in 1872.

19. *Sample interview survey - composition (strong)*: A sample interview survey if properly designed can produce population estimates in the proper categories for which it is desired to compute vital rates and other population-based proportions. Since there is no rigid limit on adding content items it is practical to produce population estimates for the desired composition factors. This factor is therefore one of the strong features of sample interview surveys.

20. *Sample interview survey - time (strong)*: The time factor is a strong aspect of the sample interview survey. Due to the relatively small volume of documents, data processing can be completed without serious delays and aside from budgetary and administrative considerations sample surveys can be repeated at frequent intervals. Of course budgetary and administrative considerations are also the only barriers to a frequent repetition of a census, but in the case of sample surveys these considerations are not so restrictive because of the much smaller cost in funds and other resources required for sample investigations.

21. *Panel longitudinal - content (medium)*: The panel longitudinal followup study method potentially can cover a wide variety of topics or items. With a relatively small number of persons comprising the panel there is no strict barrier to the addition of a wide variety of topics to the scope of the data collected. This apparent freedom is somewhat restricted by the longitudinal character of the method which then results in a sequence of observations on the same items for the same person, thus introducing problems of reconciling inconsistencies and dealing analytically with a number of individual time sequence patterns. Because of these difficulties data collected as longitudinal series are often analyzed merely as successive cross-section studies. The analytical difficulties also make it impractical to study the interrelationship of a great many items. The wide possible subject coverage of this method is more apparent than real.

22. *Panel longitudinal - area (weak)*: One of the fundamental problems with the panel followup method of study is the difficulty of tracing and identifying members of the panel that move from their original place of residence during the course of the period of the longitudinal study. A related difficulty is to identify the fact of death for panel members or to record the fact and reason for other disappearances from the roster under active study. These problems are greatly increased as the geographic scope of the panel study is extended. Longitudinal studies have many intrinsic operational limitations even if confined to a small geographic area where intensive intermittent observations of the panel are possible. For a study extending over a large area the longitudinal study is an impractical data-collecting method.

23. *Panel longitudinal - composition (weak)*: This method of study is weak with regard to its potential

for analyzing population change and related factors by various components of the population. The area limitations and the necessary limitation on the overall size of the panel is not likely to permit a panel with adequate representation of many different population components in adequate size for analysis. The method however permits the collection of a wide range of items and within the above restrictions the data can be analyzed by population composition. A major difficulty arises, however, as the study proceeds over a longer period of time. Even if the panel at its initiation contains the adequate or desired elements for a study of variables by the composition of the population represented, the gradual erosion of the panel by death and other losses produces doubt on the validity or representativeness of any analysis by the initially established categories.

24. *Panel longitudinal followup - time (medium)*: The necessity of periodic observation of or interviews with the panel members introduces a time delay in this method which does not exist, for example, in the sample registration system where the recording of vital events is continuous. However, because the panel is likely to be small and located within a compact geographic area the interval between successive observations need not be long. The analysis of simple events, such as the number of births, requires no great time for processing, but the analytical difficulties of interpreting a set of complex series means that the method is not likely to yield quick and clearly interpretable measures of population change.

25. *Demographic measurement laboratory - content (strong)*: As defined, the demographic measurement laboratory is a contiguous area for which a variety of methods are used on a continuing basis to determine the demographic characteristics of the population resident in the laboratory. Accordingly the subject scope and content of the data collected can be extensive. The content coverage can include not only typical census and vital statistics items but also many other variables concerning factors related to population change. The danger may be that the laboratory concept encourages the collection of a plethora of subject items many of which may be of tangential value to the main issues under study.

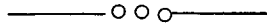
26. *Demographic measurement laboratory - area (weak)*: A concept involving data collection by any method as an intensive process in a defined and limited area has the major weakness of an area limitation in the interpretation and application of its results. The laboratory concept, implying in effect a continuous intensive field investigation, is not feasible on a nationwide basis. Conceptually it is possible to visualize a network of such laboratories distributed throughout a country to adequately represent the heterogeneous spread of a nation's population. It is entirely possible that this area disadvantage could be overcome in this way and perhaps at a cost of more or less the same order

of magnitude as the annual cost of the decennial census program or of the vital registration system. However, cost and other operating data for an illustrative demographic laboratory are not yet available to allow an evaluation of the practicality of such a national network of laboratories. Even if the laboratory idea were extended to a national network, it would still be inadequate to provide data for other political subdivisions such as states. Experience and the intrinsic concept of demographic laboratory indicate that the area factor is a weak aspect of the laboratory idea.

27. *Demographic measurement laboratory - composition (strong)*: Since the laboratory concept visualizes the frequent periodic census—a current collection of data on vital events and various ad hoc surveys—the system has the potential of permitting detailed analysis of population change for various components of the population. The restrictions on these analytic possibilities do not arise from the feasibility of col-

lecting information on the variables of interest, but rather from the fact that the area limitation of the laboratory itself may mean that the population resident in the laboratory does not include an adequate number of the various population component groups which are of interest. Nevertheless, if the laboratory site is selected with this matter in mind, its usefulness in permitting the study of population changes for different components of the population is a strong factor.

28. *Demographic measurement laboratory - time (strong)*: The time factor is one of the strong aspects of this concept. A frequent census, with current collection of information on vital events, involving a relatively small volume of data, permits a rapid collection and analysis of current material with little intrinsic timelag. The time delay in noting population changes can be reduced as much as desired so that it is limited only by administrative adeptness in the statistical operations.



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