VIII. USE OF DIRECT AND INDIRECT TECHNIQUES FOR ESTIMATING THE COMPLETENESS OF DEATH REGISTRATION SYSTEMS*

Samuel H. Preston**

This chapter reviews briefly the direct and indirect means of estimating the completeness with which deaths are recorded in a civil registration system. In accordance with the instructions of the organizers of the Meeting, it was designed as an adjunct to the paper presented by Moriyama,1 on continuous registration systems. It should be noted that the methods can be used with little modification for systems other than civil registration, for example, survey reports on household deaths in the past year. The methods are important not simply because they provide performance measures for statistical systems. More important are the opportunities they offer for adjusting or “calibrating” those systems to provide better estimates of mortality conditions. The fact that a registration system is “incomplete” has often been used to justify ignoring its products, but if the degree of incompleteness can be accurately assessed, the system becomes virtually as useful as one that is “complete”. It may be mentioned, however, that the less complete the underlying registration of deaths, the less tenable become the assumptions used in assessing the completeness level. As a rough rule of thumb, a registration system that records 60 per cent or more of deaths represents a very useful source of mortality information; if completeness is much below this level, however, problems of non-representativeness sharply limit the value of the data.

It should be stated at the outset that any estimate of “true” crude or age-specific death rates implicitly provides an estimate of the completeness of death registration. Many methods of estimating the true mortality conditions have been devised, and the United Nations2 recently published a review of these methods.

These alternative estimates are usually based on surveys containing retrospective questions on the survival of children or of other kin. The surveys may include event histories complete with dating of events, as in the World Fertility Survey; or they may be limited to reports of cumulative numbers of events, in which case the proper dating may be assigned through indirect procedures. In either case, it is clear that comparisons can be made between the frequency of events during a particular period that were reported in the survey and those reported in civil registration. This chapter does not consider these independent methods for estimating mortality, which are the subject of several other papers submitted to the Meeting. Instead, it is confined to methods for evaluating completeness that use the data from the registration system itself as input to the evaluation procedure. These data are always used in conjunction with other information. If the other information consists of an independently constructed listing of deaths, then the evaluation is considered to be “direct”. If it consists of other data on the population, particularly its age distribution or growth rate, then it is considered to be “indirect”. Indirect procedures are reviewed first.

A. INDIRECT METHODS

More than a half dozen indirect methods are currently available for estimating the completeness of death registration; most have been developed in the past two years. More are undoubtedly on the way. Each of the methods makes use of the age distribution of reported deaths within a certain age range, which may extend from birth to age 100 but which usually begins at 5 or 10 years of age. Each of them also assumes the population to be closed to migration. In addition, some other data or assumptions are used in conjunction with the age distribution of deaths. The possibilities employed to date are various combinations of:

D1: data on the age distribution of the population at one point in time (numbers by age corresponding to the date for which death information is available);

D2: data on the age distribution of the population at two points in time;

A1: assumption of population stability; the population is assumed to be characterized by constant mortality and exponential growth in the annual numbers of births;

A2: assumption of quasi-stability; the population is assumed to be characterized by a history of “typical” mortality decline that has destabilized a population that was at first stable;

A3: assumption that registered or reported deaths represent a constant proportion of true deaths at each age within the age range considered.
These methods are discussed below in more or less the chronological order in which they were developed.

**Brass “growth balance method”**

In any closed population, the following equation applies in the Brass “growth balance method”:

\[ r^T_x = b^T_x - d^T_x \]  

where \( r^T_x \) = true growth of the population aged \( x \) and over;  
\( b^T_x \) = true “birthday rate” of the population aged \( x \) and over, i.e., the number of people reaching their \( x \)th birthday in a particular year divided by the number of person-years lived above \( x \) during that year;  
\( d^T_x \) = true death rate of the population over age \( m \), \( x \), i.e., the number of deaths in a certain year at age \( x \) last birthday and above, divided by the number of person-years lived above \( x \) during that year.

The superscript \( T \) is used to denote “true” values in the population; the superscript is omitted when dealing with recorded values.

Equation (1) can be rewritten:

\[ b^T_x = r^T_x + d^T_x \]  

Brass uses the assumption of population stability, A1, so that the growth rate is constant with age and the \( x \) on \( r \) can be dropped. By assumption A3 that the completeness of death registration is invariant to age within the range specified,

\[ d_x = C \cdot d^T_x \]

where \( C \) is the completeness of death recording. Making these two substitutions, one has

\[ b^T_x = r^T + \frac{1}{C} \cdot d_x \]  

Equation (3) is a linear equation the parameters of which are \( r^T \), the intercept, and \( l/C \), the slope; \( d_x \) is simply the recorded death rate above age \( x \); and \( b^T_x \) is conventionally estimated by

\[ b^T_x = \frac{N_x + N_{x+5}}{10 \cdot N_x} \]

where \( N_x \) is the number of persons recorded in the age interval from \( x \) to \( x + 5 \).

In theory, \( r \) and \( C \) could be identified by choosing any pair of ages \( x \), since one would have two equations and two unknowns. In practice, it is more sensible to recognize that both the \( b^T_x \) series and the \( d_x \) series contain errors, particularly those resulting from age-misreporting. So one may take advantage of the linearity of equation (3) and estimate its parameters by linear regression on many data points or by other suitable fitting procedures. Note, however, that measurement errors in the death rate variable (e.g., from age-misreporting) bias the slope estimated by ordinary least squares towards zero. Because estimated completeness is the reciprocal of the slope, it is biased upward by such error. The equation can also be written so that \( d_x \) is on the left-hand side and \( C \) is estimated as the coefficient of \( b^T_x \), but in this case \( C \) will be biased downward by error in \( b^T_x \). In general, it seems best to avoid least-squares estimates and to use alternative and simpler procedures.

There are two basic problems with the Brass procedure:

(a) Errors in the data can create a scatter of points such that very different estimates of completeness can be produced by arbitrarily excluding various combinations of available data points from the fitting procedure. Usually, points for the highest ages will be most vulnerable to error, but these points are critical for estimation because they provide the highest values of \( b^T_x \) and \( d_x \). Changes in values of \( b^T_x \) and \( d_x \) at younger ages tend to be quite small so that different points add very little new information;

(b) Results are sensitive to violation of the assumption of stability. Currently, declining fertility is usually not a serious problem because the initial age at which estimation begins can be chosen in such a way as to exclude cohorts that have been reduced in size by fertility decline. However, most populations have had declining mortality for several decades and the declines affect all ages.

In her investigation of the sensitivity of Brass results to declining mortality, Martin finds that mortality decline produces estimates of completeness that are too low. For example, in a population with a gross reproduction rate of 2.5 that begins with a life expectancy of 45.0 and moves steadily to one of 66.4 after 20 years, the completeness estimated at the end of the period will be only 87 cent of the true completeness. Slower declines and shorter declines, of course, produce smaller biases.

Martin provides a way of adjusting the Brass estimates for mortality decline. The procedure requires that one know the speed and duration of mortality decline, A2. Estimating these factors is, of course, likely to involve a circularity because the aim of the exercise is to estimate current mortality conditions. Also, the recommended procedure for estimating duration of decline requires a set of age-specific growth rates; and if these rates are available, a number of alternative techniques can be used.

**Preston and Coale method**

In using the Preston and Coale method, by dividing both sides of equation (1) by \( d^T_x \) one has

\[ \frac{r^T_x}{d^T_x} = \frac{b^T_x}{d^T_x} - 1 = \frac{C \cdot r^T_x}{d^T_x} \]

or

\[ C = \frac{d_x}{r^T_x} \cdot \left[ \frac{b^T_x}{d^T_x} - 1 \right] \]  

(4)
The Preston and Coale procedure is based on the recognition that the ratio of the birthday rate above \( x \) to the death rate above \( x \) is, in a stable population, completely a function of the age distribution of deaths above that age and of the growth rate. In particular,

\[
\frac{b_x}{d_x} = \int d_x(a)e^{r(a-x)}da
\]  

(5)

where \( d_x(a) \) is the proportion of deaths above \( x \) that occur at age \( a \). The logic of equation (5) is the following. If \( B_x \) persons reach age \( x \) in a particular year, the number of deaths that occur to that cohort during the rest of their lives must also be \( B_x \). Future deaths in a stable population \((a-x)\) years hence will equal this year's deaths at that age, \( D(a) \), times an exponential growth factor, \( e^{r(a-x)} \). Summed over all future ages, then, one must have

\[
B_x = \int d_x(a)e^{r(a-x)}da.
\]

Dividing both sides by the sum of this year's deaths above \( x \) gives equation (5). Substituting (5) into (4), one has

\[
C = \frac{d_x}{b_x} \left[ \int d_x(a)e^{r(a-x)}da - 1 \right]
\]

(6)

This formula can be applied directly and does not require any fitting procedure. However, in reducing arbitrariness it also reduces flexibility; data for particular ages above \( x \) cannot be discarded because they are believed to be faulty. Note, in particular, that the summation goes to the highest age achieved and that deaths at high ages will be heavily weighted by the exponential-growth term. The method is thus vulnerable to age-misstatement and omission at the older ages, where these errors are most likely. Coale has accordingly paid much attention to developing procedures for minimizing the effects of error in the oldest age groups.\(^7\)

The Preston and Coale procedure requires as input estimates of growth rates, rather than of the age distribution of the population as used by Brass. These growth rates are often not known with much precision even when two censuses are available, and results are sensitive to the value of \( r \) adopted. Fortunately, their sensitivity varies considerably with age, being greater when the initial age of estimation, \( x \), is younger, so the results themselves provide an indication of the suitability of the growth rate used. Thus, Preston and Hill\(^8\) suggest experimenting with different growth rates and choosing that which produces the most “level” sequence of completeness estimates, i.e., the sequence that varies least with age. This procedure seems to work well in El Salvador,\(^9\) but in general may not be satisfactory. The problem is that errors at the older ages (e.g., overstatement of age at death) will also produce different errors in completeness estimates at different initial ages.\(^10\) The pattern of estimates that results from error at the very old ages is easily confused with a pattern of error produced by an incorrect choice of \( r \). It is, of course, possible to use the growth rate that emerges as a by-product of the Brass procedure as input for the Preston and Coale procedure. Experimentation with this approach in numerous countries has shown that the resulting estimate of \( C \) rarely differs from the Brass estimate by more than 0.03, so that, as a rule, little new information is gained.

Estimates of completeness derived by this method are also sensitive to violations of the assumption of stability, introduced in equation (5). In general, they appear to be somewhat less sensitive to these violations than the Brass results. In a direct comparison of the two methods applied to population with a simulated mortality decline, the Preston and Coale procedure produced errors less than half as large as the Brass procedure.\(^11\)

Bourgeois-Pichat method

There are other ways to write the basic stable equations in order to provide formulae for estimating the completeness of death registration. One such way is called here the “Bourgeois-Pichat method”, although it is implicit rather than explicit in his work. In a stable population,

\[
c(a) = b e^{-ra} \cdot \int_0^a u(t) dt
\]

(7)

where \( c(a) \) = proportion of the population at age \( a \);
\( r \) = annual growth rate;
\( b \) = birth rate;
\( u(t) \) = force of mortality (age-specific death rate) at age \( t \).

By assumption, \( A3 \),

\[
u^R(t) = C u(t)
\]

where \( u^R(t) \) is the recorded death rate at age \( t \). Making this substitution and taking logs,

\[
\ln c(a) = \ln b - ra - \frac{1}{C} \int_0^a u^R(t) dt.
\]

(8)

One now has a linear equation that can be estimated by least-squares techniques. One independent variable is age, the other is the sum of age-specific death rates from birth. The coefficient of the latter variable is the reciprocal of estimated registration completeness. The procedure can be used from any arbitrary beginning age, in which case \( a \) must be redefined as distance from that beginning age.

The procedure requires identifying three parameters: the two estimated by Brass, \( r \) and \( C \), plus the birth rate, which Brass estimates directly. Unfortunately, the two independent variables are very highly
correlated and estimates of the two coefficients are therefore quite unstable. The only application of this procedure attempted to estimate \( r \) and \( C \) in separate steps, but an apparent error in procedures renders results inconclusive.\(^{12}\)

Bennett and Horiuchi method

The Bennett and Horiuchi\(^{13}\) method provides an important development of the Preston and Coale technique that discards the assumption of stability. They note that the ratio of the birth rate over age \( x \) to the death rate over age \( x \) can be written for any closed population as

\[
\frac{b_x}{d_x} = \int_x^\infty d_x(a)e^{-\int_x^a r(t)dt}da
\]

(9)

where \( r(t) \) is the growth rate of population aged \( t \). Thus, equation (5) is seen to be a special case of equation (9) in which \( r \) is constant above \( x \). Substituting equation (9) into equation (4), which made no resort to stable assumptions, one has

\[
C = \frac{d_x}{r_x} \left[ \int_x^\infty d_x(a)e^{-\int_x^a r(t)dt}da - 1 \right]
\]

(10)

The technique embodied in equation (10) was shown to work very well when applied to data from the Republic of Korea and from Sweden.\(^{14}\) Like the Preston and Coale procedure, it requires a (set of) growth rates as input and it provides opportunity for experimenting with different values of the growth rate and choosing a set that provides a sequence of \( C \) estimates that shows minimal variance with age. The method is so recent that no other applications of the Bennett and Horiuchi approach are known to this author.

The main advantage of the approach is in its relaxation of the assumption of stability. The authors show that the Preston and Coale procedure would have given erratic results for the highly destabilized case of Sweden, whereas their procedure produced remarkably consistent and good results. Sweden is, of course, an extreme example, but it is often the case that the \( r(t) \) sequence in developing countries shows systematic departures from constancy. However, when errors in the data are abundant, the analyst may still wish to impose the stability assumption in order to "discipline" the data.

Preston and Hill method

Two censuses are required in order to obtain the set of age-specific growth rates needed for the Bennett and Horiuchi procedure. If these censuses are available, an alternative method proposed by Preston and Hill\(^{15}\) can also be applied. This procedure makes use of accounting identities relating the size of cohorts in the two censuses to intercensal deaths. For example, for censuses taken at time \( t \) and time \( t + 10 \),

\[
TN_{t+10} = TN_t - TD_t
\]

(11)

where \( TN_t \) = true number of persons aged \( x \) at time \( t \); \( TD_t \) = true number of deaths between \( t \) and \( t + 10 \) to cohort aged \( x \) at time \( t \).

Preston and Hill then invoke assumption A3, that registered deaths by age are a constant proportion of true deaths:

\[
D_t = C \cdot TD_t
\]

and that the completeness of enumeration for the population was \( E(t) \) at time \( t \) and \( E(t + 10) \) at time \( t + 10 \), both terms constant with age:

\[
N_t^{+10} = E(t) \cdot TN_t
\]

\[
N_t^{+10} = E(t + 10) \cdot TN_{t+10}^{+10}
\]

Making these substitutions into equation (11) and rearranging, they produce a linear equation:

\[
\frac{N_t^{+10}}{N_t} = \frac{E(t + 10)}{E(t)} - \frac{E(t + 10)}{C} \cdot D_t
\]

(12)

The intercept of this equation is the relative enumeration completeness of the two censuses; the coefficient of intercensal deaths is the enumeration completeness at the second census divided by the death registration completeness. To estimate mortality rates correctly, it is only necessary that the completeness of deaths be calibrated to the completeness of the censuses, so the presence of \( E(t + 10) \) in the coefficient poses no problem.

This method can be made more flexible by defining "cohorts" to be all persons over age \( x \) at time \( t \). It gave good results when applied to Thailand, in the sense that it produced estimates of registration completeness similar to those obtained in a direct inquiry and to those of the Preston and Coale procedure.\(^{16}\) Bennett and Horiuchi\(^{17}\) found that the method gave quite similar results to their own in the Republic of Korea. However, extensive application of the procedure in Latin America by the Centro Latinoamericano de Demografia (CELADE) gave quite poor results, with completeness estimates often implausibly above unity. It appears that systematic overstatement of age between one census and the next inflated cohort size at the second census and thus reduced "expected" deaths, so that recorded deaths formed too high a fraction of the expected deaths. The method may only prove workable for developing countries within the Chinese-Japanese cultural sphere, where age-reporting is typically quite good. The Bennett and Horiuchi procedure, for which calculations pertain to particular age groups rather than to particular cohorts, has clear practical advantages in situations of extensive and directional age-misreporting and can also readily accommodate intercensal periods that are not integer multiples of five. Note, however, that if intercensal
growth rates are used, the Bennett and Horiuchi (and the Preston and Coale) procedures should also be used with intercensal deaths and not simply with deaths centred on one of the two censuses.

**United Nations method**

If age-specific growth rates are available as in \( d \) and \( e \), as well as the age distribution of the population, it is possible to employ equation (1) directly. The expected death rate over age \( x \) is simply \( d_{x+} = b_{x+} - r_{x+} \), and the ratio, \( d_{x+}/d_{x+} \), is a direct estimate of registration completeness for ages \( x \) and over. No fitting procedure is required. Since \( b_{x+} \) is measured with considerable error, however, it is best to combine results for different ages, perhaps by calculating the geometric mean of estimates of \( C \) or by choosing a median. The former procedure was used by the United Nations in the only application of this method that this author has seen. The conclusion reached after applying it to many data sets was that, “More generally, the estimates obtained from this modified procedure have not proved very helpful, there being a very noticeable tendency for estimated completeness to exceed 100 per cent, sometimes seriously”. One explanation for this result may be that \( b_{x+} \) is consistently underestimated because of age overstatement.

**General remarks on indirect methods**

Each of the indirect methods identifies the completeness of death registration by attributing an inconsistency between registered deaths and some other element of the population—its age distribution, its growth rate or its intercensal cohort changes—to registration incompleteness. However, inconsistencies also may be produced by the other elements and attributing all of the disparities to death registration alone can lead to serious problems. Four of the most important of these sources of error are discussed below.

**International migration**

None of the methods is able to deal with an open population unless corrections for migration are made. Thus, the methods should not be used when international migration is substantial and populations are unadjusted.

**Age overstatement of deaths at higher ages**

When too high a proportion of deaths appears at the older ages, mortality conditions (for a given \( r \) or population age distribution) appear to be better than they in fact are, and observed deaths will thus constitute a higher fraction of expected deaths. \( C \) is biased upward. Methods for dealing with this problem in the Brass, Bourgeois-Pichat, and Preston and Hill techniques are fairly straightforward: ignore observations at the ages where problems are most likely to be encountered. In the Bennett and Horiuchi and the Preston and Coale procedures, however, the highest ages must (apparently) be included. Recommended procedures when they are believed to contain erroneous data are to employ an open-ended interval that begins at a relatively low age (say, 60) even though detailed data may be available for higher ages. Various models of age patterns of mortality are then introduced to estimate true mortality levels in this open-ended interval.

A pattern of registration completeness that increases with age, contrary to assumptions, will also bias completeness estimates upward.

Note that all but two of the methods provide estimates of registration completeness that pertain to all ages over some minimum age, under the assumption that completeness is constant over that age. They do not provide an estimate of completeness within a particular age range; even though certain observations may be discarded (e.g., in the Brass approach), the mathematical development has still utilized the assumption of no differential incompleteness by age. The exceptions are what have been called the “Bourgeois-Pichat method” and the “Preston and Hill method”. It is possible that this difference accounts for some of the unusually high estimates of \( C \) often yielded by these two techniques.

The other procedures can also be modified to yield completeness estimates that pertain to a restricted age range. To begin, equation (1) can be rewritten as:

\[
\frac{r_{xy}}{d_{xy}} = b_{xy} - d_{xy} - n_{xy}
\]

where \( r_{xy} = \) true growth rate of population between ages \( x \) and \( y \);

\[b_{xy} = \text{true birthday rate into the population aged from } x \text{ to } y, \text{i.e., number of persons reaching their } x^\text{th} \text{ birthday annually divided by person-years lived between } x \text{ and } y; \]

\[d_{xy} = \text{true death rate of the population between ages } x \text{ and } y; \]

\[n_{xy} = \text{true departure rate by aging from the population aged from } x \text{ to } y, \text{i.e., number of persons reaching their } y^\text{th} \text{ birthday annually divided by person-years lived between } x \text{ and } y. \]

It is now clear that the Brass method can be recast for application to the restricted age range from \( x \) to \( y \) as

\[
b_{xy} - n_{xy} = r - \frac{1}{C} d_{xy} \quad (3')
\]

Observations can be generated by varying \( x \) or \( y \), or both. Such a modification has been suggested by Somoza.

The United Nations method can also be modified in a straightforward way as

\[
C = \frac{d_{xy}}{b_{xy} - r_{xy} - n_{xy}}
\]

Tailoring the Preston and Coale and the Bennett and
Horiuchi procedures to a restricted age range is less straightforward. One may state without proof the following results. For the Preston and Coale method, in the age range from \( x \) to \( y \),

\[
C = \frac{d_{xy}}{r_{xy} + n_{xy} \left( 1 - e^{(v-x)} \right)} \left[ \int_x^y e^{(v-x)} d'(a) da - 1 \right] (6')
\]

and for the Bennett and Horiuchi method,

\[
C = \frac{d_{xy}}{r_{xy} + n_{xy} \left( 1 - e^{(v-x)} \right)} \left[ \int_x^y e^{(v-x)} d'(a) da - 1 \right] (10')
\]

where \( d'(a) \) is the proportion of recorded deaths between \( x \) and \( y \) that occurs at age \( a \).

### Census underenumeration

Each of the methods yields an estimate of registration completeness that is relative to the completeness of census enumeration. This result is explicit in the Preston and Hill procedure. For the others, it is only necessary to imagine that the population enumerated was arbitrarily reduced by 50 per cent. Registered death rates would rise by a factor of two and completeness would appear higher by this factor. The procedures do not give absolute but rather relative performance measures of the civil registration system. In countries where censuses miss substantial fractions of the population, it is useful to bear this caveat in mind. Normally, however, the analyst is interested in estimating mortality in the form of crude or age-specific death rates. For these purposes, what is needed is precisely an estimate of registration completeness in relation to census completeness.

### Death registration completeness varying with age

In the Brass, Bourgeois-Pichat, and Preston and Hill methods, registration completeness is inferred from the slope of a line fitted to data. If registration completeness varies with age, that slope will be biased. Increasing completeness with age will bias upward the estimated \( C \), and decreasing completeness will bias it downward.

However, in the Preston and Coale and the Bennett and Horiuchi methods, the estimated value of \( C \) will be a weighted average of the age-specific values of \( C \) actually prevailing. Since this feature is important and has not been noted previously, it is worth demonstrating despite the laborious mathematics. Let \( J(a) \) represent the actual completeness of registration at age \( a \). Suppose that one applies Preston and Coale equation (6) to data in which \( J(a) \) varies with age. Equation (6) can be rewritten as

\[
C = \frac{\int_x^y D'(a) J(a) da}{N_x + r_x} = \frac{\int_x^y D'(a) J(a) e^{(v-x)} da}{\int_x^y D'(a) J(a) da} - 1 (6')
\]

Recognizing that \( N_x + r_x \) is equal to \( N(x) - \int_x^y D'(a) da \) and that \( N(x) = \int_x^y D'(a) e^{(v-x)} da \), one can substitute into equation (6') and simplify, giving

\[
C = \frac{\int_x^y D'(a) J(a) e^{(v-x)} da - \int_x^y D'(a) J(a) da}{\int_x^y D'(a) e^{(v-x)} da - \int_x^y D'(a) J(a) da}
\]

or

\[
C = \frac{\int_x^y J(a) \left[ D(a) \left( e^{(v-x)} - 1 \right) - 1 \right] da}{\int_x^y D(a) \left[ e^{(v-x)} - 1 \right] da}
\]

Thus, \( C \) as estimated by equation (6) will be a weighted average of the actual age-specific completeness of registration over age \( x \), \( J(a) \). The weights are the difference between cohort deaths expected at age \( a \) and current deaths at \( a \), divided by the sum of this difference over all ages higher than \( x \). Older ages are clearly being heavily weighted in this process. In the Bennett and Horiuchi procedure, the weighting factor is identical except that \( e^{(v-x)} \) is replaced by \( e^{(u-x)} \) the weighting factor is identical except that \( e^{(v-x)} \) is replaced by \( e^{(u-x)} \).

That \( C \) estimated through these procedures is functioning as a weighted average of age-specific completeness increases their value in relation to other methods, although marked variation in completeness with age will make the refinement of growth rate estimates on the basis of the internal pattern of results problematical.

The Brass and the Preston and Coale procedures have been widely applied. They were used on many data sets in the model life-table construction project of the United Nations and in that of the Organisation for Economic Co-operation and Development (OECD). They have been applied to almost all of the countries for which the United States National Academy of Sciences has formed panels or working groups, including the two largest countries—India and China. They are providing information on inconsistencies between reported deaths and other features of the population structure. Results cannot, of course, be accepted blindly, because inconsistencies can be produced by many sources, as discussed above. However, the information they generate on these inconsistencies, taken together with other information, usually brings the demographic circumstances of a population into sharper focus.

Among the other techniques described here, that of Bennett and Horiuchi appears particularly promising. It requires nearly the same input as the Preston and
Coale method and is based on similar mathematical development, but it dispenses with the assumption of stability; and it shares with the Preston and Coale method the absence of dependence on the assumption that registration is invariant to age. A summary of the salient features of these procedures is presented in Table VIII.1. Experience with truncated versions of these procedures (except those of Bourgeois-Pichat and Preston and Hill) is too limited to allow a general assessment of their performance.

It should be mentioned that another indirect technique is available to measure completeness. Rather than relying on the demographic accounting framework of the other methods, it assumes that the age pattern of mortality in the population being studied belongs to a particular set of model relationships. It then solves for the "level" of mortality in that model life-table system which is consistent with the recorded age pattern of mortality. The population need not be stable or even closed. This advantage is purchased at a considerable cost, however, because the United Nations model life-table project has found age patterns of mortality in developing countries to be highly variable. The method also appears to be very sensitive to age-reporting patterns.

**B. DIRECT ESTIMATION OF COMPLETENESS**

An alternative way of estimating the completeness of death registration is to use an independent source of information on the number of deaths that occurred. If the alternative source itself is known to be complete, then an estimate of registration completeness follows directly from a comparison of totals, but there is no chance that such a source will be available. Instead, the alternative source will itself be suspected of being incomplete. Nevertheless, if it is statistically independent of death registration, it can be used to estimate registration completeness. Statistical independence simply means that the likelihood that an event will be recorded in the alternative system is not affected by whether it was registered. If independence is a tenable assumption, then the completeness of registration is estimated by

\[ C = \frac{D_{R,A}}{D_A} \]  

where \( D_{R,A} \) = deaths that appeared both in registration and in the alternative recording system; and \( D_A \) = total deaths in the alternative recording system.

This equation follows directly from the definition of statistical independence.

In order to estimate completeness by equation (13), it is clearly necessary to perform a case-by-case examination of records from both recording systems. Only by "matching" records from the two sources can \( D_{R,A} \) be established. Two major possibilities exist for the alternative system: surveys asking questions about deaths in the household in the same time-frame and space-frame to which registered deaths pertain; and an "active" recording of events by knowledgeable persons more or less continuously present in the community. Note that what have come to be known as "dual-record systems" use the two alternative systems and bypass civil registration altogether.

Direct estimation of completeness has considerable theoretical appeal. Its logical basis is simple and

| Table VIII.1. SUMMARY OF MAJOR FEATURES OF SIX METHODS FOR ESTIMATING COMPLETENESS OF DEATH REGISTRATION |
|--------------------------------------------------------|---------------------------------|----------------------------------------------------------|
| **Method**                                             | **Data required in addition to age distribution of deaths** | **Strengths and weaknesses encountered in applications** |
| Brass                                                  | Stable population               | Age distribution of population                           | Arbitrariness in choice of points for fitting; biased by declining mortality; flexible and requires least data. |
| Preston and Coale                                      | Stable population               | Number of persons and population - growth rate above initial age | Sensitive to growth rate chosen; biased by overstatement of age at death; provides diagnostics for errors of data and assumption; less biased by mortality decline than the Brass method; does not require assumption that completeness is invariant to age. |
| Bourgeois-Pichat                                      | Stable population               | Age distribution of population                           | Limited experience with method; seems to overestimate completeness because of age overstatement at high ages; requires least data; automatically provides estimates within truncated age range. |
| Bennett and Horiuchi                                   | Closed population               | Age-specific growth rates (i.e., age distributions of two censuses) | Sensitive to growth rate chosen; biased by overstatement of age at death; provides diagnostics for errors of data; unbiased by mortality or fertility change; flexible in implementing for irregular intercensal periods; does not require assumption that completeness is invariant to age. |
| Preston and Hill                                       | Closed population               | Age distributions of two censuses                        | Seems to overestimate completeness when age overstatement prevalent; awkward to use for irregular intercensal periods; arbitrariness in choice of points for fitting; flexible; automatically provides estimates within truncated age range. |
| United Nations                                         | Closed population               | Number of persons and population - growth rate initial age | Limited experience with method; seems to give erratic results. |
straightforward, unlike many of the indirect methods. Like the indirect methods, however, it is subject to error of assumption, data and implementation. The only assumption involved is that of independence of the two statistical systems, but there are many reasons why that assumption might be violated. The likelihood of a death being reported in either system probably varies in many populations with characteristics of the deceased (religion, socio-economic group, literacy). If deaths that are not recorded in one system are more likely than average to be omitted from the other, then completeness will be overestimated. A solution frequently suggested for dealing with this problem is first to make completeness estimates within (preferably homogeneous) population strata and then to aggregate the strata to estimate the number of deaths. Deliberate concealment of child death by some women, which appears to have occurred in a region of the Philippines, will also bias completeness estimates upward if the concealment enters both systems. Consequence of death—or, more accurately, reluctance to mention a recent grief-provoking event—has also been noted in a completeness evaluation in Turkey.

Independence of the two systems may also be difficult to attain administratively, since the recording of an event in one system may call its attention to the other system. It is suggested that a third party be responsible for matching records to avert any problems resulting from either system's desire to look more complete. But such procedures are "slow and costly". In the largest and longest attempt to maintain two record-keeping systems, the Sample Registration System in India, it has been decided that independence of the systems is an impractical goal.

Perhaps more serious, in general, than errors of assumption are data and implementation errors. This reference is not to incompleteness of records, since the procedure is designed to deal with these. Rather, data errors result from the presence of events in the alternate system that are "out of scope", i.e., that refer to periods or regions other than those to which registered deaths pertain. For example, if events in the alternate system refer to a 15-month period encompassing a 12-month period of death registration, then completeness estimates are biased downward because the denominator of equation (13) is increased by the three-month extension whereas the numerator is not. (Note that use of a period shorter than 12 months in the alternative system would not necessarily introduce any bias.) Since civil registration of deaths often occurs substantially later than the event, there can be confusion about the correct reference period for the alternative estimator. In addition, death often occurs elsewhere than the deceased's place of legal residence. Confusion about where to register such a death is widespread in Thailand, for example, and also increases the chances for "out-of-scope" reports.

The most important problem in many applications of this procedure is identifying what constitutes a true match of records in the two systems. If true matches are underestimated in equation (13), the completeness estimate will obviously be too low. One of the most important criteria for establishing a match is the name that appears on the death certificate and on the other record. In the Republic of Korea and in Trinidad and Tobago, frequent repetition of a few popular names confounds the matching process. Variability in the reporting of infant names has been noted in Saint Lucia. In many countries, a child dying in early infancy has been given no name. Another common criterion for the match is place of residence, but in many countries there is no formal address. Scores can, of course, be assigned on the basis of similarity of reports on different items in the two sets of records and a "match" created when the total score equals or exceeds a required minimum, but it will be rare that complete confidence could be attached to all matches and to all non-matches alike. It is possible, of course, to use probabilistic matches in which a score between 0 and 1 is assigned to a particular record in the alternative system in forming the numerator of equation (13).

An extensive literature has accumulated on matching studies. The interested reader may consult reviews in Marks, Seltzer and Krotki, in Wells and in Myers. Carver's work is an extensive bibliography of matching studies. Seltzer and Adlakha provide a formal evaluation of the sensitivity of results to certain kinds of error. It should be noted that matching studies are also used to estimate birth rates and to evaluate birth registration completeness. Studies of births seem to be more common; for example, the first study mentioned above lists twice as many matching studies of births as of deaths. The advantages of studying births instead of death are obvious: in the case of birth, usually two people who experienced the event (the child and the mother) will be present at the time of survey to report on or serve as a reminder of the event, whereas the decedent is no longer a household member; death may lead more frequently than birth to a reconstruction of the household or to migration; and the frequency of birth is usually from two to four times greater than the frequency of death in developing countries, so that the same size of population sampled will lead to greater reliability in the case of birth matching studies.

C. COMPARATIVE FEATURES OF DIRECT AND INDIRECT PROCEDURES

Direct and indirect approaches are not necessarily to be viewed as substitutes for each other. Ideally, both approaches would be applied to the same set of data, so that the analyst could base his or her final estimates on both sets of results. In some instances, such as Thailand, the results have been very similar; in others, such as Liberia, they were disparate. However, it will not always be possible to utilize both approaches, and they have rather differing strengths and weaknesses. What follows is a brief list of the relative advantages of each approach.
Areas of advantage for direct methods

Timeliness

The indirect procedures usually require a population census to provide input into the techniques. These are obviously available only sporadically in developing countries and are often processed slowly. In addition, several techniques yield only intercensal estimates, which require two censuses and assure that results pertain to periods that are, on average, 5–10 years distant. Direct procedures can, in theory, be used with a more or less continuous survey system and can yield results that are as current as data processing permits.

Socio-economic and geographical differentials

The indirect techniques all utilize the assumption of a closed population. Therefore, they are not suited for estimating completeness with respect to characteristics with changing distributions. These characteristics usually include socio-economic group and region of residence. Age-specific inflows and outflows among groups clearly violate the assumption of closure. Exceptions are characteristics fixed at birth, such as race, ethnicity, sex and region of birth, for which indirect procedures are completely applicable. The direct procedures can yield estimates of differentials with regard to any characteristic desired as long as it appears on the death certificate and the sample size is adequate. In practice, it is rare to see completeness estimates differentiated by characteristics other than age, sex and rural/urban residence.

Estimates of infant and child mortality

The indirect procedures generally use the assumption that completeness is invariant with age above some beginning age; however, the tendency to omit a higher fraction of neonatal and infant deaths is so pervasive that analysts rarely make use of estimates that begin at age zero. Thus, the indirect methods usually give estimates of registration completeness of later childhood and adults. This restriction often means that from one quarter to one half of the deaths occurring are not subject to investigation of completeness. The possibility of estimating registration completeness among infants and young children is one of the strongest arguments for direct procedures. Excellent advantage of this possibility was taken in a large study by the Pan American Health Organization. 41 Completeness of infant death registration was estimated for 13 areas in Latin America by comparing registered deaths to information from a wide variety of sources, including a household survey, hospital records of maternity admissions and births and foetal death certificates. The results are among the only examples of completeness estimates by fine categories of age in the first year of life.

The main competitor of direct completeness estimates for estimating childhood mortality is not indirect completeness methods but the survey-based retrospective procedure of Brass. An exceptionally interesting comparison has been made of dual-record results and the Brass type of results in a region of the Philippines. 42 The Brass results appear to be somewhat better, perhaps because they do not require a direct report on death (only on the numbers surviving) and because the events of death are more distant on average and hence less emotion-laden.

Areas of advantage for indirect methods

Coverage of population

Estimates of mortality are usually desired at the national level. The indirect methods are well-suited for providing this level of coverage because they usually compare national-level deaths to national-level census information. In order for the direct methods to yield nationally representative results, it is necessary that extensive geographical stratification be introduced in the alternative system. Even if it is successful in the sense of providing nationally unbiased estimates, the sampling required introduces sampling error that is not present in the indirect procedures. Areal sampling also introduces the possibility of geographical out-of-scope biases that are not present in a system of national scope.

Administrative and financial costs

Mounting an independent survey to evaluate registration completeness is a costly undertaking. One must determine the sampling strategy to be used, develop the appropriate maps, prepare questionnaires, statistical forms and manuals for field-workers, recruit and train interviewers, pretest the procedures, code both sets of data and match the records. While some use may be made of pre-existing apparatus and personnel and of international experience in the conduct of such surveys, the costs will nevertheless be much greater than for indirect procedures. For the latter methods, all that is required is the appropriate data, which are usually routine products of a country's statistical system, and an effort of from several days to several weeks duration by a well-trained analyst. The cost factor is surely the major advantage of indirect procedures.

D. Discussion

An important feature of estimates of registration completeness is not discussed in the foregoing account: the sensitivity of mortality estimates to error in estimates of registration completeness. The estimated crude death rate corrected for completeness of registration is, of course, simply the registered crude death rate divided by C. In the author's judgement, sufficient accuracy can be attained in the estimation of C, whether by direct or indirect means, so that the corrected crude death rate will usually be within 10 per cent, and almost always within 18 per cent, of its true
value. This is clearly a subjective assessment using imprecise language.

What may not be clear to the reader is that life expectancy estimates are much less sensitive to error in estimates of completeness than are crude death rates. The reason for this differential response is the bunching of deaths (in the life table) at the higher ages in almost all populations. Suppose in the life table that one inappropriately "saves" 10 per cent of the persons who should have died at age 65–69 because C has been overestimated and mortality thus underestimated. These persons will not be expected to live an additional 65–69 years (which would result in an inflation of 10 per cent in e) simply because they are entering ages of very high, even if underestimated, mortality. An investigation of this feature of mortality measurement concludes that the proportionate change in life expectancy at birth is only 10–40 per cent of an equiproportionate change introduced into all age-specific death rates. Thus, if one comes within 10 per cent of the true value in the corrected estimates of age-specific death rates, one should be within 1–4 per cent in the corresponding estimates of life expectancy at birth. At a life expectancy at birth of 55, typical of developing countries, the error introduced by a 10 per cent error in estimates of 1/C is only 0.5–2.2 years. The insensitivity of life expectancy to error in C is even greater for ages beyond zero because the bunching of life-table deaths at high ages is more extreme. This relative insensitivity of life-expectancy measures is an important reason to capitalize on the vital registration data available on deaths by age in developing countries, in combination with estimates of registration completeness.

NOTES
1T. M. Moriyama, "Advantages and disadvantages of continuous registration systems for national, subnational and differential mortality analysis", chap. VI of the present volume.
2Manual X. Indirect Techniques for Demographic Estimation (United Nations publication, Sales No. E.83.XIII.2).
4Several are described in Manual X. Indirect Techniques for Demographic Estimation.
6Ibid., compiled from table 1.
9"Model life tables for developing countries; an interim report" (ESSA/P/WP.63), January 1979.
10S. H. Preston and others, loc. cit.
11Ibid., pp. 189 and 192.
14In applications and development of the method, Bennett and Horiuchi, loc. cit., use a different functional form of equation (10) but one that can be shown to be mathematically equivalent. Results may differ slightly because of different discrete approximations required in the different formulae.
15P. Preston and K. Hill, loc. cit.
16Private correspondence with the author.
17Model life tables for developing countries: an interim report".
18Ibid., p. 36.
20Model Life Tables for Developing Countries (United Nations publication, Sales No. E.81.XIII.7).
21Organisation for Economic Co-operation and Development, Mortality in Developing Countries; vol. II. Data Bank; vol. III. Evaluation.
31E. S. Marks, W. Seltzer and K. J. Krótki, op. cit.
32Ibid.
33H. B. Wells, op. cit.
34R. J. Myers, op. cit.
37E. S. Marks, W. Seltzer and K. J. Krótki, op. cit., p. 54.
38S. Preston and K. Hill, loc. cit.
39In particular, application of the Brass and the Preston and Coale
procedures to the "corrected" death rates from the Population Growth Survey of Liberia, 1969–1972, found completeness levels substantially above unity, raising the possibility that the matching procedure had underestimated true completeness. The unpublished analysis was performed by K. Burni, Population Studies Center of the University of Pennsylvania.


42F. C. Madigan and A. N. Herrin, *op. cit.*, chap. 5.

43See also E. Chanlett, *op. cit.*, p. 20.