Civil Registration & Vital Statistics Program

Estimating Completeness of Birth and Death Registration

Methods and Options for Estimating Completeness of Civil Registration

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Acronyms

CHS	Commune Health Station
CPFPC	Commune Population and Family Planning Committee
CRVS	Civil Registration and Vital Statistics
DDM	Death Distribution Methods
MoH	Ministry of Health
SRS	Sample Registration System

Purpose of the Guide

This guide describes the key principles, data needs, and methodology for a range of methods that are available for estimating the completeness of birth and death registration at local, district, and national levels. Reliably estimating completeness of birth and death registration is central to achieving targets in the Sustainable Development Goals aiming for universal birth registration and high levels of death registration.

The guide is written for demographers, epidemiologists, or statisticians advising government on measuring completeness of Civil Registration and Vital Statistics (CRVS) systems. It can also serve as a reference for data managers in national registration units and subnational level offices of the CRVS system, or other government and nongovernment agencies interested in assessing the completeness of birth or death registration. Where relevant, practical examples have been included, along with supporting details for conducting statistical analysis. More details for all methods are available in the reference section.

Routine measurements of completeness of registration provide timely and locally relevant feedback on system performance and can guide interventions to strengthen and improve CRVS performance over time.

Background

Reliable data from Civil Registration and Vital Statistics (CRVS) Systems are essential for population health policy and research. At the global level, many countries encounter challenges with CRVS data quality, including completeness of vital event registration and accuracy of reported causes of death (1). Completeness is defined as the proportion of vital events (births or deaths) recorded by the CRVS system during a reference time period out of the total events estimated to have occurred in the study population over the same time period (2).

Currently, several international initiatives and activities are being coordinated and implemented to strengthen CRVS systems in developing countries (3), resulting in a need for empirical assessments of completeness of vital registration. These assessments serve two purposes: The first is to establish a baseline of CRVS performance with regard to completeness. This can set the stage for system strengthening activities. The second is to help countries derive adjusted birth and death rates so they can provide more accurate evidence for informing health policy and program evaluation. In general, evaluation of system performance can be achieved through an approximate means of measuring completeness, whereas adjustment of mortality rates require more exact measures.

This guide surveys methods available for statistical measurement of completeness of registration of births and deaths in terms of data needs and analytical principles, as well as providing relevant examples from recent applications in a variety of settings. The guide discusses the strengths and limitations of these methods and recommends a stepwise approach to the use of different methodologies for implementation.

Overview of Completeness Estimation Methods

The basic requirement for measuring completeness is to derive the best estimate of the denominator of expected births and deaths. There are a range of approaches to derive the estimate of expected vital events. Each approach has its own data needs, statistical methods, assumptions, ease in application, and interpretation of outcome measures (4). Completeness estimates operate in a wide range of settings, creating the need for careful individualized implementation strategies in different country settings. More than one approach or method may be applicable in a given country, offering opportunities to optimize results to determine the most appropriate measure of completeness based on the intended use of the data.

For appropriate application of these methods, the primary data compiled by the local civil registration system should be available, including individual records with accurate information on essential details, including name(s), age, sex, location/address, and date(s) of events (birth/death occurrence and registration). Although electronic data helps facilitate implementation of these methods, physical records may be required for data verification and follow-up activities.

Categories of Methods

Generally, methods used for estimating completeness fall into four categories:

1. Aggregated data analysis: These methods involve comparing aggregated numbers of observed vital events with reference aggregated numbers from an alternate source deemed to represent the potential *true* value of expected events. The method employs use of crude death rates as described later in the document, and uses the reference denominator to calculate completeness of different sources of numerators for the study population. This can be further extended to comparisons of aggregated numbers by categories of sex, age, and subpopulations, as required.

2. Record linkage analysis: This approach involves direct comparison and linkage of individual records of vital events from two or more different data sources to identify linked (matched) records, as well as records present in one data source but missing from the other.

3. Indirect demographic analysis: These methods specifically apply to measuring completeness of death registration. They involve analytic techniques based on specific demographic assumptions of fertility, mortality, migration, and population growth to estimate the age-sex distribution of expected deaths. These expected deaths are then aggregated across specific age categories to be used as denominators for completeness assessment.

4. Internal assessment: This approach involves adding specific self-disclosure questions to existing mortality modules in household survey programs or censuses to enquire whether vital events reported in the survey or census have been registered with the local CRVS unit. Respondents are asked whether the event they have reported has or has not been registered at the local CRVS unit. The measure of completeness is taken as the proportion of self-reported births and deaths registered with the local CRVS authority to the total reported births and deaths captured in the survey. All data for this method is usually internal to the survey or census itself, without reference to any external data source. However, where feasible, respondents may also be asked to produce registration documents as proof in order to validate the completeness estimate.

Though their approaches vary, each of these methods draws upon a common set of data sources that are used to collect and analyze vital statistics, as outlined in Table 1. As the table shows, each data source can provide one or more data elements comprising event counts, event rates, or individual records. Each of those elements could be compatible with one or more of the above methods to evaluate completeness. More than one data source is likely to be available in individual settings, thereby creating the potential for more than one approach to be used for estimating completeness.

The characteristics of each of these specific methods are described below. Evaluation of completeness for death registration is generally more complex than for birth registration because mortality varies by age, sex and other sociogeographic factors. Therefore, completeness of death registration is the focus of the methodological descriptions and comparisons below. Where applicable, the use and implications of these methods for birth registration are mentioned.

Table 1. *Data sources for birth and death records and their potential use for analysis of completeness of vital registration*

Vital event data source*	Variables for completeness assessment	Potential methods for completeness assessment	Remarks
CRVS systems	• Event numbers • Event rates • Individual records	• Aggregated analysis Demographic analysis • Record linkage	Continuous, permanent and mandatory recording
Population census	• Event numbers • Event rates • Individual records	• Aggregated analysis • Record linkage • Demographic analysis Internal assessment	Sporadic availability Known recall bias
Household registers	• Individual records	• Record linkage	Dispersed in every household and therefore not practical for use
Sample registration / surveys (SRS)	• Event numbers • Event rates • Individual records	• Aggregated analysis • Record linkage • Demographic analysis • Internal assessment	Most robust alternate data source to ensure reliability for completeness assessment
Health and demographic surveillance systems (HDSS)	• Event numbers • Event rates • Individual records	• Aggregated analysis • Record linkage • Internal assessment	Relatively small sample size, usually not nationally representative
Special completeness surveys	• Event numbers • Event rates • Individual records •	• Record linkage • Aggregated analysis • Internal assessment	Can be implemented as an additional module in the form of routine household surveys
Health program / disease registers	• Event numbers • Individual records	• Record linkage	Maternal and child health, TB, cancer registries – Useful for data reconciliation
Administrative health / insurance records	• Individual records	• Record linkage	Increasingly used for electronic data linkage and reconciliation
Population and mortality models	• Event numbers • Event rates	• Aggregated analysis • Demographic analysis	Subject to modelling assumptions

* all of these sources (except "Population and mortality models") collect individual records, and all can produce numbers of events.

Aggregated Data Analysis

In this method, the denominator of expected deaths can be estimated using data elements from several sources using the fundamental assumption that reference data is 100% complete. A practical example illustrating this approach is the evaluation of completeness of the Indian CRVS system at the national and state level as reported in the annual national vital statistics reports (5). The reference values are derived from the Indian Sample Registration System (SRS), which operates in parallel to the CRVS system in a representative sample of population clusters across the country and has a documented record of near complete death registration.

First, the crude death rates observed in the SRS are applied (through multiplication) to the relevant national or state level projected population (5) to derive an estimate of expected deaths during the study period. This estimate serves as the denominator to calculate completeness of the events registered in the civil registration system. The ratio of observed deaths in the civil registration system to expected deaths calculated as above, expresses the estimate of completeness. Table 2 illustrates this method for death registration data from India and selected states in 2017(5).

***Table 2**. Estimated CRVS death registration completeness for India and selected states, 2017, based on expected deaths derived using crude death rates from the national Sample Registration System*

Area	Population (millions)§	SRS crude death rate/1,000 pop	Expected Deaths ((CDR*pop)/1000)	Observed CRVS deaths	Completeness (%) Obs/Exp *100
India	**1288.56**	**6.3**	**8,117,689**	**6,463,779**	**79**
Andhra Pradesh	52.33	7.2	376,704	355,546	94
Madhya Pradesh	79.33	6.8	539,451	370,538	69
Jharkhand	34.84	5.4	188,155	116,393	52
Uttarakhand	10.81	6.7	72,387	33,931	47
West Bengal	94.61	5.8	548,633	442,995	81

§ Central Bureau of Health Intelligence. Table 1.1.3: state/Union Territory wise distribution of project population of India, 2017 - 2026. In: National health profile of India. New Delhi: Ministry of Health & Welfare, Government of India, 2018

In other settings, locally derived current crude death rates may not be available to use as a reference. Ideally the reference value should be derived from an alternate data source for the same population for which completeness is being measured. This approach would enhance the reliability of the completeness estimate and, for the most recent reference time point, minimize temporal changes in the population mortality as a result of demographic or epidemiological phenomena or events. Some examples of alternate sources for the crude death are as follows:

a. CRVS data for the same population from the recent past.
b. A sample mortality surveillance program (similar to the Indian SRS).
c. A recent population census that collected mortality data within a specified recall period.
d. Sample household survey (e.g. intercensal survey; socioeconomic or demographic and health surveys).
e. Estimates from population and mortality models for individual countries, as published in the United Nations World Population Prospects[1], the World Health Organization's Global Health Estimates[2], or other global data reference sources.

In some instances, the reference value for the crude death rate may only be available at a broad level. For example, a national crude death rate derived from a nationally representative sample population survey or modelled estimates will not capture subnational or population variation and may lack sufficient statistical power to produce decentralized crude death rate estimates. In such instances, the national measured rate or modelled estimate of the crude death rate may have to be used to estimate and compare completeness across all subnational locations.

An example of this approach can be found in the assessment of local level completeness of death registration in the Indonesian SRS in 2016 (6). In this analysis, the modelled 2015 crude death rate from the WHO estimates for Indonesia (6.4 per 1,000 population) was taken as the reference value to derive the denominator for estimating completeness for each of the 128 population clusters comprising the Indonesian SRS sample. The range of levels of completeness for clusters

[1] https://population.un.org/wpp/Download/Standard/Population/
[2] https://www.who.int/healthinfo/global_burden_disease/en/

distributed across 7 national regions – using the same national level crude death rate for all the regions – is depicted in Figure 1.

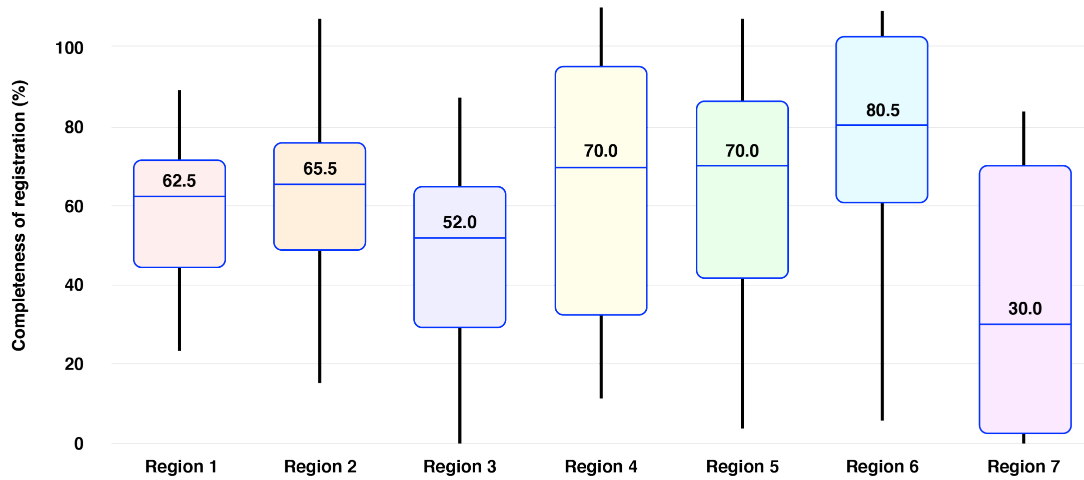

Figure 1*. Variations in estimated completeness of death registration in individual population clusters of the Indonesian Sample Registration System in 2016 (Source (6))*

In this case, assessment of completeness based on a single, national crude death rate could only be used as a broad approximation. This is because actual mortality rates in the seven regions depicted in Figure 1 may vary significantly from the national average. However, the graphic depiction still shows that regions 3 and 7 need specific attention to improve performance. This method was also capable of showing that some population clusters in all regions have very high completeness. These clusters could provide lessons for designing system improvement interventions.

Two key assumptions underpin aggregated analyses based on crude death rates:

a. The reference source of the crude death rate represents 100% completeness.
b. The resultant measure of completeness does not vary mathematically by age, sex, geography or any other disaggregation when estimated as a combined population value. This means that the completeness measure derived from this analysis is the same across all subgroups within the measure. That is, a completeness based on crude death rate for males of 70% implies that it is 70% for each age group (infants, adults, elderly, etc.).

It is often difficult to establish the first assumption, and there are no perfect solutions to the problem. For example, crude death rates derived from a population census or a periodic household survey are known to be affected by recall bias. Other sources of reference for crude death rates include modelled estimates for the study population (often projections based on under-5 mortality) or borrowed estimates from a population with similar demographic and epidemiological characteristics. With such sources, the risk exists of creating a distorted picture of completeness.

Additionally, completeness tends to vary by sex and age, and these variances are masked by aggregated analysis based on crude, rather than sex- or age-specific, death rates. Therefore, it is strongly recommended that completeness be estimated separately for sex and age categories, *regardless of the method used*.

Table 3 shows a more detailed version of an aggregated analysis — an extension of the crude death rate analysis presented in Table 2. An important prerequisite for a detailed completeness analysis is for the reference data source to include information on population and deaths by specific sex and age categories, as is available from the Indian SRS.

To carry out the analysis shown in Table 3, the age-sex population and death distributions from the CRVS and SRS for each location were used as inputs to compute life tables for males and females separately, using a publicly available life table template (7). From these life tables for each data source, death probabilities were extracted for five broad age groups (Table 3). Completeness ratios of the civil registration data were then derived for each location-sex-age group category using the SRS values as reference. Ratios are depicted in Table 3 using a color-coded stratification of completeness ratios to enable ready comparison. The detailed analysis highlights the gender differentials in completeness, the general underreporting of childhood deaths in the civil registration system, and the relatively higher levels of registration among adults. The analysis also revealed that for certain age groups in different states, particularly at ages 30 to 69 years, the CRVS data recorded slightly higher than expected numbers of deaths, resulting in completeness levels that were › 100%.

***Table 3**. Estimated levels of CRVS completeness by sex and age for India and selected states in 2017, based on SRS age specific death rates as reference values (source(5))*

Location	Estimated completeness (%)	Ratios of risk of dying per 1000 by age group CRVS / SRS				
		0 - 4	5 - 14	15 - 29	30 - 69	70 - 84
MALES						
India	88	33	76	87	104*	89
Andhra Pradesh	105	65	75	106	105	103
Madhya Pradesh	75	25	65	76	114	71
Jharkhand	83	33	111	96	110	72
Uttarakhand	46	14	51	38	54	73
West Bengal	88	59	38	62	109	79
FEMALES						
India	73	27	65	70	93	81
Andhra Pradesh	85	58	86	81	94	86
Madhya Pradesh	64	22	92	71	109	58
Jharkhand	46	26	90	54	66	50
Uttarakhand	46	15	22	35	42	78
West Bengal	74	44	65	46	95	74

Very low	Low	Similar	High
≤ 79	80 - 89	90 - 99	≥ 100

*values greater than 100 are possible when higher number of deaths are recorded in the CRVS system than what was expected

Such detailed analysis offers clear advantages in terms of identifying populations and locations requiring interventions to strengthen registration performance. These completeness ratios also have the potential to be used as adjustment factors to derive more reliable estimates of mortality indicators for the population being investigated.

Ideally, the reference set of age-specific death rates for such completeness estimates would be available for the same population and time point, as in the Indian example. However, this may not be realistic in many locations. Death probabilities from modelled life tables from national or international sources can also be used as reference values to estimate local levels of completeness, but because they relate to different times or places, the reliability of those probabilities may vary with regard to the study population.

Birth registration: The completeness of birth registration can also be estimated using the aggregated analysis method, using estimates of crude birth rates or age-specific fertility rates from alternate sources to derive the denominator of estimated births.

Advantages and Limitations

An aggregated analysis of completeness based on reference crude death rates is thus a simple approach and can be effective in tracking overall system performance. The advantages lie in the usually ready availability of reference values from one or more sources, and their relative ease in computation, interpretation, and utility to guide system strengthening activities.

The main drawback is their limited value for understanding underlying factors responsible for overall incompleteness. These include sex and age specific reporting gaps as well as possible variations across locations covered by the data. This drawback can be addressed through more detailed analysis as demonstrated in Table 3 and associated text, if the applicable data is available. In addition to evaluating system performance, findings from detailed analyses of completeness can be used in a data synthesis-based adjustment of CRVS data to estimate mortality indicators.

Record Linkage Mechanism

In this approach, individual records of vital events from two different sources for the same population are linked using defined variables and specific matching criteria, to generate three categories of records: one set of matched records and two sets of unique records from each data source (8). This linkage is valuable for improving the completeness of CRVS data by identifying additional records from other sources to be reconciled with CRVS records and creates opportunities for measuring completeness. Accuracy in data reconciliation largely depends on the efficiency of matching records across the two sources. The more accurate the matching, the less likely that events will be double-counted. The reconciled set of records, comprising the sum of the matched events and the unique sets from each source, can serve as the denominator of total events in the population, which can be divided by the observed events from CRVS to calculate the proportion of completeness:

$$\text{Completeness} = \frac{Observed\ events\ from\ CRVS}{Matched\ events + unique\ events\ from\ each\ source} \text{ X } 100$$

In addition, statistical methods can be used to estimate the potential number of events missed by both data sources, based on specific assumptions underlying the data collection methods and quality of data from either source (9). This procedure, shown below in the Oman example, is used to derive a more "realistic" completeness estimate that can then be applied to generate adjusted mortality indicators for policy purposes. This estimate of missed events can then be added to the reconciled number of events to derive an estimated total of events in the study population for the reference period, which serves as the denominator for estimating completeness:

$$\text{Completeness} = \frac{Observed\ events\ from\ CRVS}{Matched\ events + unique\ events\ from\ each\ source + estimated\ missed\ events} \text{ X } 100$$

These analyses can be disaggregated by sex and age categories to improve the level of detail in completeness assessment and enable more refined adjustment of mortality indicators.

As explained in Table 1, several data sources can be used to evaluate completeness through record linkage analysis. These include continuous recording systems such as sample registration systems, demographic surveillance, and routine health records, which collect data on specific variables on identity, address, and event details that can be used for matching across data sources. Other sources that enable matching and linkage analysis include periodic data collection through household surveys and population censuses that are designed to record similar details of individual events.

Until recently, the common study design for record linkage analysis has used periodic data collection as a secondary data source to evaluate the completeness of a continuous recording system such as the CRVS system. However, with the increasing availability of electronic data sources, record linkage is increasingly practiced across parallel continuous recording sources of vital events, as explained later. The analytical methods described below can be used to evaluate completeness of both births and deaths registration.

Several concepts and principles underlie record linkage analysis:

- Compatibility of data sources: The two sources should cover the same defined populations, geographically and administratively, as well as a specified time period. This will eliminate the potential for "out-of-scope" mismatches, which have major implications for accuracy of data reconciliation as well as for the evaluation of completeness. In addition, several additional commonalities should exist in the two data sources in addition to geography and time. This will improve the efficiency of linkage. Examples of such commonalities are identity (name, age, sex, parent's names); location or address (street, suburb/village, town, province) and event details (date of birth/death/registration), among others.
- Clear descriptions of data collection and record linkage: Often, data collection for each source is undertaken by separate teams and usually at widely differing points in time, creating the potential for variations in data recording arising from both respondent and operator error. This could affect record linkage. Variations in data collection processes should be documented in detail. This will help evaluate whether these data sources meet the conditions for applying capture-recapture analytical methods, as discussed later.
- Assured data quality of variables: Information for all variables in both sources should be complete and accurate, to enable correct identification of matched and unmatched records. To achieve this, every effort should be undertaken during data recording in the

CRVS system to ensure recording of the full name, date of birth, accurate determination of age at death and date of death, and detailed address.

- Process of matching and explicit matching criteria: This should include documentation of steps involved in manual or electronic record linkage. Matching criteria should be specified, including those accounting for variations in names, ranges for age at death and date of death, and assumptions for missing address variables or partial names. Electronic linkage usually requires some degree of follow-up using manual processes to investigate discrepancies resulting in partial matches. Manual verification allows the evaluation of matching errors and can guide the refinement of criteria to improve matching results.
- Field verification of matching results: To improve confidence in the reliability of the linkage results, a process for field verification of a sample of matching results could be undertaken. In practical terms, record linkage and matching are often undertaken at the local level to improve the completeness and quality of vital records. This usually involves local staff who are closely linked to the community, and who can be relied on to make reasonably accurate judgements about specific events and assist in the matching of records across sources. Such examples of local knowledge by field staff could be used to verify results from record linkage.
- Data analysis for measurement of completeness: The results of record linkage can be used to reconcile records across data sources to generate a larger set of vital records for computing outcome indicators. This reconciled set of records can then be a denominator to estimate the completeness of data from either source. However, if one data source has only partial coverage of the population, the record linkage and reconciled set may only be used as numerators for computing outcome indicators. For example, information on neonatal deaths from a hospital death register could be searched to identify events that had not been registered, and these could then be added to the CRVS data to derive a reconciled number of neonatal deaths as the numerator for the neonatal mortality rate. However, because the hospital death register has only partial population coverage (some births would have taken place at home or in other health facilities), it does not qualify as a separate population-based data source for undertaking completeness analysis.

There are other, more complex approaches to using record linkage methods for estimating completeness, including methods that estimate events potentially missed by both data sources. These concepts are illustrated through examples from field applications in various countries that demonstrate practical issues encountered in the implementation of record linkage analysis and approaches to resolving these issues.

The following example includes a brief description of the analysis design and setting and covers relevant aspects of its principles and concepts.

Evaluation of Completeness of Death Registration in Oman

This evaluation was part of a comprehensive review of death registration systems in Oman (10). The primary data source for completeness assessment was death registration data for 2010 from the Birth and Death Notification System (BDNS) database maintained by the Oman Ministry of Health (MoH), which is the legally mandated source for vital statistics in the country. The secondary source of data for record linkage was the individual records of deaths for 2010 that were compiled from the Oman national census conducted on 15 Dec 2010, with a recall period from 01 January. The study report provides detailed descriptions of data collection and management for each source, and the availability of variables from the two sources for record linkage analysis are shown in Table 4.

Table 4. Variables available from each data source for record linkage analysis, Oman 2010 (source: (10))

Variable	BDNS database	Census 2010 database
Notification number	●	
Reported institution	●	
Name and tribe name of deceased	●	
Name and tribe name of death informant		●
Governorate/region	●	●
Wilayat (district)	●	●

Variable	BDNS database	Census 2010 database
Town/village	●	●
Locality or compound	●	●
Sex	●	●
Date of death	●	●
Age at death	●	●
Date of birth	●	

To ensure compatibility, MoH data were only taken for the same recall period as the census. Further, data from both sources were only taken for Oman nationals and excluded deaths of expatriates. For both sources, care was taken to include events among Omani nationals that had occurred in other countries during the reference period. One limitation of the census database was that the name of the deceased was not recorded, so the tribe name of the informant was used as a proxy to be matched with the complete name (which includes the tribe name) of the deceased in the MoH database. Findings from the data quality assessment is presented in Table 5.

The data quality evaluation provides an initial understanding of the challenges that may arise in undertaking a record linkage exercise. The initial round of linkage was attempted using six variables: tribe name, age at death, date of death, sex, district, and village name. This first linkage yielded only 9.5% of records with exact matches for all six variables. Among the remaining 90.5% of unmatched records, about 35% were unmatched because of one or more missing variables in the BDNS database, rather than any potential data error in either data source.

Table 5. *Quality of data for variables from two sources used for record linkage analysis, Oman 2010 (source: (10))*

Items	BDNS	Census
Total records	6,039	5,400
Missing date of death	0	0
Duplicates	3	19
Missing age	652	0
Missing sex	18	0

Items	BDNS	Census
Missing governorate	457	0
Missing Wilayat	535	0
Missing nationality	18	0
Missing Wilayat and governorate	457	0
Records used in matching	6,036	5,381

The unmatched records were scrutinized, and the following discrepancies were noted in many records:

a. Minor spelling differences in tribe names and village names
b. Minor variations in age, or date of death within the month
c. Differences in sex in the case of some neonatal deaths

After correction of spellings, a second round of linkage was attempted, with the following additional criteria to define a match:

1. All variables match but the date of death differs, but is within the same month
2. All variables match and the age at death is within five years
3. Neonatal deaths match on all variables but a difference in sex

After the second round, the proportion of matched records increased to 49.5%.

At this stage, the study team undertook an extensive field verification exercise of unmatched cases with one or more missing variables. These were traced back to the health institutions from where they were registered, and the missing piece of information, such as age, date, or address, were extracted from the health records and entered into the MoH death notification database. Certain additional strategies, such as reliance on district-level staff's local knowledge about association between tribe names and geographical location, were also used to infer missing village names, which were then added to the database. This entire field exercise took six months. Also, it was observed that age recording for the elderly in Oman was known to be potentially inaccurate, since there had been no historical practice of recording date of birth or age prior to nation state formation in 1970.

Taking these considerations into account, and after all the corrections from field verification, a third round of record linkage was undertaken, with the following additional criteria to define a match:

1. Where all variables matched except month of death, a difference of one month was allowed.
2. Given the known weaknesses in recording of age for deaths in the elderly, the acceptable margin of difference between ages for deaths older than 65 years from the two sources was extended to 10 years.

The final tally of matched records was 80%. This level of matching allows for further analysis and use of the dataset for matched and unmatched deaths for estimation of completeness. Hence, these final results from the record linkage were then used to estimate the completeness of death recording in the MoH death notification database, discussed in a later section.

This example illustrates the concepts of defining compatibility of data sources; assessment of data quality; the iterative process of conducting record linkage; and the practice of field verification using local knowledge to improve data quality and minimize potential for matching error.

Statistical Analysis

The results from the record linkage process can be displayed in a conventional matrix as in Table 6, with each cell defined below the Table:

Table 6*. Conceptual model for capture-recapture analysis of registration completeness*

	Source 1		
Source 2	Reported	Not reported	**Total**
Reported	M	U_2	N_2
Not reported	U_1	Z	V_2
Total	N_1	V_1	N

Where:

M = events that are matched across the two sources, i.e. recorded in both sources

N_1 = total events reported in source 1= M + U_1 where U_1 =records in source 1 not matched in source 2

N_2 = total events reported in source 2= M + U_2 where U_2 =records in source 2 not matched in source 1

Z = number of events estimated to be missed by both sources; computed as $Z = \frac{U_1 U_2}{M}$

V_1 = number of events missed by source 1

V_2 = number of events missed by source 2

N = estimate of total events = M + U_1 + U_2 + Z

Completeness of source 1 = N_1 / N

Completeness of source 2 – N_2 / N

The estimation of Z (events missed by both sources) is based on the following conditions (9):

- Independence of the two sources: The probability of an event being included in one source is independent of its probability of being included in the second source. This could be established through a detailed review of data collection processes in the two sources in order to demonstrate that different institutions and personnel were used for each source, and that no communication occurred between these institutions at any point, ultimately demonstrating one source's independence from the other.
- Homogeneity of reporting in each source: All events have an equal probability of being recorded in the data sources. This means that there is no likelihood of either source systematically excluding some subpopulation (examples: geography, age, sex, socio-economic status), which would affect the compatibility of data for matching.
- Accuracy of reporting in each source: All events recorded in each source are correctly recorded with regard to being from the same geographic area and time frame, as well as accuracy of information recorded for each matching variable (example: age, sex, date of event, etc.), which will indicate compatibility of records for matching.

- Accuracy of matching: The procedures for correctly linking and matching records identify those that are truly recorded in both sources and correctly identify those recorded in either but not both of the sources. In other words, it ensures that no erroneous matches or erroneous non-matches exist — in other words, that there is zero net matching error.

In actual field operations, it is unlikely that all the above conditions will be fulfilled without some element of bias from one or more sources. For instance, health system records could be biased by differential community access to health services across populations, hence violating the condition of homogeneity of data capture. Field personnel from different systems often communicate and share their records, which violates the condition of independence. Operations could have problems with accuracy of reporting time reference or actual address of residence. All these issues can influence matching accuracy. These factors should therefore be carefully evaluated at the start, and a capture-recapture analysis of completeness should be undertaken only when near-ideal conditions are in place. However, record linkage also facilitates measuring completeness using a process of data reconciliation, as well as through hybrid methods that incorporate processes for both reconciliation and capture-recapture analysis. For this reason, record linkage should be attempted wherever multiple data sources are available, after which an appropriate analytical approach to estimate completeness could be adopted, based on attributes of the data sources and viability of estimated outcomes. Below are sample approaches to estimating completeness based on record linkage mechanisms.

Completeness Based on Capture-recapture Analysis

The Oman study estimated completeness using the capture-recapture method after a careful evaluation of whether conditions for the estimation of Z are likely to be fulfilled. First, the data collection processes and the two data sources were evaluated for independence. The MoH BDNS database compiled data from routine and continuous reporting of vital events from hospitals and community health facilities directly to the MoH. Only MoH personnel handled this process.

In the second source, the household Census 2010, deaths were reported by household respondents to census enumerators, without any contact or input from health service personnel. The census data were then compiled into a statistical database by the National Statistics Office, with no communication with the health sector. Examining these processes clearly established the independence of the two data sources.

The total national coverage of the two systems inferred an equal capture probability for all events in both data sources. The potential for bias arising from reporting inaccuracies was addressed through intensive field activities to rectify missing data, which established accuracy of data records for linkage. The iterative matching process established an eventual set of criteria that, in the opinion of the investigators, maximized the accuracy of matching, with zero net matching error. Therefore, all remaining unmatched records were assumed to be true unique records in either source.

After accounting for all these factors, the Oman data was analyzed by the capture-recapture method to estimate the number of deaths missed by both sources (Z). The results are shown in Table 7.

From this analysis, the completeness of the BDNS system was calculated as follows:

$$\text{Completeness} = \frac{6{,}036}{6{,}740} * 100 = 90\%$$

Table 7. *Capture-recapture analysis of deaths from two sources in Oman, 2010 (source: (10))*

Data source		**BDNS database**		
		Yes	No	Total
Census 2010	Yes	4,819	562	5381
	No	1217	142*	1359
	Total	6036	704	6,740

*estimated from $\frac{\mathbf{1{,}217}\ \boldsymbol{X}\ \mathbf{562}}{\mathbf{4{,}819}} = \mathbf{142}$

The method also provides for calculating the variance of the completeness measure, which can be used to estimate the 95% confidence interval (CI) for the completeness measure, as shown in Annex 1. This calculation of variance is valid only under the assumption that all conditions for estimating Z have been fulfilled.

Further illustrating application of the capture-recapture analysis method, the Oman dataset was stratified across several age groups, and completeness was estimated for each stratum (see Table 8)

Table 8*. Capture recapture analysis of completeness by age, Oman 2010 (adapted from source (10))*

Age	Matched	Only in BDNS	Only in Census	Z	Total	Completeness (95% CI)
0-4	570	95	246	41	952	70 (69-71)
5-14	139	4	92	3	238	68 (59-61)
15-24	327	8	43	1	379	88 (87-89)
25-44	482	61	44	6	593	92 (91-93)
45-64	1,054	182	31	5	1,272	97 (97-98)
65-84	1,647	720	44	19	2,430	97 (97-98)
85+	600	45	62	5	712	91 (90-91)
Total	**4,819**	**1,217**	**562**	**142**	**6,740**	**90 (89-90)**

Completeness Based on Data Reconciliation Across Various Sources

In some situations, it may be possible to obtain individual records for linkage and analysis from two or more sources without the conditions for capture-recapture analysis being met. This most commonly arises from the lack of independence between the two data sources, owing to commonality of individuals or institutions involved in the data collection processes at the local level. For example, the health sector serves as one data source through its maintenance of community-based birth and death registers, but often local health personnel are consulted by local civil registration officials for information on vital events. From another perspective, one or more of the local data sources may only record events in a population subgroup (example: Senior

Citizens Welfare Group, Maternal and Child Health Program registers, disease-specific registers, etc.), negating the possibility of equal capture probability for the entire population in that source.

Under these circumstances, record linkage through careful matching may yield accurate information for three cells — M, $U_1$and U_2 — but it may not be feasible to estimate Z, the number of events expected to be missed by both sources. In this situation, the total of these three cells could be considered as the estimate of expected deaths in the study population, and the observed deaths in each source could be used as the numerator to estimate the completeness of that source.

This approach was adopted to estimate completeness for a mortality registration project in Indonesia(11). Samples of 12 villages in rural areas and 13 urban wards from one metropolitan area were selected for the completeness evaluation. Information on individual death records were available for the study population from three sources for the reference period of January to October 2007, as follows:

- <u>Health system registers</u>: Local community health centers routinely record deaths that are compiled by staff based on their knowledge and regular interactions with the community. This is sometimes supplemented by information from village community social volunteers and the village head. However, the health system only registers recorded deaths that have occurred in local areas.
- <u>Civil registration death registers:</u> Registers of deaths are maintained by the village head, and data are reported to administrative authorities. These registers often include information from health staff, interactions with community social volunteers, and deaths of residents that occur offsite.
- <u>Household survey</u>: In December 2007, a household survey by an independent survey team enquired about household deaths during the period of January to October 2007. However, the data from this survey was not deemed sufficient to be treated as a viable source for capture-recapture analysis because the capture probability for deaths was affected by known instances of collaboration between surveyors and local health staff as well as inadequate response from households.

For the specified reference period, the numbers of events recorded in each of the three sources are shown in Table 9.

Table 9. *Results from different death recording systems in a sample of localities in Central Java, 2007 (adapted from source (11))*

Location	Localities	Health system	Civil Registration	Survey
Rural	12 villages	223	259	248
Urban	13 wards	278	457	286
Total	25 village/wards	501	716	536

Data was matched across the three data sources using multiple variables as follows:

a. Name(s)
b. Sex
c. Age at death
d. Address
e. Date of death

Matching was undertaken at the national level by an independent team of investigators from the MoH. The adjudication process also included consultations with village and ward-level health system officials to follow up on partially matched or doubtful matches. The criteria allowed for matches by month rather than the exact date of death, and for a five-year variation in the reported age at death from different sources, if all other variables matched. Following the matching process, the data were reconciled to develop a final list of unique events from all the three sources, and this total set of unique deaths in the study population was used as the denominator for estimating completeness.

The results from the matching process across the three sources are depicted separately for rural and urban areas in Figure 2. The matching and reconciliation process across the three sources identified a total of 306 unique deaths in the study's rural areas, and 536 unique deaths in urban areas. As can be seen, the percentage of records that were matched across all through sources was about 60% in rural areas ($\frac{167}{306}$); and only about 28% in urban areas ($\frac{128}{536}$). The diagram also shows the matched records in pairs of data sources.

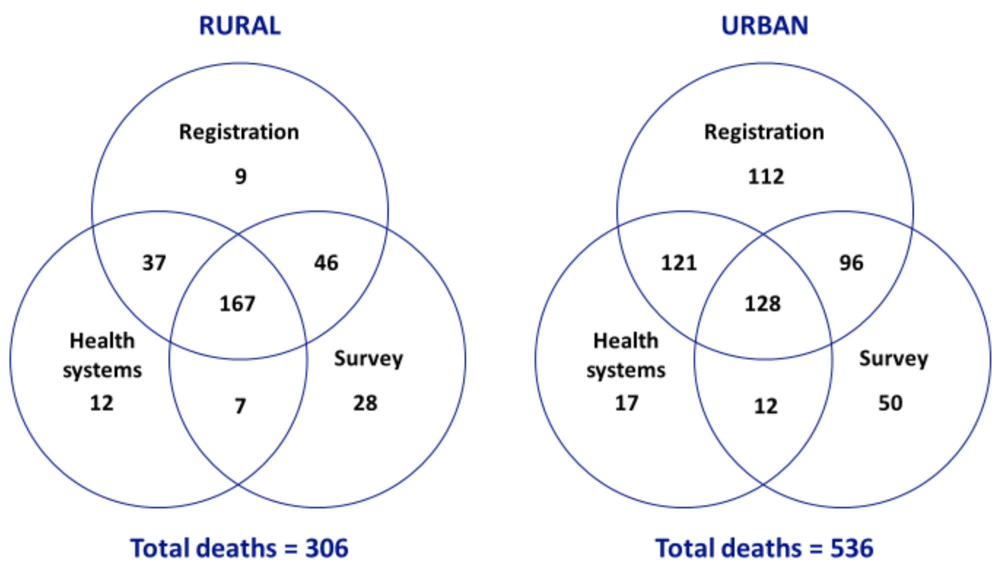

***Figure 2**. Distribution of deaths from three data sources in selected rural and urban areas of Central Java, Indonesia, 2007 (source (12))*

Using the number of reconciled deaths from the three sources as the denominator, completeness of each data source was estimated separately for urban and rural areas, as shown in Table 10.

For example, the completeness (C) of death registration for health system data for rural areas is calculated as follows:

$$C = \left(\frac{Health\ system\ deaths}{Reconciled\ deaths}\right) * 100 = \frac{223}{306} * 100 = 72.9\%$$

***Table 10**. Estimated completeness of death registration for different data sources in selected areas of Central Java, Indonesia, 2007*

Location	Reconciled Data	Health System	Civil Registration	Survey	Combined Health and Civil Registration
Rural	306	73%	85%	81%	90%
Urban	536	52%	85%	53%	91%
Total	842	60%	85%	64%	91%

The analysis shows that the civil registration system had the best performance out of all three sources. However, the analysis also identified that reconciliation of data from the two routine mechanisms operated by the health system and civil registration would yield a completeness of more than 90%, which would be a sound basis for strengthening mortality statistics derived from CRVS systems in Indonesia. The findings were also used to develop age-specific and cause-specific death rates, adjusted for completeness.

Completeness from Combined Reconciliation and Capture-Recapture Analysis

Record linkage methods can also be used to estimate completeness through a hybrid approach using both reconciliation and capture-recapture analysis. One example is a completeness assessment conducted for mortality surveillance in Vietnam (12). The assessment involved compilation and analysis of mortality statistics in a nationally representative sample of 192 communes in Vietnam, covering a population of approximately 2.6 million people. The study aimed to measure levels of mortality and causes of death for 2009. Data collection was implemented during January to August of 2010.

The first step was establishing a comprehensive list of deaths among the usual resident population of each commune during the reference period (January to December of 2009). Several local data sources were used in each commune. The following sources were used, with respective population coverage and data collection protocols:

- <u>Commune Health Station (CHS)</u> <u>death registers</u>: All deaths in a commune are reported and recorded by the commune health station.
- <u>Commune Population and Family Planning Committee (CPFPC)</u> <u>household registers</u>: All vital events in the community are reported by citizens and local leaders to the CPFPC, which is an organization that maintains local household registers for community services. In practice, there is collaboration and information-sharing between the health staff at the

CHS and the CPFPC officials at the commune level, but there are instances where some records may only be recorded in one source.

- Ministry of Justice civil registration death registers: For administrative and legal purposes, births and deaths are recorded in the civil registers maintained by the Justice Clerk at the commune administration office. These events are directly reported by family members or other informants, and in some instances, the Justice Clerk conducts follow up verification household visits.

Separate lists of deaths were compiled from each data source. For descriptive purposes, death records from each of these data sources were totaled across communes at the regional level, as shown in the first three columns of Table 11. The records were linked and reconciled across the data sources for each commune, and the sum of reconciled deaths for all communes in each region is listed in the fourth column of Table 11. These reconciled deaths were used in a preliminary analysis to understand the proportion of records that were derived from the three different recording systems, as interpreted from the percentages in Table 11.

Substantial regional variation was observed in the recording of deaths across different recording systems, with higher recording by the CHS in three regions and higher death recording by the civil registration system in the other two regions. This inconsistent pattern indicated the importance and need for data reconciliation across the available sources in all locations in Viet Nam, to derive a more comprehensive and inclusive data set of observed death events for mortality measurement, and to estimate completeness of individual data sources. In addition, these variations in death recording practices in different regions of Viet Nam were inherently useful observations that were shared with officials from all three death recording systems as a basis for future streamlining of processes and quality assurance of data compilation.

***Table 11**: Findings from reconciliation of data from three main data sources on deaths at commune level in Vietnam, 2009 (source: Unpublished intermediate data used for analysis presented in Table 12)*

Regions	CHS	CFPFC	civil registration	Reconciled Total
1	1,723 (75%)	1,580 (69%)	1,665 (72%)	**2,304**
2	999 (85%)	210 (18%)	181 (15%)	**1,185**
3	1,768 (78%)	1,043 (47%)	1,306 (59%)	**2,221**
4	435 (18%)	571 (23%)	1,868 (76%)	**2,453**
5	872 (49%)	758 43%)	1,079 (62%)	**1,758**
Total	**3,797 (38%)**	**4,162 (42%)**	**6,099 (62%)**	**9,921**

Figures in parentheses are percentages of the reconciled total. The shaded yellow cells indicate that for regions 1-3, the CHS recorded a higher percentage of deaths from the reconciled total, while for regions 4-5, the civil registration data recorded higher deaths.

The record linkage and data compilation for death records were conducted using these steps:

1. In each commune, all records from the CHS and the CFPFC were combined to create a single merged data source. This was done because of the known collaboration between these two recording systems. For convenience, this data source was termed 'CHS/CPFPC'.
2. In each commune, the record matching and linkage exercise were conducted between this combined source (CHS/CPFPC) and the list of deaths compiled from the civil registration records at the Justice Department records (civil registration), which was considered an independent source for capture-recapture analysis.
3. The variables used for linkage were name, sex, age at death (within five years) and month of death.

   The linkage yielded a set of matched deaths (M) for each commune, along with the records noted only in either the CHS/CPFPC data set or the Justice data source, and these were first categorized at commune level by sex and four broad age groups (0-14, 15-59, 60-74, 75+).

4. Following the matching exercise, a reconciled list of deaths (R) was also prepared for each commune, noting whether it had been present in the CHS/CPFPC data, the Justice data, or both sources.
5. The numbers of deaths from each category (Matched, CHS/CPFPC, Civil Registration, and Reconciled) for each commune were then totaled across all communes to generate the deaths for these categories at the national level, and presented in Table 12 or each age-sex group of the study population.

Table 12. *Analysis of completeness of death records from mortality surveillance program in Viet Nam, 2009 (source: Adapted from (12))*

Age-sex group	Pop	Matched	CHS/ CPFPC	Civil Registration	Z	Reconciled	Total	$C_{H/P}$	C_{CR}	C_R
Males	**1,239,937**	**2,138**	**1,984**	**1,363**	**1,265**	**5,485**	**6,750**	**61%**	**52%**	**81%**
0–14	289,373	72	68	39	37	179	216	65%	51%	83%
15–59	873,727	903	873	597	577	2,373	2,950	60%	51%	80%
60–74	53,985	453	414	274	250	1,141	1,391	62%	52%	82%
75+	22,852	710	629	453	401	1,792	2,193	61%	53%	82%
Females	**1,309,462**	**1,572**	**1,413**	**1,026**	**922**	**4,011**	**4,933**	**61%**	**53%**	**81%**
0 – 14	269,006	45	58	23	30	126	156	66%	44%	81%
15 – 59	929,773	373	350	251	236	974	1,210	60%	52%	80%
60 – 74	72,999	342	271	213	169	826	995	62%	56%	83%
75+	37,684	812	734	539	487	2,085	2,572	60%	53%	81%

6. These data were then used to estimate the events missed by both data sources (Z) for each age-sex group (see Table 12) with the assumptions that CHS/CPFPC and civil registration were independent data sources, and that all other conditions for capture-recapture analysis were met.
7. The Z value for each age-sex group was added to the three cells to develop the estimate of total deaths.
8. Completeness was estimated for CHS/CPFPC ($C_{H/P}$) and civil registration (C_{CR}) record systems by the conventional approach described earlier, as follows:

a. $C_{H/P} = \frac{M+CHS/CPFPC}{Total} * 100$

e.g $C_{H/P}$ (males) $= \frac{2138 + 1984}{6750} * 100 = 61\%$

b. $C_{CR} = \frac{M+Justice}{Total} * 100$

e.g $C_{CR}\,(\text{females}) = \frac{1572 + 1026}{4933} * 100 = 53\%$

9. The reconciled list was used as a basis in each commune for follow-up procedures to ascertain causes of death. The data from this reconciled list was used to generate overall and cause-specific mortality indicators.
10. For the purpose of this assessment, completeness was also estimated for the reconciled deaths (C_R), which can be extrapolated to be the completeness of data from the mortality surveillance program.

$$C_R = \frac{M+CHS/CPFPC + Justice}{Total} * 100$$

$$C_R \text{ (Males 60-74 y)} = \frac{453+414 + 274}{1391} * 100 = \frac{1141}{1391} *100 = 82\%$$

11. Age-specific death rates were calculated from the reconciled list, which were subsequently adjusted for completeness using the factor estimated for the reconciled list in Step 11.
12. These adjusted age-specific death rates were used to estimate life tables, summary mortality measures, and cause-specific mortality rates for the study population.

This example demonstrates the use of capture-recapture analysis to estimate the deaths potentially missed by both sources to develop the denominator, but uses the reconciled list as the numerator for estimating completeness. The findings from Tables 11 and 12 also helped clarify operational issues affecting completeness of data sources at the commune level, and highlighted the value of routine data-sharing and reconciliation at local level, which could improve overall timeliness and completeness of death registration data.

Advantages and Limitations

The advantages of record linkage analysis are that the matching and reconciliation methods are intuitively easy to understand, the computational method for measuring completeness is straightforward, and the assumptions and conditions for the capture-recapture analysis can be readily evaluated using the data at hand. Because multiple local sources for vital records can commonly be found and used to undertake matching and reconciliation analysis, completeness assessments are likely to have sufficient data samples to derive estimates by age, sex, or sublocations.

One key limitation of these methods is that any problems with data quality from either source could affect the accuracy of the matching process. Challenges could also exist in establishing the independence of data sources for applying the capture-recapture analysis technique. It may also be difficult to gain access to individual record data from either source. However, the case studies have demonstrated the possibilities of addressing these challenges in implementation.

Indirect Demographic Analytical Techniques for Death Registration Completeness

A third approach to estimate death registration completeness is through the application of demographic techniques and models. The underlying principle remains the same in terms of estimating a denominator of expected deaths in the study population. This denominator is then used to compute the proportion of observed deaths as the estimate of completeness. These demographic techniques have evolved over the past several decades, but they have three fundamental limitations: 1) their complex data needs; 2) their low validity due to methodological assumptions; and 3) a general lack of technical capacity to apply these methods in local settings.

Early versions of these techniques involved analysis of cross-sectional data on population and deaths by age from a single year, available from death registration. However, these methods were based on assumptions of constant fertility and mortality in the decade preceding the analysis, an absence of migration, and equal levels of completeness at all ages — assumptions that do not hold for any current population.

More recently, the techniques have developed into Death Distribution Methods (DDMs). These methods are based on mathematical relationships between age distributions of populations and age distributions of deaths, which link the age pattern of deaths with the level of mortality in the population. These relationships are used to generate a schedule of expected deaths that then serves as the denominator for estimating completeness.

These methods require data on age distributions of population from two consecutive censuses, along with information on annual registered deaths by the same age categories for each intervening year between the censuses. The methodology is based on an assumption that migration is absent, and it is very sensitive to the accuracy of age records in both population and death data. In addition to having these complex data needs, these methods also rely on complete data from both population censuses, although techniques have been developed to measure and adjust for deficiencies in census completeness.

DDMs only provide a single estimate of completeness for the entire intercensal period of the analysis, which usually spans a decade, and this is a major limitation for these methods. The completeness estimate is also the same for all age groups, which often is implausible. Finally, a comprehensive methodological review of these methods identified that the completeness estimate from DDMs incorporates an error of ±25%, which limits the utility of these methods (13).

A detailed description of the DDMs is available from a recent technical paper published by the United Nations Population Division (2). A well-described recent example of its application is available from Brazil for the period 1990 to 2000 (14). Given the complexity of the method, along with the elaborate data needs and challenges with interpretation, it is recommended that these methods be implemented through collaboration with experts in applying such models.

The Adair-Lopez Empirical Method

The Adair-Lopez Empirical Method is an indirect demographic technique that has recently been developed as a relatively simple method for estimating completeness of death registration. The method is based on a statistical model that estimates death registration completeness as a function of its relationship with the registered crude death rate, the registered under-5 mortality rate, and proportion of individuals aged 65 years and older in the study population(15).

The models for these relationships were developed using population and mortality rates from 2,451 country years of vital registration data. The Adair-Lopez model comprises two variants, the first of which includes an estimated factor of child mortality registration completeness in the study population, while the second variant excludes this factor. The first variant (Model 1) is recommended for use in settings where a strong correlation is expected between completeness of child death registration and completeness of registration at all ages. Where such association is not expected, the second variant (Model 2) should be used.

The completeness estimation model is implemented through a spreadsheet that is part of an electronic program for analyzing the quality of mortality and cause of death data developed by the University of Melbourne (16). A stand-alone version of the spreadsheet is also available from the tool developers (a screenshot of the tool is depicted in Figure 3). The following inputs are required for the study population, preferably by sex, although it is also possible to use the tool for both sexes combined:

a. Total registered deaths
b. Total population estimate
c. Proportion of the population aged 65 years and older
d. Estimate of true under-5 mortality rate (U5MR) by sex from another reliable source (e.g. DHS)
e. Registered under-5 mortality rate (used in Model 1)

f. Random effects factors for each model, to be used only for countries represented in the original dataset from which the model relationships were developed. These random effects factors for respective countries are available in the spreadsheet tool.

The original article by Adair and Lopez presents several examples of the method's application. An additional example is also available from a study in India that was used to demonstrate the methods for aggregated analysis within the same Indian states shown above in Tables 2 and 3. That example estimates completeness using the second variant of the model only; the data from the Indian Civil Registration System did not fulfil the requirement for Model 1, as child mortality registration completeness is observed to be poorly associated with overall death registration completeness, as demonstrated in Table 3 (pg. 10).

West Bengal	**2017**		
Data inputs	**Both sexes**	**Males**	**Females**
Deaths **(FROM CRS)**	442,995	255,925	187,070
Mid-year population **(FROM CRS)**	94,597,000	48,319,040	46,277,960
Registered CDR (per 1000)	4.68	5.30	4.04
Registered CDR (per 1000) squared	21.93	28.05	16.34
% population 65+ **(FROM CRS)**	5.35%	5.40%	5.30%
True under-five mortality rate **(FROM SRS 2017)**	0.028	0.026	0.029
ln (under-five mortality rate)	-3.58	-3.65	-3.54
Registered under-five mortality rate **(FROM CRS)**	0.013	0.015	0.012
Completeness of under-five death registration	46%	46%	46%
Random effects - model 1	0.000	0.000	0.000
Random effects - model 2	0.000	0.000	0.000
Model 1	**Both sexes**	**Males**	**Females**
Model equation	1.1913	1.3348	1.1254
Predicted completeness	**76.7%**	**79.2%**	**75.5%**
Model 2	**Both sexes**	**Males**	**Females**
Model equation	1.6198	1.741	1.495
Predicted completeness	**83.5%**	**85.1%**	**81.7%**

Legend	
	Data input
	Predicted completeness

Figure 3. Spreadsheet version of Adair Lopez method for estimating death registration completeness

Table 13 displays the model input parameters and estimated completeness levels at the national and state levels. These estimated completeness levels closely correlate with the findings on completeness for these same study populations from the aggregated analysis presented in Tables 2 and 3.

Table 13. Input parameters for estimating completeness of civil registration data for selected states in India, 2017, using the Adair Lopez method

	MALES					FEMALES				
Area	**Pop**	**Deaths**	**Pop65+**	**U5MR (SRS)**	**Est C %**	**Pop**	**Deaths**	**Pop65+**	**U5MR (SRS)**	**Est C %**
India	664,802,000	3,825,085	4.9	0.039	82.0	618,799,000	2,620,467	5.3	0.042	75.1
Andhra Pradesh	26,253,874	217,429	6.3	0.034	92.7	26.066,126	138,117	5.7	0.029	90.2
Gujarat	33,225,950	231,433	4.6	0.045	86.7	30,543,050	156,883	6.0	0.044	80.5
Himachal Pradesh	3,636,777	23,103	7.0	0.031	84.7	3,533,223	16,000	7.7	0.024	82.7
Madhya Pradesh	41,084,303	223,500	4.4	0.058	69.0	38,246,697	147,038	4.8	0.058	60.2
West Bengal	48,319,040	255,925	5.4	0.026	85.1	46,277,960	187,070	5.3	0.029	81.7

Advantages and Limitations

Indirect demographic techniques such as Death Distribution Methods have several limitations: 1) complex data needs, 2) the derivation of a completeness measure that is constant for all ages, and 3) the lack of timeliness in the completeness estimate from an intercensal period rather than a single point in time. In contrast, the Adair–Lopez method has relatively simple data needs that can be implemented using a simple spreadsheet tool and can readily be used to monitor changes in completeness over time. The key limitations are that the method does not derive age-specific measures of completeness that could be used for finer adjustments of mortality rates, and that the model cannot be applied in settings where there are high levels of mortality from HIV/AIDS.

Internal Assessment Based on Self-reports of Registration

This method takes the form of a special module on birth and death registration that is added to existing fertility and mortality survey platforms. It enquires whether survey-reported events have also been recorded by local CRVS systems. Completeness is simply measured as follows:

$$\text{Completeness} = \frac{\textit{Survey reports of events registered with CRVS system}}{\textit{Total survey reported events}} * 100$$

This method has been recently developed and tested in the periodic Demography and Health Survey program operated by MEASURE DHS, and the Multiple Indicator Cluster Survey operated by UNICEF (17). These surveys compile information from complete pregnancy histories of women of reproductive age in a sample of households and enquire about registration of the most recently reported event. The application of this method thus far has focused on deriving information to measure completeness of live births, still births, and neonatal death registration. There is potential to extend this approach to enquire about registration of deaths reported in sibling or parental survival history modules for adults, which are sometimes implemented in censuses and survey programs (18). It is possible to improve the reliability of data from such surveys by asking respondents to show physical proof of registration documents, as done during the Thai Inter Censal Survey of Population Change (19).

In principle, this method represents a self-reported internal assessment of registration completeness without any reference to the official CRVS record. Hence there is potential for recall bias because respondents may not remember details, and because the event may have been communicated to CRVS officials by key informants without participation of family members. The latter is possible in areas where little incentive exists for families to obtain birth or death registration records for personal use.

The method is also limited in scope by the relatively small survey sample size, which reduces the potential for sex-wise disaggregation of birth registration completeness or sex-age disaggregation of death registration completeness measures. Implementation in national censuses is also of limited value since those are conducted only once per decade.

In summary, this method only offers the potential to estimate a crude measure of completeness that could be used to evaluate CRVS system performance. However, this can be augmented through a recently developed module of additional questions that enquire about contextual factors and reasons for events not being registered (e.g., availability/access to registration services; costs; time factors) (17). This method therefore should be implemented wherever feasible to obtain approximate measures of system performance, as well as information to guide interventions to strengthen the CRVS system.

Advantages and Limitations

The advantage of this method is that data collection can be implemented easily in conjunction with existing and ongoing periodic survey programs, and that adequate attention to interviewer training and community sensitization can generate reasonably adequate data quality for assessing completeness. Moreover, the method facilitates the collection of information on contextual factors that can influence completeness. The key limitation is that the method is reliant on self-reported information; the results can only be used to assess system performance and would be insufficient to derive sex and age-specific measures of completeness.

Recommendations for Completeness Assessment Strategies

The following aspects need to be considered when selecting which approach to adopt in a completeness estimation exercise:

- The purpose and application of the completeness estimates – to infer system performance or to correct observed mortality rates
- Administrative levels for which completeness estimates are required (national, urban/rural; province/state/district levels)
- The need for completeness estimates by sex and age categories
- Availability of data from primary and secondary data sources
- The use of all methods for which data are available, and triangulation of results to guide interpretation of completeness levels

Table 14 presents a summary of the data needs, advantages, and limitations of each of the methods for estimating completeness.

Table 14. Summary of data needs, advantages and limitations of methods for estimating death registration completeness

Method	Data needs	Advantages	Limitations
Aggregated analysis using crude death rate	• Study population (by sex) • Reference crude death rate	Data readily available	Bias due to age variations in completeness
Aggregated analysis using age-specific death rates	• Age-specific death rates from study population and reference	Age-specific completeness to adjust mortality estimates	Reference age-specific death rates not readily available
Adair-Lopez model	• Study population: crude death rate, % pop ›65y; registered under-5 mortality rate • Reference: True under-5 mortality rate	Data readily available, simple implementation tool	Completeness estimate for all ages
Record linkage with data reconciliation	• Common variables for matching across sources	Direct assessment with verifiable results	Poor data quality in either source can affect linkage
Record linkage with capture-recapture analysis	• Common variables for matching across independent and compatible data sources	Direct assessment with verifiable results	Poor data quality can affect linkage; questionable viability of assumptions
Death distribution methods	• Age-specific population data from two consecutive censuses; annual deaths by age for all intervening years	Only secondary data required	Data usually not available; results with wide uncertainty margins
Internal assessment methods	• Survey responses on registration of reported events	Can be included in all household surveys	Small sample size, limited external validity

With this in mind, the following approach could be adopted for completeness assessments. As explained below in Box 1, it is recommended that the completeness measurement first be attempted at Level 1. The question of whether to attempt methods listed in subsequent levels will likely be based on data availability and resources, given the increasing data requirements and complexity in completeness estimation methodology. It is likely that different methods may be applicable at national or subnational level due to differences in data availability. Consequently, all possible methods for which data requirements can be satisfied and the level of accuracy needed should be considered to provide a comprehensive and detailed assessment of completeness. Even where completeness appears to be low from a simple aggregated data analysis, record linkage should be attempted whenever multiple data sources are available. Such analyses can give useful insight into structural factors that limit data recording in the CRVS system, and these factors can be addressed through system strengthening interventions.

Box 1. Levels of Completeness Estimation Methodology

Level 1: Aggregated data analysis using the crude death rate

- Use observed rate for the same population from an alternate source (census, survey, surveillance program) in the same year, or within the previous three years. *See Indian Study: Table 2*
- For province- or district-level completeness, use observed rates (national or provincial) for higher aggregations. *See Indonesian study: Figure 1*
- If no national observed rate is available, use country estimate of CDR for the current year from the World Population Prospects.

Level 2: Application of Adair-Lopez model

- Use observed input parameters from CRVS data, and an estimate of the true under-5 mortality rate in the study population from an alternate source. *See Table 13*

Level 3: Aggregated data analysis based on age-specific death rates

- Use data from empirical or local data adjusted life tables. Avoid using Model Life tables for this approach. *See Indian Study: Table 3*

Level 4: Record linkage and data reconciliation-based completeness assessment

- *See Indonesian Study: Figure 2 and Tables 9 and 10*

Level 5: Record linkage and capture-recapture analysis

- *See Oman study: Tables 4, 5, 7 and 8*

Level 6: Combination of record linkage-based data reconciliation and capture recapture analysis

- In specific circumstances. *See Vietnam Study, Tables 11 and 12*

Additional Methods to Consider

- Internal assessment method used in population surveys
- Indirect demographic techniques based on Death Distribution Methods (depending on data availability and technical capacity)

Interpretation and Use of Completeness Estimates

As mentioned earlier, it is likely that more than one method category or application level could be used to estimate completeness for a population and its subgroups. While it is recommended that multiple possible methods should be considered, care should be taken in interpreting the results and using them only for their originally intended purposes. Completeness estimates for evaluating system performance can be a relatively approximate measure, whereas use of completeness estimates for adjusting mortality counts and rates, or for generating data on population disease burden, would require more exact measures. Measures derived for evaluating system performance may therefore be unsuitable for adjusting mortality rates.

A first principle in preparing results from a completeness evaluation is to thoroughly document all technical details for each method used. These include data sources used, parameters of data quality for each source, methodological details, criteria or assumptions applied, and details of intermediate and final results, along with their calculations. Where feasible, some level of confidence in the estimates — usually the 95% confidence intervals — should be presented along with the calculation methodology.

Where estimates from several methods are available, nuanced interpretation is necessary. A general principle for such a situation could be that if all the different estimates are within 10% of each other, their average could be taken as the central measure of completeness. However, if the range is beyond 10%, more care is required. The methodology for each measure should be reviewed to decide if one estimation method produced more plausible results than others with regard to quality of data sources, appropriateness of assumptions, and accuracy of calculations. A high level of technical expertise may be required for such review and judgment. This may be available from national scientific experts or universities.

Regarding the potential use of estimates, the completeness of birth registration is estimated mostly as a guide to assess system performance and gauge the gap that needs to be addressed.

However, as completeness and quality of birth registration data improve, these data – after adjustment – can be used to assess fertility indicators and maternal and child health services at local levels. For these purposes, it would be appropriate to adjust birth registration data only at completeness levels of 85% or above.

Death registration completeness estimates are usually required for adjusting mortality indicators. However, such adjustments are best conducted within specific sex-age categories, rather than for all ages combined. This will avoid any distortions that may result from implausible sex-age patterns in adjusted mortality estimates. Where data are available only for aggregated data analysis based on crude death rates, the resultant estimates are at best useful to evaluate system performance. Even when using age-specific measures, they can only be used to adjust all cause age-specific mortality rates when completeness levels are at least 75%. Additionally, these adjusted all-cause mortality rates should only be used for estimating life tables or age-standardized all-cause mortality rates — not for subsequent generation of adjusted cause-specific death rates or numbers.

Adjustments to derive estimates of cause-specific mortality may be needed for estimating population-level disease burden from specific causes. However, such adjustments should be conducted only when completeness of death registration is estimated at or above 85% to 90%, to minimize the potential for bias caused by the unknown cause profile of the deaths added by the adjustments. In general, adjustments to cause-specific mortality for up to 10% to 15% of deaths with ill-defined or unknown causes is considered acceptable for public-health analyses (20).

At death registration completeness levels below 70%, outcome indicators should not be estimated or adjusted for completeness since they may not be plausible. In such cases, the completeness estimate should only be used as an indicator of data gaps and as a baseline to evaluate the impact of system-strengthening initiatives over time.

Finally, the Sustainable Development Goals and Targets have stressed the importance of birth and death registration in their own right. Yet it is important to ensure completeness is as uniform as possible to achieve equity in spreading the benefits of registration. Disaggregating and comparing completeness by sub-national administrative unit and sex can point to populations or locations where interventions might be possible to boost registration rates.

References

1. Rao C. Elements of a strategic approach for strengthening national mortality statistics programmes. BMJ Glob Health. 2019;4(5):e001810.
2. Hill K. Analytical Methods to Evaluate the Completeness and Quality of Death Registration: Current State of Knowledge. New York.: Population Division: United Nations Department of Economic and Social Affairs; 2017. Available from: http://www.un.org/en/development/desa/population/publications/pdf/technical/TP2017-5.pdf.
3. United Nations Statistics Division. Global Civil Registration and Vital Statistics Group New York: United Nations; 2014 [Available from: https://unstats.un.org/unsd/demographic/crvs/globalcrvs.html.
4. Mrkic S, Cobos MI, (Eds). Evaluation of the quality of civil registration and vital statistics systems. Handbook on Civil Registration and Vital Statistics Systems: Management, Operation and Maintenance - Revision 1. New York: Department of Economic and Social Affairs: United Nations Statistics Division; 2018. p. 72-101. Available from: https://unstats.un.org/unsd/demographic-social/Standards-and-Methods/files/Handbooks/crvs/crvs-mgt-E.pdf.
5. Rao C, Gupta M. The civil registration system is a potentially viable data source for reliable subnational mortality measurement in India. BMJ Glob Health. 2020;5(8).
6. Usman Y, Iriawan RW, Rosita T, Lusiana M, Kosen s, Kelly M, et al. Indonesia's Sample Registration System in 2018: A work in progress. Journal of Population and Social Studies. 2019;27(1):39-52.
7. Taylor R, Morell S. Life table and probability of dying calculation tool. Sydney, Australia: School of Public Health and Community Medicine, University of New South Wales; 2015. Available from: https://sphcm.med.unsw.edu.au/node/303112492.
8. Rao C, Kelly M. Overview of the principles and international experiences in implementing record linkage mechanisms to assess completeness of death registration. In: Technical Paper Series: No. 5 - 2017, editor. Population Division: United Nations Department of Economic and Social Affairs. New York2017. p. 1-54. Available at: http://www.un.org/en/development/desa/population/publications/pdf/technical/TP2017-5.pdf.
9. Chandrasekar C, Deming W. On a method of estimating birth and death rates and the extent of registration. Journal of American Statistics Association. 1949;44:101.
10. Salah NK Al-Muzahmi. Mortality patterns in Oman: Demographic and Epidemiological Review [PhD thesis]. Brisbane, Australia: University of Queensland; 2015.
11. Rao C, Soemantri S, Djaja S, Suhardi, Adair T, Wiryawan Y, et al. Mortality in Central Java: results from the indonesian mortality registration system strengthening project. BMC Res Notes. 2010;3:325.
12. Hoa NP, Rao C, Hoy DG, Hinh ND, Chuc NT, Ngo DA. Mortality measures from sample-based surveillance: evidence of the epidemiological transition in Viet Nam. Bull World Health Organ. 2012;90(10):764-72.
13. Murray CJ, Rajaratnam JK, Marcus J, Laakso T, Lopez AD. What can we conclude from death registration? Improved methods for evaluating completeness. PLoS Med. 2010;7(4):e1000262.
14. Franca E, de Abreu DX, Rao C, Lopez AD. Evaluation of cause-of-death statistics for Brazil, 2002-2004. Int J Epidemiol. 2008;37(4):891-901.

15. Adair T, Lopez AD. Estimating the completeness of death registration: An empirical method. PLoS One. 2018;13(5):e0197047.
16. CRVS Gateway. ANACONDA Mortality Data Quality Assessment Tool. University of Melbourne, Australia. 2019. Available from: https://crvsgateway.info/ANACONDA-Mortality-Data-Quality-Assessment-Tool~686.
17. Simon Kasasa S, Natukwatsa D, Galiwango E, Nareeba T, Gyezaho C, al. e. Birth, stillbirth and death registration data capture, quality and feasibility in Africa: EN-INDEPTH multi-country population-based study. Popul Health Metr. 2020;In press.
18. Hill K, Lopez AD, Shibuya K, Jha P. Interim measures for meeting needs for health sector data: births, deaths, and causes of death. Lancet. 2007;370(9600):1726-35.
19. Prasartkul P, Vapattanawong P. The completeness of death registration in Thailand: evidence from demographic surveillance system of the kanchanaburi project. World Health Popul. 2006;8(3):43-51.
20. Ruzicka L, Lopez AD. The use of cause-of-death statistics for health situation assessment: National and international experiences. World Health Statistics Quarterly. 1990;43:249-57.