SOCIETY OF ACTUARIES

Mortality and Longevity

Final Report on the Activities of 2019 HMD Project

August 2021

Final Report on Activities of 2019 HMD Project

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SPONSOR Mortality & Longevity Strategic Research Program Steering Committee

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Report on the Activities of the HMD 2019 Project

Work accomplished under the 2019 agreement between the Human Mortality Database (HMD) team and the Society of Actuaries (SOA) was divided between two main projects: 1) the continuous development of the United States Mortality Database (USMDB) and 2) the publication of cause-specific mortality series for selected HMD countries. Due to administrative delays at both the University of California, Berkeley, and the Society of Actuaries, work on these projects did not begin until July 2019. Furthermore, due to restriction in data access associated with the Covid-19 pandemic, a no-cost extension was requested by Magali Barbieri, the Principal Investigator for the projects, and accepted by the SOA to extend the project beyond the initial December 31, 2019 deadline.

Section 1: The United States Mortality Database (USMDB)

GENERAL AIM

The overall goal of the project was to provide access to a series of life tables at various geographic levels for the United States using official demographic statistics from the National Center for Health Statistics at the Centers for Disease Control and from the United States Census Bureau. This statistical information is not available elsewhere, so the project was filling a gap. By fostering new research, it is expected to greatly improve the understanding of levels and trends in geographic variations in mortality in the United States. Until then, life tables by state were limited to more aggregate publications from the National Vital Statistics Report, and they were only available for selected years surrounding the national census (with the latest series for the period 1999-2001). The Institute for Health Metrics and Evaluation (IHME) also publishes selected mortality statistics for the U.S. states and counties but the current series stop in 2014. Neither of these two organizations publishes detailed historical life table series by sex for all calendar years, updated in a timely manner.

MAIN GOAL

Using U.S. population information and vital statistics data from the CDC, the researcher and her team extended work initiated in previous years to construct up-to-date life table series for U.S. states and counties in collaboration with the U.S. National Center for Health Statistics (NCHS, at the Centers for Disease Control and Prevention). The methods implemented for the construction of the U.S. state data series closely follow those described in the HMD methods protocol. As in the HMD, all resulting mortality series as well as the methods protocol, information about data sources and background and documentation files have been made available to users on an open-access website (at usa.mortality.org).

PRIOR WORK

As of the end of 2018, the United States Mortality Database (USMDB) had been published at ww.usa.mortality.com with life tables by sex for all years since 1959 and up to 2016 for the United States as a whole, the four Census Regions, the nine Census Divisions, the 50 states and the District of Columbia. The life tables were published in six different formats corresponding to different combinations of age (single years, five-year age groups, and 10-year age groups) and time (single calendar years, 5- and 10-year periods). Documentation similar to that available in the

HMD for each country is also published on the website. Access to the data is free, upon a short registration procedure.

WORK ACHIEVED UNDER THE 2019-2021 GRANT

The activities conducted in 2019-2021 have been:

- To update and publish the life table series, first (in 2019) to 2017 and second (in 2020) to 2018 for each state, division and region, with data from the NCHS (deaths) and the Census Bureau (population).

- To prepare internal reports on the reliability of the updated data series on a similar format as the report prepared for the 2016 update; a copy of this report for the extension of the series to 2018 has been provided to the Society of Actuaries team managing the project to show the accomplishment. This Data Quality report is used internally, to validate the updated data series. It is not for public consumption and might in fact be very confusing to an outside readership not aware of the details of HMD methods and implementation procedures. We are also providing it to the SOA team to illustrate the extent of the verifications we carry out at each update.

- To update the Background and Documentation file for the USMDB state data series each time the series are updated (see Appendix A for the report associated with the extension to 2018)

- To compute age-standardized death rates for a small number of cause-of-death categories so as to explore the possibility of enriching the USMDB with cause-specific data (see Appendix B for a list of the 57 cause-of-death categories for which the death rates have been calculated. These categories are the same as those used for the new HMD/HCD scheme for the sake of consistency). The data are made available to the SOA team managing the project as a comma-separated text file. Negotiations are on-going with the National Center of Health Statistics to publish the cause-of-data on the USMDB website. .

- To produce the results of an analysis on interstate variations in mortality since 1959. We were hoping to benefit from collaboration with our colleagues at NCHS (Robert Anderson and Elizabeth Arias) as initially planned but given the current health crisis, they have not been able to contribute. The analysis has been summarized in a separate report, Interstate Variations in Mortality in the United States, 1959-2018 published on the SOA website . As part of this report, we have also prepared simple Excel files listing basic mortality indicators (the expectation of life at birth and at age 65 and the infant mortality rate) by sex for each state and the U.S. as a whole and for selected years.

Section 2: The Cause – Specific Mortality Component of the HMD

GENERAL AIM

A growing course of study in mortality improvement focuses on specific trends by causes of death. In almost all countries (though notably not in the former Soviet Republics until the 2000s), causes of death have been categorized according to the International Classification of Diseases (ICD), which has been revised ten times since the late 19th century. Such data contain rich information about historical changes in patterns of disease and other fatal risks. Aggregate and cause-of-death methods have been highlighted by national social security systems in their estimations of future mortality development.

Death rates by sex, age and for some cause-of-death shortlists are available for various periods from National Statistics Offices but the methods implemented are typically not well documented and because both methods and shortlists of causes vary from country to country, the data are not comparable. Death counts by cause are also

available for a large number of countries in the World Health Organization and in the Eurostat databases. The usefulness of these databases is however limited because of the very short time series available (at most 15-20 years in the Eurostat database) or because the cause-of-death categories used to classify the deaths vary widely from one period to the next and it is nearly impossible to reconstruct a consistent series of cause-specific death counts (in the WHO database). The proposed work will thus produce a unique collection of historical standardized cause-specific mortality series.

MAIN GOAL

The ultimate goal is to add cause-of-death information to the HMD, including cause-specific death counts and cause-specific death rates by sex and age, with series extending as close as possible to 1950 for as many HMD countries as possible.

CHANGE IN THE INITIAL PLAN

A great opportunity has arisen in 2019 to expand considerably the scope of the cause-of-death project for the Human Mortality Database. Following discussions with our HMD collaborators at the Max Planck Institute for Demographic Research (MPIDR) and colleagues at the French Institute for Demographic Studies (INED, www.ined.fr/en), we have decided to combine the cause-specific data series prepared for the HMD with National Institutes of Health and SOA support with those in the Cause-of-death Human Mortality Database (www.causeofdeath.org). Both projects rely on original and detailed data from national statistics offices (exhaustive death counts by calendar year, sex, age and underlying cause of death coded to the 3rd or 4th digit of the International Classification of Diseases).

The Human Cause-of-Death Database (HCD) is a joint project of INED and the MPIDR. The HCD was developed to provide free and user-friendly access to time series of cause-specific mortality consistent over all International Classifications of Diseases Revisions to researchers, students, journalists, policy analysts, and others interested in investigating cause-of-death patterns. In contrast to other existing databases on causes of deaths, the purpose was to make available time series with causes of death classified according to a constant (fixed) list/classification of causes of death in order to document trends in cause-specific mortality and to facilitate international comparisons since the 1950s.

Cause-of-death time series are severely disrupted by periodic changes in disease classification. Since the first International Classification of Diseases (ICD) was developed at the end of the 19th century, it has been revised 10 times. Nearly all of the world countries are currently implementing the 10th Revision of the ICD. To reconstruct consistent series, it is necessary to establish transition coefficients between items of two successive classifications, in order to redistribute deaths classified according to the old classification into items of the new classification. When bridge coding (the double classification of all deaths simultaneously into the old and new classifications) has been performed at a detailed level, transition coefficients can be inferred directly from the results. However, there are only two countries where this has ever been carried out on a systematic basis (and only for the last transition, i.e. from ICD-9 to ICD-10), namely England and Wales and the U.S.. For the other transitions in the two countries and for all transitions in other countries, consistent time series are reconstructed within the HCD project by producing ex-post double coding. The method developed at INED in the 1980s (Vallin and Meslé, 1988, 1998; Meslé and Vallin, 1996) is used as a guideline, but for the HCD the work was tailored to each country independently. The results have been extensively checked statistically to detect and solve any remaining breaks in the series. Such checks are carried out by age group and sex.

We decided to merge the cause-of-death component developed for the HMD with the HCD data series by using a common shortlist of causes in order to expand the range of countries in the study as much as possible. Indeed, while only eight countries were initially included in the HMD cause-of-death project (namely Canada, the Czech Republic,

England and Wales, France, Japan, Norway, Sweden and the United States), the HCD covers a total of 15 countries. The HCD countries include Belarus, Estonia, Germany, Latvia, Lithuania, Moldova, Poland, Romania, Russia, Spain and Ukraine, in addition to France, the Czech Republic, England and Wales, and Japan, also in the HMD project.

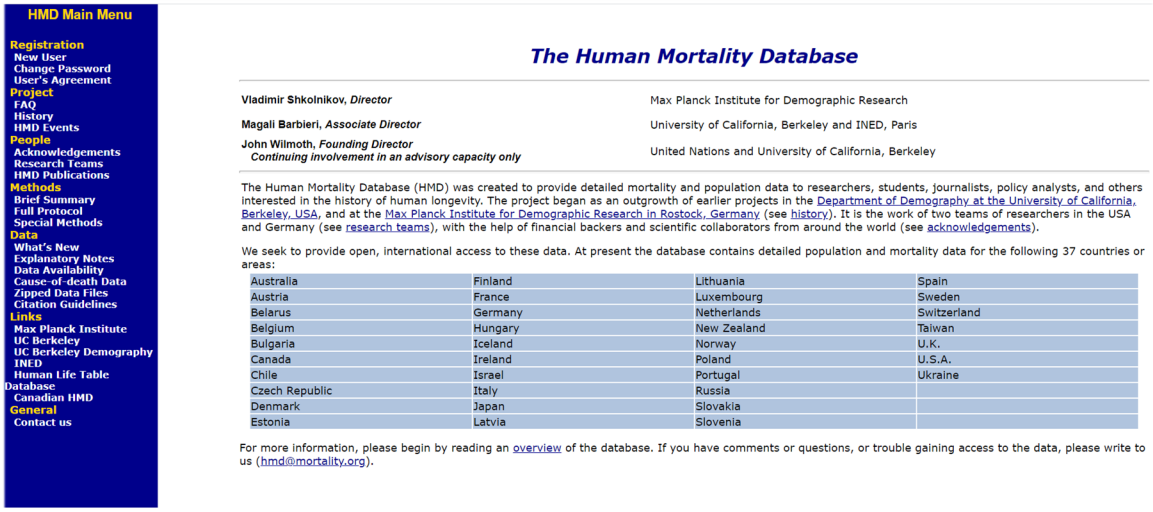
The HMD team at UC Berkeley has been working with the INED colleagues in charge of the HCD to develop a common list of cause-of-death categories that we have now applied to both the HMD and the HCD country series. The list includes 57 exhaustive cause-of-death categories (see Appendix C for the associated codes in each ICD Revision). The reason why a new list had to be produced (i.e. why we could not use the 92 cause-of-death categories previously developed) is that many of the HCD countries were part of the Soviet Union and used their own classification of diseases until they progressively all adopted the World Health Organization standard classification in the 2000s or 2010s. The 92 cause-of-death categories we had initially constructed are not compatible with the Soviet scheme so we had to create a new shortlist of cause-of-death categories that was consistent with the shortlists implemented in the HCD.

The two teams are working collaboratively to produce a prototype of what the final website would look like. Figure 1b-1e below presents some screen shots of the prototype, including the website home page and three country pages illustrating three situations: for countries included in both the HMD and the HCD initial projects (i.e. the United States), for countries included in the HMD but not in the HCD (i.e. Canada), and for countries in the HCD but not in the HMD and for which the raw data are protected (i.e. Russia). The difference between the HCD data series (available from the top two tables accessible on the country pages) and the HMD data series (available from the third table on the country page) is that the HCD series are reconstructed so that all deaths are classified into ICD-10 items while the HMD series have been not been adjusted for ICD change.

A link to the cause-of-death web pages will be added to the menu on the home page of the Human Mortality Database website as shown in Figure 1a.

Figure 1a

HOME PAGE OF THE HMD WITH LINK TO THE CAUSE-OF-DEATH PORTAL



HMD Main Menu

Registration
New User
Change Password
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Project
FAQ
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Acknowledgements
Research Teams
HMD Publications
Methods
Brief Summary
Full Protocol
Special Methods
Data
What's New
Explanatory Notes
Data Availability
Cause-of-death Data
Zipped Data Files
Citation Guidelines
Links
Max Planck Institute
UC Berkeley
UC Berkeley Demography
INED
Human Life Table Database
Canadian HMD
General
Contact us

The Human Mortality Database

Vladimir Shkolnikov, *Director*	Max Planck Institute for Demographic Research
Magali Barbieri, *Associate Director*	University of California, Berkeley and INED, Paris
John Wilmoth, *Founding Director* *Continuing involvement in an advisory capacity only*	United Nations and University of California, Berkeley

The Human Mortality Database (HMD) was created to provide detailed mortality and population data to researchers, students, journalists, policy analysts, and others interested in the history of human longevity. The project began as an outgrowth of earlier projects in the Department of Demography at the University of California, Berkeley, USA, and at the Max Planck Institute for Demographic Research in Rostock, Germany (see history). It is the work of two teams of researchers in the USA and Germany (see research teams), with the help of financial backers and scientific collaborators from around the world (see acknowledgements).

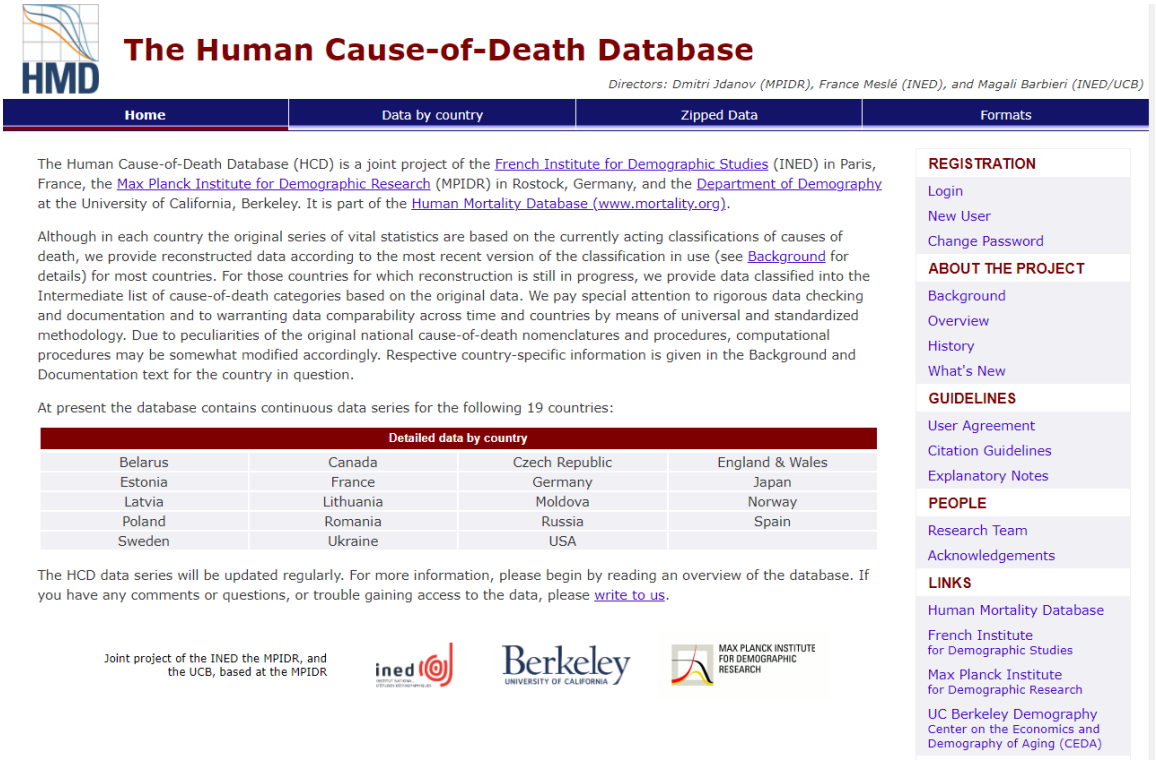
We seek to provide open, international access to these data. At present the database contains detailed population and mortality data for the following 37 countries or areas:

Australia	Finland	Lithuania	Spain
Austria	France	Luxembourg	Sweden
Belarus	Germany	Netherlands	Switzerland
Belgium	Hungary	New Zealand	Taiwan
Bulgaria	Iceland	Norway	U.K.
Canada	Ireland	Poland	U.S.A.
Chile	Israel	Portugal	Ukraine
Czech Republic	Italy	Russia	
Denmark	Japan	Slovakia	
Estonia	Latvia	Slovenia	

For more information, please begin by reading an overview of the database. If you have comments or questions, or trouble gaining access to the data, please write to us (hmd@mortality.org).

Figure 1b

HOME PAGE OF THE HMD/HCD CAUSE-OF-DEATH PORTAL



The Human Cause-of-Death Database

Directors: Dmitri Jdanov (MPIDR), France Meslé (INED), and Magali Barbieri (INED/UCB)

Home | Data by country | Zipped Data | Formats

The Human Cause-of-Death Database (HCD) is a joint project of the French Institute for Demographic Studies (INED) in Paris, France, the Max Planck Institute for Demographic Research (MPIDR) in Rostock, Germany, and the Department of Demography at the University of California, Berkeley. It is part of the Human Mortality Database (www.mortality.org).

Although in each country the original series of vital statistics are based on the currently acting classifications of causes of death, we provide reconstructed data according to the most recent version of the classification in use (see Background for details) for most countries. For those countries for which reconstruction is still in progress, we provide data classified into the Intermediate list of cause-of-death categories based on the original data. We pay special attention to rigorous data checking and documentation and to warranting data comparability across time and countries by means of universal and standardized methodology. Due to peculiarities of the original national cause-of-death nomenclatures and procedures, computational procedures may be somewhat modified accordingly. Respective country-specific information is given in the Background and Documentation text for the country in question.

At present the database contains continuous data series for the following 19 countries:

Detailed data by country			
Belarus	Canada	Czech Republic	England & Wales
Estonia	France	Germany	Japan
Latvia	Lithuania	Moldova	Norway
Poland	Romania	Russia	Spain
Sweden	Ukraine	USA	

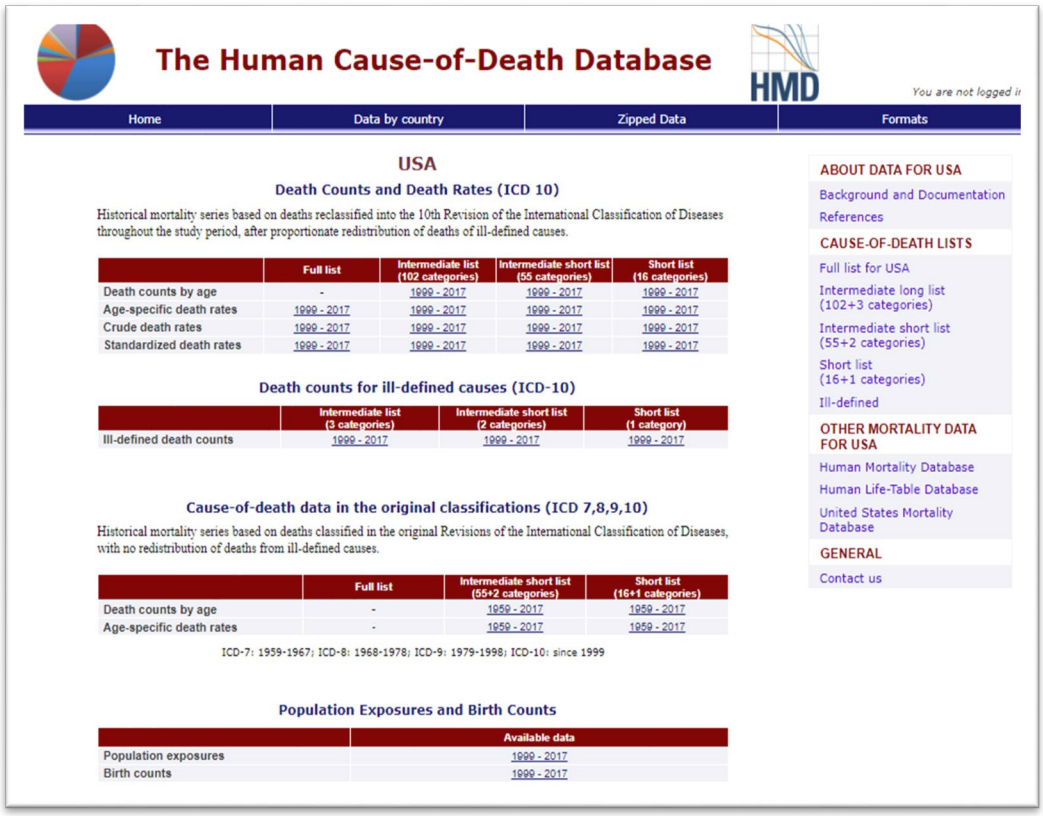
The HCD data series will be updated regularly. For more information, please begin by reading an overview of the database. If you have any comments or questions, or trouble gaining access to the data, please write to us.

Joint project of the INED the MPIDR, and the UCB, based at the MPIDR

REGISTRATION
Login
New User
Change Password
ABOUT THE PROJECT
Background
Overview
History
What's New
GUIDELINES
User Agreement
Citation Guidelines
Explanatory Notes
PEOPLE
Research Team
Acknowledgements
LINKS
Human Mortality Database
French Institute for Demographic Studies
Max Planck Institute for Demographic Research
UC Berkeley Demography Center on the Economics and Demography of Aging (CEDA)

Figure 1c

USA COUNTRY PAGE, AS EXAMPLE OF A COUNTRY WITH BOTH HMD AND HCD DATA



The Human Cause-of-Death Database

HMD

You are not logged in

Home | Data by country | Zipped Data | Formats

USA

Death Counts and Death Rates (ICD 10)

Historical mortality series based on deaths reclassified into the 10th Revision of the International Classification of Diseases throughout the study period, after proportionate redistribution of deaths of ill-defined causes.

	Full list	Intermediate list (102 categories)	Intermediate short list (55 categories)	Short list (16 categories)
Death counts by age	-	1999 - 2017	1999 - 2017	1999 - 2017
Age-specific death rates	1999 - 2017	1999 - 2017	1999 - 2017	1999 - 2017
Crude death rates	1999 - 2017	1999 - 2017	1999 - 2017	1999 - 2017
Standardized death rates	1999 - 2017	1999 - 2017	1999 - 2017	1999 - 2017

Death counts for ill-defined causes (ICD-10)

	Intermediate list (3 categories)	Intermediate short list (2 categories)	Short list (1 category)
Ill-defined death counts	1999 - 2017	1999 - 2017	1999 - 2017

Cause-of-death data in the original classifications (ICD 7,8,9,10)

Historical mortality series based on deaths classified in the original Revisions of the International Classification of Diseases, with no redistribution of deaths from ill-defined causes.

	Full list	Intermediate short list (55+2 categories)	Short list (16+1 categories)
Death counts by age	-	1959 - 2017	1959 - 2017
Age-specific death rates	-	1959 - 2017	1959 - 2017

ICD-7: 1959-1967; ICD-8: 1968-1978; ICD-9: 1979-1998; ICD-10: since 1999

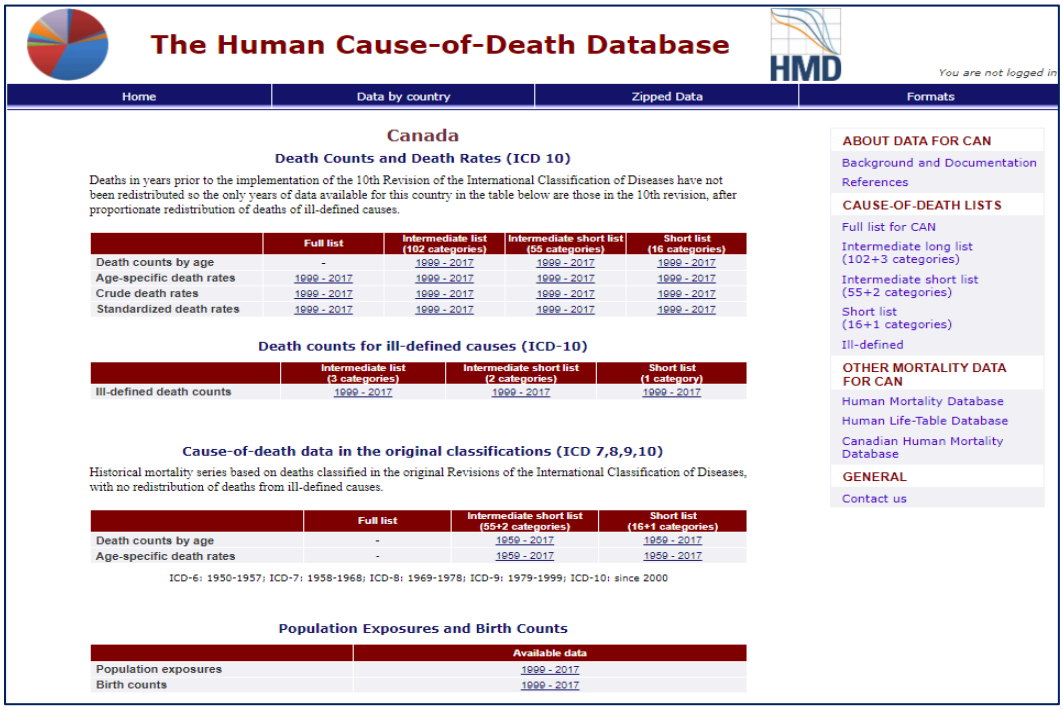
Population Exposures and Birth Counts

	Available data
Population exposures	1999 - 2017
Birth counts	1999 - 2017

ABOUT DATA FOR USA
Background and Documentation
References
CAUSE-OF-DEATH LISTS
Full list for USA
Intermediate long list (102+3 categories)
Intermediate short list (55+2 categories)
Short list (16+1 categories)
Ill-defined
OTHER MORTALITY DATA FOR USA
Human Mortality Database
Human Life-Table Database
United States Mortality Database
GENERAL
Contact us

Figure 1d

CANADA COUNTRY PAGE, AS EXAMPLE OF A COUNTRY WITH HMD BUT NOT HCD DATA



The Human Cause-of-Death Database

HMD

You are not logged in

Home | Data by country | Zipped Data | Formats

Canada

Death Counts and Death Rates (ICD 10)

Deaths in years prior to the implementation of the 10th Revision of the International Classification of Diseases have not been redistributed so the only years of data available for this country in the table below are those in the 10th revision, after proportionate redistribution of deaths of ill-defined causes.

	Full list	Intermediate list (102 categories)	Intermediate short list (55 categories)	Short list (16 categories)
Death counts by age	-	1999 - 2017	1999 - 2017	1999 - 2017
Age-specific death rates	1999 - 2017	1999 - 2017	1999 - 2017	1999 - 2017
Crude death rates	1999 - 2017	1999 - 2017	1999 - 2017	1999 - 2017
Standardized death rates	1999 - 2017	1999 - 2017	1999 - 2017	1999 - 2017

Death counts for ill-defined causes (ICD-10)

	Intermediate list (3 categories)	Intermediate short list (2 categories)	Short list (1 category)
Ill-defined death counts	1999 - 2017	1999 - 2017	1999 - 2017

Cause-of-death data in the original classifications (ICD 7,8,9,10)

Historical mortality series based on deaths classified in the original Revisions of the International Classification of Diseases, with no redistribution of deaths from ill-defined causes.

	Full list	Intermediate short list (55+2 categories)	Short list (16+1 categories)
Death counts by age	-	1959 - 2017	1959 - 2017
Age-specific death rates	-	1959 - 2017	1959 - 2017

ICD-6: 1950-1957; ICD-7: 1958-1968; ICD-8: 1969-1978; ICD-9: 1979-1999; ICD-10: since 2000

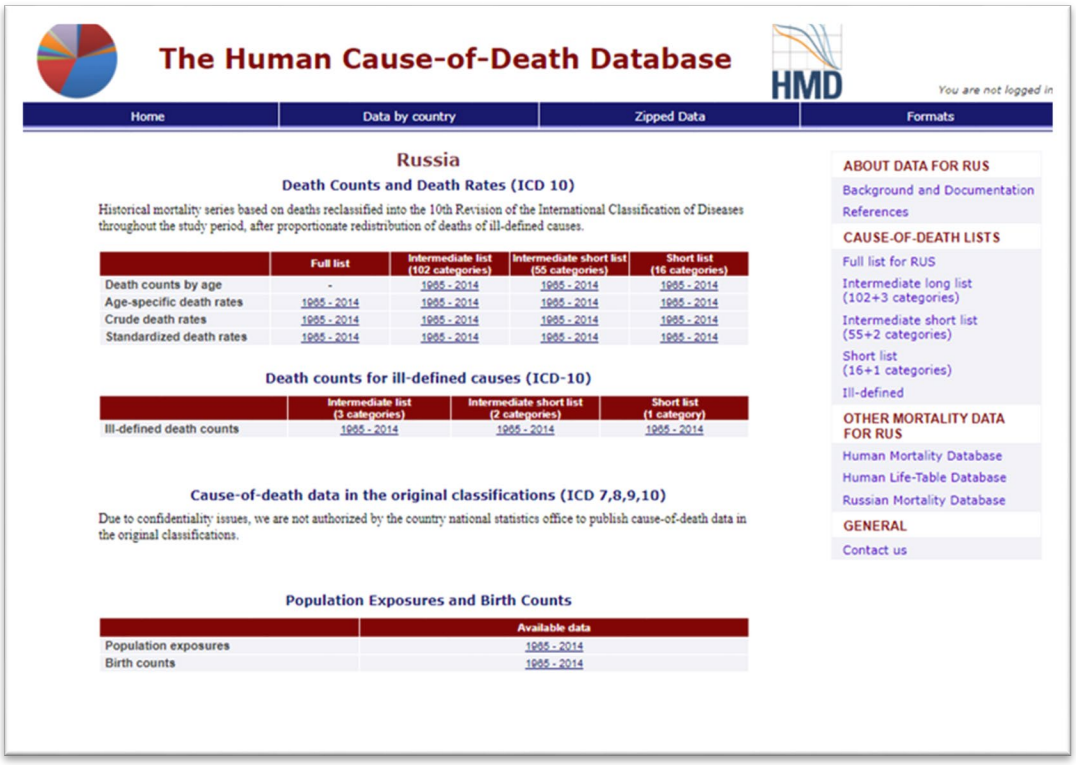
Population Exposures and Birth Counts

	Available data
Population exposures	1999 - 2017
Birth counts	1999 - 2017

ABOUT DATA FOR CAN
Background and Documentation
References
CAUSE-OF-DEATH LISTS
Full list for CAN
Intermediate long list (102+3 categories)
Intermediate short list (55+2 categories)
Short list (16+1 categories)
Ill-defined
OTHER MORTALITY DATA FOR CAN
Human Mortality Database
Human Life-Table Database
Canadian Human Mortality Database
GENERAL
Contact us

Figure 1e

RUSSIA COUNTRY PAGE, AS EXAMPLE OF A COUNTRY WITH HCD BUT NOT HMD DATA



The Human Cause-of-Death Database

HMD

You are not logged in

Home | Data by country | Zipped Data | Formats

Russia

Death Counts and Death Rates (ICD 10)

Historical mortality series based on deaths reclassified into the 10th Revision of the International Classification of Diseases throughout the study period, after proportionate redistribution of deaths of ill-defined causes.

	Full list	Intermediate list (102 categories)	Intermediate short list (55 categories)	Short list (16 categories)
Death counts by age	-	1965 - 2014	1965 - 2014	1965 - 2014
Age-specific death rates	1965 - 2014	1965 - 2014	1965 - 2014	1965 - 2014
Crude death rates	1965 - 2014	1965 - 2014	1965 - 2014	1965 - 2014
Standardized death rates	1965 - 2014	1965 - 2014	1965 - 2014	1965 - 2014

Death counts for ill-defined causes (ICD-10)

	Intermediate list (3 categories)	Intermediate short list (2 categories)	Short list (1 category)
Ill-defined death counts	1965 - 2014	1965 - 2014	1965 - 2014

Cause-of-death data in the original classifications (ICD 7,8,9,10)

Due to confidentiality issues, we are not authorized by the country national statistics office to publish cause-of-death data in the original classifications.

Population Exposures and Birth Counts

	Available data
Population exposures	1965 - 2014
Birth counts	1965 - 2014

ABOUT DATA FOR RUS
Background and Documentation
References
CAUSE-OF-DEATH LISTS
Full list for RUS
Intermediate long list (102+3 categories)
Intermediate short list (55+2 categories)
Short list (16+1 categories)
Ill-defined
OTHER MORTALITY DATA FOR RUS
Human Mortality Database
Human Life-Table Database
Russian Mortality Database
GENERAL
Contact us

Section 3: Acknowledgments

The author thanks the Project Oversight Group and others for their wisdom, insights, advice, guidance on the research and review of this report.

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Mark Alberts, FSA, MAAA

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Ronora Stryker, ASA, MAAA

Jan Schuh

Appendix A: Additional Background and Documentation file for the USMDB

Mortality Data for the United States Mortality Database (USMDB)[1]

By Magali Barbieri and Celeste Winant

GENERAL

National censuses and population estimates for the United States are produced by the U.S. Department of Commerce at the US Census Bureau (www.census.gov). Vital statistics data are collected and disseminated by the National Center for Health Statistics (NCHS), which is part of the Centers for Disease Control (CDC) (www.cdc.gov/nchs/). Though information on burials was collected routinely in some areas of the United States in the 19th century, it is only in 1933 that the quality of the information collected was deemed good enough (with over 90% of vital events registered) in all of the States and the District of Columbia for the system to cover the whole territory of the United States (National Research Council, 2009). The present format of US death certificates was established in the 1940s and follows the recommended international standards. It has been revised periodically to reflect medical progress and changing public health concerns (Rosenberg, 1999). The last notable revision was implemented in 2003.

Sources of Data

The USMDB population data originate from population censuses conducted every 10 years. The USMDB makes use of the censuses conducted from 1960 to 2010. Census counts serve as the basis for producing annual July 1st population estimates for intercensal and postcensal periods, published by the Census Bureau. Postcensal population estimates are revised every year and intercensal population estimates are substituted to postcensal estimates as new census data become available. Intercensal population estimates are available at the state level for all years since 1970. They have been published on the Census Bureau website (U.S. Census Bureau, Population Estimates Program, https://www.census.gov/programs-surveys/popest.html). Additional (sometimes more detailed) census data are available through the Inter-University Consortium for Political and Social Science Research (ICPSR, www.icpsr.umich.edu) with restricted access for participating organizations. For years between 1959 and 1969, we constructed our own annual intercensal population estimates using census data and birth and death counts by age during the intercensal period. To construct these estimates, we followed strictly the methods of the Human Mortality Database Version 5 (Wilmoth et al., 2007).

Starting with 1959, data on deaths are available electronically from the National Center for Health Statistics (NCHS) in the form of Mortality Multiple Cause of Death Files (see National Center for Health Statistics, 1959–). These data include individual death records coded from death certificates. Public files are available on the NCHS website, at https://www.cdc.gov/nchs/data_access/vitalstatsonline.htm. However, geographic information (including state of residence and state of occurrence) has been suppressed from the public files for years since 2004 to protect confidentiality. Access to the restricted data is only possible through special arrangement. The USMDB has obtained access to these data through the Berkeley Research Data Center after completing a strict vetting procedure. All of the USMDB mortality data processing has taken place within the RDC (including for years prior to 2004 because more detailed information on the date of birth is available in the restricted files, which allow for a more accurate allocation of deaths to the upper or lower Lexis triangle for each combination of age and year of death).

[1] This document partly relies on the information included in the Human Mortality Database Background and Documentation File for the United States (http://www.mortality.org/hmd/USA/InputDB/USAcom.pdf), initially prepared by Ludmila Andreeva.

TERRITORIAL COVERAGE

Since 1959, when both Alaska and Hawaii became US states, national statistics has been publishing information for all 50 states and the District of Columbia. There has been no change to state boundaries since then.

DEATH COUNT DATA

Coverage and Completeness

In the early years of the 20th century, vital statistics for United States were based on data from those states admitted to the Death Registration Area, the number of which increased over time. To be included in the Death Registration Area, the vital statistics system for a state had to demonstrate coverage of at least 90% of the state population. This process was completed in 1933 for the US as a whole with the admission of Texas into the Death Registration Area. Given the legal requirements for death registration, mortality data for the United States are considered to be complete and of acceptable quality since 1933.

Mortality data for the United States are confined to events registered within the territory of the United States. Vital events to US residents occurring outside of the United States are not included but those to non-US resident occurring within the United States are. Since 1970, it is possible to identify deaths of non-residents and, consequently, to exclude them from tabulations. Therefore, for the years 1959–1969, deaths in the USMDB include both residents and nonresidents (i.e., the *de facto* population), and for the period starting in 1970, only residents are included.

Specific Details

Deriving Death Counts by Lexis triangles from Individual Death Records

Death counts for years since 1989 can be precisely tabulated by Lexis triangle (i.e., by age and birth cohort) because the original data from NCHS include the exact date of birth as well as the exact date of death.

For prior years, the original data identify deaths by single year of age, but not by birth cohort (because the date of birth is not included on the death records). It is possible to estimate deaths by Lexis triangle using the exact date of death, although this approximation (and the resulting mortality estimate) is unlikely to be as accurate as the observed counts for years in which the date of birth is available. Procedures used to derive the death counts by Lexis triangle for years prior to 1989 are described in Appendix 2.

POPULATION COUNT DATA

Coverage and Completeness

Data on population refer to the resident population of the United States. No adjustments have been made to the published population estimates.

Specific Details

Because the Census Bureau annual state-level population estimates by sex and age are only available for years since 1970, we have constructed our own intercensal estimates using a cohort component method described in the 2007 Human Mortality Database Methods Protocol (http://v5.mortality.org/Public/Docs/MethodsProtocol.pdf) for the years 1959-1969. Further details are provided in Appendix 3.

BIRTH COUNT DATA

Coverage and Completeness

As for the mortality statistics, due to the legal requirements of birth registration, data on births are considered to be virtually complete and of a good quality since 1933.

Birth data for the United States are confined to events registered in the United States. Births to legal

residents of the U.S. that occurred in other parts of the world are excluded from published vital statistics. Prior to 1970, births to non-residents (that occurred in the US) were included in the statistics, whereas for 1970 and thereafter, births to non-residents are excluded.

Specific Details

The distribution of births by sex at the state level was missing from the NCHS files for the year 1967. In the USMDB, we thus used the state-specific average of the sex ratio in the two surrounding years, i.e. 1966 and 1968, to split the births by sex within each state.

ACKNOWLEDGEMENTS

We are grateful to Elizabeth Arias and Robert Anderson at NCHS for their collaboration to this project. We also wish to acknowledge John Wilmoth, current Director of the Population Division at the United Nations, and former PI for this project, who developed the initial idea for the USMD. We also recognize the contributions of Kirill Andreev and of Ludmila Andreeva to the early stages of the USMDB. And of course, this project would not have been possible without prior experience with the Human Mortality Database (HMD), including all the work carried out by both the DataLab team at the Max Planck Institute for Demographic Research and in the Department of Demography at the University of California, Berkeley, to develop the HMD Methods Protocol, of which we have made extensive use in the USMDB.

Financial and logistical support was received from the USMDB two sponsoring institutions, the Department of Demography at the University of California, Berkeley (UCB) and the NIA-funded Center on the Economics and Demography of Aging at UCB (CEDA). The project has been initially funded by a grant (R01 AG040245) awarded to John Wilmoth by the National Institute on Aging (NIA). Additional technical and research support has been provided by the French Institute for Demographic Studies (INED). Additional financial support has been provided to the project on an annual basis since 2016 by the Society of Actuaries-REX Pool Fund as well as through occasional gifts from the following sponsors: the AXA Research Fund, SCOR, Hannover-Re and Reinsurance Group of America (RGA). None of the funders had any role in the data collection, analysis, preparation, review or approval of the final data series.

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APPENDIX 1: DESCRIPTION OF USMDB INPUT DATA[2]

DEATHS

Period	Type of Data	Age groups	Comments	RefCode(s)
1959-2018	Annual death counts for U.S. residents by geographic area, sex, single year of age and date of death (in months)	0, 1,…maximum age attained	Deaths to U.S. residents occurring in outlying territories (e.g., Puerto Rico, U.S. Virgin Islands) or a foreign country (including Canada) are excluded, as are deaths to non-residents for years since 1970. Deaths have been tabulated from individual records. †	1

† For details, see Appendix 2.

[2] The reference codes indicated in the last column of each of the tables below correspond to the sources listed in Appendix 4.

POPULATION

Period	Type of Data	Age groups	Comments	RefCode(s)
1960	Official Census estimates	0, 1, … , 84, 85-89,90-94,95-99,100+	Custom computations based on population available from different sources†	10, 11, 12
1970	Official Census estimates	0, 1, … , 84, 85-89,90-94,95-99,100+		20
1971–1979	Intercensal population estimates for the resident population	0, 1-4, 5-9, …, 80-84, 85+		40
1980	Official Census estimates	0, 1, … , 89, 90-94, 95-99,100+		50
1981–1989	Intercensal population estimates for the resident population‡	0, 1 … 85+		60
1990	Official Census estimates‡	0, 1, … , 89, 90-94, 95-99,100+		70
1991–1999	Intercensal population estimates for the resident population‡	0, 1 … 85+		80
2000	Official Census estimates‡	0, 1, … , 99, 100-104, 105-109, 110+		90
2001–2009	Intercensal population estimates for the resident population‡	0, 1 … 85+		100
2010	Official Census estimates‡	0, 1, … , 89, 90-94, 95-99,100+		110
2011-2019	Intercensal population estimates for the resident population‡	0, 1 … 85+		120

† For details, see Appendix 3.

‡ Data are available on the Census Bureau web site (http://www.census.gov). For the specific URLs and download dates, see the reference file for the raw data.

BIRTHS

Period	Type of Data	Comments	RefCode(s)†
1959–1964	Annual births for the *de facto* population by sex	Counts for 1959 have been adjusted to include births that occurred in Hawaii (see section "Births Count Data"). No sex detail for year 1967 (see the Specific Details in the "Birth count data" section above for imputation method).	200
1965–1979	Annual births for the *de facto* population by sex		210
1980–2003	Annual births for the resident population by sex	Births to U.S. residents that occurred abroad are excluded as are births to non-residents.	220
2003–2006	Annual births for the resident population by sex	Births to U.S. residents that occurred abroad are excluded as are births to non-residents.	230
2007–2018	Annual births for the resident population by sex	Births to U.S. residents that occurred abroad are excluded as are births to non-residents.	240

Appendix 2: Tabulation of Deaths from the Mortality Detailed Files by Lexis triangle

The information required to precisely and accurately allocate each death to either the upper or the lower Lexis triangle within each combination of single year of age and calendar year is the birth cohort. This combination of information is available for all years since 1989 in the restricted mortality files to which we have access but information on the date of birth is not available for years 1959-1988. In some instances, there are inconsistencies between the date of birth, the date of death, and the age at death (Appendix Table 1). In addition, some of the information is missing for a small number of records, though the number and proportion of problematic records (with either inconsistencies or missing information) has always been marginal (representing less than 0.5% of all records in 1989) and has been declining consistently over time (representing less than 0.05% of all records for years since 2013). For those records with inconsistencies between the age at death, the date of birth and the date of death, we decided to ignore age and only rely on the dates of birth and death, *except* for those records when the age at death was below one. This is because in such cases, the information provided is extremely detailed (down to the number of minutes lived) which makes it less likely than a coding error would have occurred.

WHEN THE BIRTH COHORT IS UNKNOWN

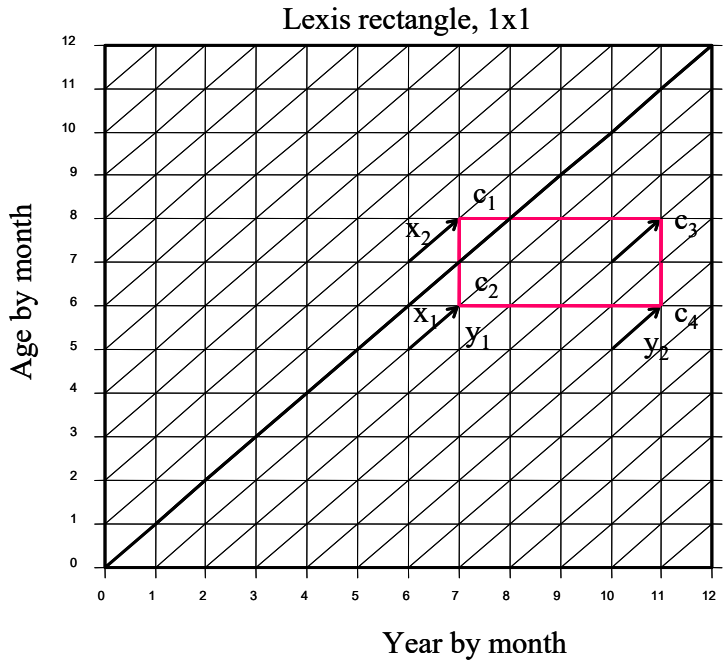
For years of data (1959-1988) when we lack information about the date of birth (and thus about the cohort to which the deceased belonged), we indirectly estimated the Lexis triangle to which deaths should be allocated. As noted earlier, the age variable identifies the age of the decedent at his/her last birthday in single years. The month of death is provided as well as, for several years (1962-1967 and since 1972), the exact date of death. This information was used in the USMDB to allocate the death counts to each Lexis triangle as further explained below.

Table 1. Number of death records with inconsistent or missing information, 1989-2016

Year	All dates/age complete and consistent	Inconsistencies between the age and dates of birth/death	Missing age only	Missing date of birth only	Missing age and date of birth	All incomplete or inconsistent records	In proportion to total records
1989	2150466	6472	45	3183	517	10217	0.48
1990	2148463	6023	45	2949	517	9534	0.44
1991	2169518	5920	29	2476	547	8972	0.41
1992	2175613	5120	7	1963	467	7557	0.35
1993	2268553	4891	25	1883	482	7281	0.32
1994	2278994	4181	29	1578	385	6173	0.27
1995	2312132	3520	36	1646	427	5629	0.24
1996	2314690	3584	25	1603	498	5710	0.25
1997	2314245	3355	17	1697	384	5453	0.24
1998	2337256	3275	2	1400	409	5086	0.22
1999	2391399	2980	8	1077	348	4413	0.18
2000	2403351	2108	2	868	354	3332	0.14
2001	2416425	2286	4	955	418	3663	0.15
2002	2443387	2616	2	939	355	3912	0.16
2003	2448288	2380	2	850	340	3572	0.15
2004	2397615	2027	3	614	343	2987	0.12
2005	2448017	2099	8	487	247	2841	0.12
2006	2426264	1779	1	524	219	2523	0.10
2007	2423712	1931	8	326	193	2458	0.10
2008	2471984	1675	0	217	147	2039	0.08
2009	2437163	1167	1	179	254	1601	0.07
2010	2648435	891	1	301	125	1318	0.05
2011	2515458	980	2	144	132	1258	0.05
2012	2543279	1208	0	170	147	1525	0.06
2013	2596993	798	0	137	132	1067	0.04
2014	2626418	661	0	164	163	988	0.04
2015	2712630	414	0	73	138	625	0.02
2016	2744248	345	0	52	137	534	0.02

Figure 1 illustrates a 1x1 Lexis square (by age and year of death), divided into two Lexis triangles (by age, birth cohort, and year), each of which is further divided into 144 smaller Lexis triangles (by age in months, birth month, and month of death). Suppose that we know a death occurred between July and November (months 7-11) and between age (x + 6 months) and (x + 8 months) (shown by the red rectangle in Figure 1). The red rectangle includes 16 of the smaller Lexis triangles (by month), of which 15 belong to the lower Lexis triangle (by year) and one to the upper triangle. If we assume that the probability of dying is the same in each of the smaller Lexis triangles, then the probability that such deaths occurred to someone from the older cohort is 1/16. Therefore, among all individual death records that fall within this red rectangle, we assign $1/16^{th}$ of such deaths to the upper triangle and $15/16^{th}$ to lower triangle. This simple example captures the gist of the method.

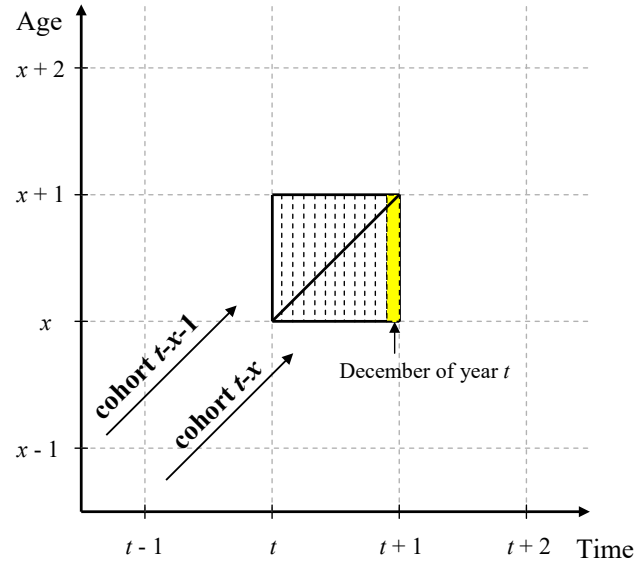
Figure 2. 1x1 Lexis Square by age (in months) and month/year of death



WHEN ONLY THE MONTH OF DEATH IS AVAILABLE

For some years (1959–1961 and 1968–1971), only the month and year of death are included in the MDF (not the day of death or the date of birth). Therefore, within a given 1x1 Lexis square (age by calendar year), we can further split the deaths into 12 rectangles representing the month of death (age by month/year of death), as shown on Figure 2. The proportion of deaths falling within the upper and lower triangles of each rectangle can be computed assuming a uniform distribution of deaths. For example, for deaths occurring in December of year *t* (shown in yellow on Figure 2), $23/24^{th}$ would fall into the lower triangle and $1/24^{th}$ in the upper triangle.

Figure 3. Illustration of Lexis Triangles and Rectangles



EXACT DEATH OF DEATH AVAILABLE

For some other years (1962-1967 and 1972-1988), the files include complete information for the date of death but the date of birth is not available. Therefore, a procedure similar to that described in the previous section can be applied. That is, deaths within each 1x1 Lexis square can be split into 365 rectangles representing each possible day of death. Again assuming that deaths are distributed uniformly within each of these rectangles, the proportion of deaths falling within the upper and lower triangles can be computed.

WHEN THE EXACT DATES OF BIRTH AND DEATH ARE AVAILABLE

For years since 1989, the exact dates of birth and death (day, month and year) are available in the data files. Thus, it is possible to identify precisely whether the death occurred in the upper triangle or whether it occurred in the lower triangle, without making any assumption.

APPENDIX 3: Population estimates for 1959-1969

One of the guiding principles of this database is to provide mortality estimates with as much age detail as possible. U.S. data on deaths by single year of age are available starting with 1959. To compute death rates by single year of age, they must be combined with population counts by single year of age, i.e., annual population estimates by state. Such data are not available from the U.S. Census Bureau for years before 1960. We thus had to calculate our own inter-censal estimates for 1959 using the classic demographic approach of a cohort component method. The 1959 estimates by back projecting the 1960 population estimates using the death counts by age within each cohort as well as the birth count for 1959.

In addition, for years 1960-1969, we identified two sets of annual population estimates available from the Census Bureau. A first set of estimates was available by single year of age but yielded figures which were inconsistent with both the 1970 Census counts and the Census count and estimates for 1980 and beyond. A second set was available by five-year age group and highly consistent with prior and succeeding years. We thus decided to use this second set of estimates but redistributed the five-age group deaths to each single year of age using the proportional distribution from the first set of estimates.

APPENDIX 4: Detailed sources of the data used for the USMDB and corresponding RefCodes (see Appendix 1)

RefCode 1
National Center for Health Statistics, United States. Mortality Multiple Cause Restricted Use File, Accessed in the Berkeley RDC [Date]
Tabulation of deaths by Lexis triangle from individual records by state, single year of age and birth cohort (where available).

RefCode 10
Hybrid series of population data for USA states years 1960 by 1 year age, computed from combined series RefCode 11 and RefCode 12. The primary sources used to construct the hybrid series are:
(Census) Population Data for USA states years 1960, by 5 year age (RefCode 11)
(Census) Population Data for USA states, years 1960 (RefCode 12)

RefCode 11
Census of Population: 1960 (Volume I)
U.S. Department of Commerce Bureau of the Census (1961)
Characteristics of the Population
General Population Characteristics
Table 94. Single year of Age by color, nativity, and sex, for the state: 1960
(retrieved from https://www.census.gov/prod/www/decennial.html on 13-Apr-2015)

RefCode 12
Census of Population: 1960
Department of Commerce
Characteristics of the Population
General Population Characteristics, USA Summery
Table 59. Age by color, sex, for the state: 1960
(retrieved from
https://www.census.gov/prod/www/decennial.html
on 5-May-2015)

RefCode 20
Census of Population on
U.S. Department of Commerce Bureau of the Census (1972)
Characteristics of the Population
General Population Characteristics
Table 19. Single year of Age by Race and Sex: 1970
(retrieved from https://www.census.gov/prod/www/decennial.html on 1-Dec-2014)

RefCode 40
United States Department of Commerce. Bureau of the Census.
Intercensal Estimates of the Population of Counties by Age, Sex, and Race [United States]: 1970-1980.
Ann Arbor, MI: Inter-university Consortium for Political and Social Research [distributor], 1992-02-16.
https://doi.org/10.3886/ICPSR08384.v1
(Retrieved from https://www.icpsr.umich.edu/icpsrweb/ICPSR/studies/8384 on 23-Oct-2015)

RefCode 50
Census of Population on
U.S. Department of Commerce Bureau of the Census

Characteristics of the Population
General Population Characteristics
Table 18. Single year of Age by Race, Spanish Origin, Sex: 1980
(retrieved from
https://www.census.gov/prod/www/decennial.html
on 20-May-2015)

RefCode 60
U.S. Department of Commerce Bureau of the Census
State Intercensal Datasets: 1980-1990
State Population Estimates and Demographic Components of Change: 1981 to 1989, by Age, Sex, Race, and Hispanic Origin
(retrieved from
https://www.census.gov/data/datasets/time-series/demo/popest/1980s-state.html)

RefCode 70
U.S. Department of Commerce Bureau of the Census
Report Number: CP-1 (Volumes 1990 CP-1-2 to 1990 CP-1-52)
1990 Census of Population: Characteristics of the Population
General Population Characteristics
Table 18. Single year of Age by Race, Spanish Origin, Sex: 1990
(retrieved from
https://www.census.gov/prod/www/decennial.html
on 20-May-2015)

RefCode 80
Center for Disease Control and Prevention
National Center for Health Statistics
National Vital Statistics System
Bridged-race intercensal population estimates for July 1, 1990-July 1, 1999
(retrieved from https://www.cdc.gov/nchs/nvss/bridged_race/data_documentation.htm)

RefCode 90
U.S. Department of Commerce Bureau of the Census
Program: Decennial Census – Census United States
Data Set: Census 2000 Summary File 1 (SF 1) 100-Percent Data
Table: PCT012 Sex by age [Total population]
(retrieved from https://factfinder.census.gov)

RefCode 100
Center for Disease Control and Prevention
National Center for Health Statistics
National Vital Statistics System
July 1, 2000-July 1, 2009 Revised bridged-race intercensal population estimates
(retrieved from https://www.cdc.gov/nchs/nvss/bridged_race/data_documentation.htm)

RefCode 110
U.S. Department of Commerce Bureau of the Census
Program: Decennial Census – Census United States
Data Set: Census 2010 Summary File 1
Table: PCT012 Sex by age [Total population]
(retrieved from https://factfinder.census.gov)

RefCode 120
Center for Disease Control and Prevention
National Center for Health Statistics
National Vital Statistics System
Vintage 2019 bridged-race postcensal population estimates
(retrieved from
https://www.cdc.gov/nchs/nvss/bridged_race/data_documentation.htm#vintage2019)

RefCode 200
US Department of Health, Education, and Welfare, Public Health Service, National Center for Health Statistics, United States. Vital Statistics of the United States, Volume 1-Natality. Live Births by Specified Race and Sex: United States and Each State.
(retrieved from https://www.cdc.gov/nchs/products/vsus/vsus_1939_1964.htm on 14 August 2013)

RefCode 210
US Department of Health, Education, and Welfare, Public Health Service, National Center for Health Statistics, United States. Vital Statistics of the United States, Volume 1-Natality. Live Births by Specified Race and Sex: United States and Each State.
(retrieved from https://www.cdc.gov/nchs/products/vsus/vsus_1965_1979.htm on 14 August 2013)

RefCode 220
US Department of Health, Education, and Welfare, Public Health Service, National Center for Health Statistics, United States. Birth Data Files for 1980-2003.
(retrieved from https://www.cdc.gov/nchs/data_access/vitalstatsonline.htm on 22 April 2015)

RefCode 230
United States Department of Health and Human Services (US DHHS),
Centers for Disease Control and Prevention (CDC),
National Center for Health Statistics (NCHS),
Division of Vital Statistics (DVS),
Natality public-use data on CDC WONDER Online Database,
for years 2003-2006 available March 2009
(retrieved from https://wonder.cdc.gov/natality-v2006.html on 30-July-2015)

RefCode 240
United States Department of Health and Human Services (US DHHS),
Centers for Disease Control and Prevention (CDC),
National Center for Health Statistics (NCHS),
Division of Vital Statistics (DVS),
Natality public-use data on CDC WONDER Online Database,
for years 2007-2018 available September 2020
(retrieved from https://wonder.cdc.gov/natality-current.html on 15 September 2020)

Appendix B. List of the 57 causes of death categories used for the HMD/HCD project with their corresponding ICD codes

No.	Title	Category codes according to			
		ICD-6/7	ICD-8	ICD-9	ICD-10
1	Intestinal infectious diseases	040-049	001-009	001-009	A00-A09
2	Tuberculosis	001-019	010-019	010-018	A15-A19, B90
3	Septicaemia	053	038	038	A40-A41
4	Other and unspecified infectious and parasitic diseases	020-039, 050-052, 054-091, 093-138, 571, 764	020-037, 039-068, 071-136	020-037, 039-041, 045-066, 071-139	A20-A39 A42-A99, B00-B09, B25-B89, B91-B99
5	HIV disease	--	--	042-044	B20-B24
6	Viral hepatitis	092	070	070	B15-B19
7	Malignant neoplasms of lip, oral cavity and pharynx	140-148	140-149	140-149	C00-C14
8	Malignant neoplasm of esophagus	150	150	150	C15
9	Malignant neoplasm of stomach	151	151	151	C16
10	Malignant neoplasm of colon, rectum and anus	153-154	153-154	153-154	C18-C21
11	Malignant neoplasm of pancreas	157	157	157	C25
12	Other malignant neoplasm of digestive system	152, 155, 156, 159	152, 155, 156, 159	152, 155, 156, 159	C17, C22-C24, C26
13	Malignant neoplasm of larynx, trachea, bronchus and lung	161-163	161-162	161-162	C32-C34
14	Malignant neoplasm of skin	190-191	172-173	172-173	C43-C44
15	Malignant neoplasm of breast	170	174	174-175	C50
16	Malignant neoplasm of uterus	171-174	180, 182	179-180, 182	C53-C55
17	Malignant neoplasm of ovary	175	183	183	C56

18	Malignant neoplasm of prostate	177	185	185	C61
19	Malignant neoplasm of other genital organs	176, 178-179	181, 184, 186-187	181, 184, 186-187	C51-C52, C57-C60, C62, C63
20	Malignant neoplasm of bladder	181	188	188	C67
21	Malignant neoplasms of kidney and other urinary organ	180	189	189	C64-C66, C68
22	Leukemia	204	204-207	204-208	C91-C95
23	Other cancer, including in situ neoplasms, benign neoplasms and neoplasms of uncertain or unknown behaviour	158, 160, 164-165, 192-203, 205-239	158, 160, 163-171, 190-203, 208-239	158, 160, 163-171, 176, 190-203, 209-239	C30-C31,C37-C41, C45-C49, C69-C90, C96-C97, D00-D48
24	Blood diseases	290-299	280-289	280-289	D50-D89
25	Diabetes mellitus	260	250	250	E10-E14
26	Other endocrinologic and metabolic diseases	240, 245-254, 270-289	240-246, 251-279	240-249, 251-279	E00-E07, E15-E90
27	Alcohol abuse	307, 322	291, 303	291, 303	F10
28	Drug abuse	323	304-305	304-305	F11-F19
29	Other mental disorders	300-306, 308-321, 324-326	290, 292-302, 306-315	290, 292-302, 306-319	F00-F09, F20-F99
30	Other diseases of nervous system	330-398	320-389	320-389	G00-G44, G46-G99, H00-H95
31	Rheumatic heart diseases	400-416	390-398	390-398	I00-I09
32	Hypertensive disease	440-447	400-404	401-405	I10-I15
33	Other Ischaemic heart diseases	420-422	410-414	410-414	I20-I25
34	Other heart diseases	430-434, 465	420-429	415-429	I26-I52
35	Cerebrovascular diseases	330-334	430-438	430-438	I60-I69, G45

36	Other circulatory diseases	450-456, 460-464, 466-468	440-458	440-459	I70-I99
37	Influenza	480-483	470-474	487-488	J09-J11
38	Pneumonia	490-493, 763	480-486	480-486	J12-J18
39	Other acute respiratory infections	470-475, 500	460-466	460-466	J00-J06, J20-J22, U04
40	Other chronic obstructive pulmonary disease	241, 501-502, 526-527	490-493, 518	490-494, 496	J40-J47
41	Other diseases of the respiratory system	510-525	500-517, 519	470-478,495, 500-519	J30-J39, J60-J99
42	Gastric and duodenal ulcer	540-542	531-534	531-534	K25-K28
43	Liver diseases	580-583	570-573	570-573	K70-K77
44	Other digestive diseases	530-539, 543-570, 572-578, 584-587	520-530, 535-569, 574-577	520-530, 535-569, 574-579	K00-K23, K29-K67, K80-K93
45	Diseases of skin and subcutaneous tissue	243-244, 690-716	680-709	680-709	L00-L99
46	Diseases of the musculoskeletal systeme and connective tissue	720-749	710-738	710-739	M00-M99
47	Diseases of genitourinary system	590-637, 792	580-629, 792	580-629	N00-N99
48	Complications of pregnancy, childbirth and puerperium	640-689	630-678	630-679	O00-O99
49	Certain conditions originating in the perinatal period	760-762, 765-776	760-779	760-779	P00-P96, R95
50	Congenital malformations, deformations, and chromosomal abnormalities	750-759	740-759	740-759	Q00-Q99
51	Transport accidents	E800-E866	E800-E845	E800-E848	V01-V99
52	Other accidents	E870-E965	E850-E949	E850-E949	W00-W99, X00-X59, Y40-Y98
53	Suicide and self-inflicted injury	E970-E979	E950-E959	E950-E959	X60-X84

54	Assault	E980-E999	E960-E978, E990-E999	E960-E978, E990-E999	X85-Y09, Y35, Y36
55	Event of undetermined intent	--	E980-E989	E980-E989	Y10-Y34
56	Senility	794	794	797	R54
57	Other ill defined and unspecified causes of death	242, 780-791, 793, 795	780-791, 793, 795-796	780-796, 798-799	R00-R53, R55-R94, R96-R99

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Relevance: The SOA provides timely research on public policy issues. Our research advances actuarial knowledge while providing critical insights on key policy issues, and thereby provides value to stakeholders and decision makers.

Quantification: The SOA leverages the diverse skill sets of actuaries to provide research and findings that are driven by the best available data and methods. Actuaries use detailed modeling to analyze financial risk and provide distinct insight and quantification. Further, actuarial standards require transparency and the disclosure of the assumptions and analytic approach underlying the work.

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