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Population Division
Expert Group Meeting Report
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United Nations expert group meeting on methods for World Population Prospects 2021 and beyond

(Virtual meeting)

New York, 6-8 April 2020

Report of the meeting

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I. BACKGROUND AND SCOPE OF THE MEETING

For the 2021 revision of *World Population Prospects* (WPP),[1] the Population Division of the United Nations Department of Economic and Social Affairs (UN DESA) is planning to implement major changes in order to better respond to the needs of Member States, the United Nations System and other users, and to ensure greater compliance with existing international standards for the production of population estimates and projections. Starting with the 2021 revision, the WPP will provide estimates and projections by single year of age and sex and by one-year time interval, the so-called "1x1" method, instead of the "5x5" method employed so far.[2] The "1 by 1" method will apply to all demographic balancing equation relationships, which use the cohort-component analytical framework to account for changes in fertility, mortality and international migration over time, and by age and sex.

The upgrade responds to the growing demand for annual population estimates and demographic indicators in order to assess progress in implementing the Sustainable Development Goals (SDGs).[3] In addition, the planned upgrade will include additional provisions to provide greater transparency about the empirical data, procedures, methods used, the assumptions made, and further the understanding about the use of national estimates in preparing the WPP. Moreover, it will ensure that the production of international estimates follows the best available analytical practices to reconcile potential differences between population data and information for the various demographic components of population change.

It is expected that the new framework will help to reduce differences between national estimates of key development indicators and those produced by the United Nations and other international agencies, especially for countries with advanced data systems. Furthermore, the proposed future upgrades will bring the WPP in line with the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER),[4] which seek to ensure greater transparency as well as reproduction of results in the context of global health statistics.

The expert group meeting consisted of three half-day sessions which were held from 6 to 8 April 2020. Due to the COVID-19 pandemic and the ensuing travel restrictions, the meeting was held online.

In total, 23 experts presented, discussed, and shared their experiences in the use of methods to produce robust annual times series of various demographic indicators,[5] to incorporate uncertainty in population estimates, to produce models for deriving abridged and complete mortality and fertility age patterns, and to reconcile the various demographic components of change to reconstruct coherent populations by age, period and cohort from 1950 to 2020. The virtual nature of the meeting allowed for reaching a larger audience: in total, the meeting brought together between 60 and 70 participants, depending on the session.

The three sessions of the meeting focused on key methodological choices the Population Division needs to make in order to produce the *World Population Prospects 2021*. Some of the core issues addressed during the meeting were the choice of the most appropriate methods available to model robust annual time series for mortality and fertility indicators; the evaluation and modelling of adult mortality in countries with deficient or lacking vital registration systems; the modelling of abridged and complete age

[1] https://population.un.org/wpp/
[2] Until the 2019 revision, the population estimates and projections in the WPP were produced using the "5 by 5" framework, whereby populations were estimated and projected by five-year age group and sex, and by five-year time interval.
[3] Transforming our world: the 2030 Agenda for Sustainable Development. Resolution adopted by the United Nations General Assembly on 25 September 2015 (A/RES/70/1).
[4] http://gather-statement.org/
[5] Child, adult and old-age mortality, fertility and international migration.

patterns of mortality and fertility; and best practices for population reconciliation and demographic balance.

This report summarizes the main points from each session, highlights cross-cutting themes and presents a set of recommendations. The materials from the expert group meeting can be accessed on the following web location: https://www.un.org/development/desa/pd/events/expert-group-meeting-methods-world-population-prospects-2021-and-beyond.

II. SUMMARY OF SESSIONS

A. WELCOME

Mr. John Wilmoth, Director of the Population Division, expressed his appreciation to all participants for joining the meeting, despite the challenges posed by COVID-19. World Population Prospects (WPP), initiated in 1951, was one of the most important publications of the Population Division. The WPP, an authoritative source of information on population trends and characteristics, was used to estimate many of the indicators developed for monitoring the implementation of the Sustainable Development Goals (SDGs). Mr. Wilmoth presented key features of WPP 2019 as well as the upgrades planned for WPP 2021. In particular, he focused on the most challenging one: moving from five-year age group and sex, and five-year intervals (5x5) to a single age and sex, and one-year intervals (1x1) for the estimates and projections of all the components of demographic change, that is fertility, mortality and international migration, in the cohort component framework.[6] The upgrade needs to ensure that the demographic equation balance is consistent for each single year and single age. The goal is, on one hand, to support United Nations entities who need single year and single age data,[7] and on the other hand, to provide users with more open, transparent and replicable data. Population estimates and projections need to use the best available methods and protocols. The Division should make this work as efficient, reliable and sustainable as possible. Mr. Wilmoth stressed the challenges due to the COVID-19 pandemic. The lack of resources made the contribution by participants in this meeting even more crucial.

B. SESSION 1

1. Towards a more transparent and reproducible World Population Prospects

Mr. Patrick Gerland, Chief, Population Estimates and Projections Section, gave an overview of the upgrades made in past rounds of WPP and the challenges that needed to be addressed in the next phase, especially concerning estimations. Member States requested more transparency regarding the empirical data and sources used. A better documentation of the methods used to derive the demographic estimates for each component and the reconciliation with total population estimates was needed. In addition, a growing number of users demanded annual data by single year of age.

Mr. Gerland indicated the elements of WPP which were already compliant with the Guidelines for Accurate and Transparent Health Estimates Reporting (GATHER), those elements that would be addressed as part of the 2021 revision, and the ones that would be targeted in future revisions. The goal would be to provide greater access to information on methods, underlying empirical data and statistical

[6] United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Population Prospects 2019: Methodology of the United Nations population estimates and projections*. (ST/ESA/SER.A/425). https://population.un.org/wpp/Publications/Files/WPP2019_Methodology.pdf
[7] For instance, the United Nations Educational, Scientific and Cultural Organization (UNESCO) requires population estimates by single year of age to prepare its educational statistics.

analysis, and to engage in greater interaction with national statistical authorities and other data producers and users. In the short term, the Division would produce "1x1" estimates and projections, streamline the use of the available information, ensure access to empirical data for some demographic components of population change (fertility, mortality), and achieve greater compliance with the GATHER framework. He also highlighted the limited time and resources available. Mr. Gerland gave an overview of the inventory (Data Catalog) and repository (Data Archive) of the data sources used for the compilation of WPP as well as the database (Demo Data) used to store and update the contents. The dissemination platform (Data Portal), which was still under development, would give access to both estimates and projections together with the underlying empirical data in tabular forms and interactive visualizations. Mr. Gerland illustrated the compilation process of the WPP estimates, starting from the country data, then moving to the initial estimates for each demographic component, evaluation and analysis, and finally the population reconciliation and generation of the final output.

Given the tight production schedule for WPP 2021, Mr. Gerland proposed a strategy to address the challenge of moving to one-year estimates, which would entail using probabilistic estimates for countries with very high vital registration coverage (more than 99 per cent since the 1950s) and using the deterministic approach for the remaining countries. The probabilistic approach would be applied to countries with vital registration coverage above 60 per cent in WPP 2023, while countries with vital registration coverage lower than 60 per cent would be included in WPP 2025. These further upgrades, which rely on greater use of advanced statistical methods, would be conditional upon the availability of human and technical resources.

2. World Population Prospects: method protocol

Mr. Peter Johnson, independent consultant, presented his work on the documentation of the WPP method protocol. His work should be considered as a "living" document that would evolve as the project progressed. The protocol focused on each demographic component independently rather than on the overall reconciliation process and statistical modeling. The documentation included several flowcharts representing the steps involved in evaluating and using different types of data sources, methods and time periods and some decision tables that helped to address problematic cases. In discussing future steps, Mr. Johnson highlighted the importance of distilling the correct trends out of the large amount of data available, which very often are "noisy" (separating the signal from the noise), and the need to make as many comparisons as possible with the available data. There was a need to develop tools, well documented and validated, that could be quickly communicated. Mr. Johnson underlined the need for decisions on the reference date of the population estimate, that is, whether to use mid-year or the beginning of the year,[8] as well as on how to take into account the impact of the COVID-19 pandemic on the estimates.

3. World Population Prospects: probabilistic projection models and incorporating uncertainty in estimates

Professor Adrian Raftery, University of Washington, presented his work to develop a probabilistic method for deriving robust annual time series of estimates and projections of total fertility rates (TFRs), taking into account uncertainty. The method[9], based on the *World Fertility Data* (WFD)

[8] Calendar year would be more consistent with other calendar year events.

[9] Liu, P., & Raftery, A. E. (2020). Accounting for uncertainty about past values in probabilistic projections of the total fertility rate for most countries. *Annals of Applied Statistics*, 14(2), 685-705. https://projecteuclid.org/euclid.aoas/1593449321.

database,[10] entails the estimation of the bias and measurement error variance for each type of data. By extending the Bayesian hierarchical model for the TFRs[11], the method includes an extra level to take into account the characteristics of the empirical estimates from the *World Fertility Data* database, in particular the different types of data sources and estimation methods for each country. Estimates were computed using a Markov Chain Monte Carlo (MCMC) method, which resulted in annual time series of estimates of the TFRs for all countries, with uncertainty about the past, and accounting for estimation uncertainty in projections.

Professor Raftery presented two country examples, one for a country without good vital registration data (Nigeria) and one for a country with good vital registration data (Hungary). The first example showed how the uncertainty increases going back in time, when data were scarcer. The second example highlighted how the one-year curve followed more closely the vital registration data compared to the WPP curve using five-year data. In future, this work could focus on how the current method for decomposing TFR for five-year age groups based on convergence to low fertility age patterns could also be applied to one-year age groups. While his presentation focused mostly on fertility, the same approach could also be applied to mortality. The current method for converting probabilistic life expectancy forecasts to age-specific mortality of five-year age groups using the Lee-Carter or the pattern of mortality decline (PMD) method could also be applicable to one-year age groups. The probabilistic population projections should be available in a "1x1" format by applying the cohort component method to the obtained outputs of mortality and fertility. Eventually, it could be possible to also incorporate uncertainty in the migration component, replacing the deterministic migration assumptions currently used in the WPP.

Following a question about the sequence of first estimating total fertility rates and then breaking down the series into age-specific fertility rates, Professor Raftery responded that the Division had a long history of producing projections following this strategy, and that the approach had proven to work well. In particular, when doing scenarios, this approach allowed for preparing different combinations of "what if" assumptions for the fertility level and the age pattern of fertility.

Ms. Hana Ševčíková, University of Washington, informed the meeting on the progress of work to updating the R packages *bayesTFR*, providing a set of functions to produce probabilistic projections of the total fertility rate (TFR) for all countries, and *bayesLife*, making probabilistic projections of life expectancy for all countries of the world using a Bayesian hierarchical model, which was already used for WPP revisions with data by five-year period. Ms. Ševčíková presented the changes required in the parameters of the model for the package *bayesTFR* to handle annual input data. Results of initial tests using three simulations had indicated that the annual fertility projections were likely to have less uncertainty than the projections based on five-year data as in the 2019 revision of the WPP, especially for countries with declining fertility above replacement level. Results from the annual model did, however, not take into account additional autocorrelation in the residuals. Furthermore, Ms. Ševčíková noted that the Markov chain Monte Carlo (MCMC) method did not perform well with interpolated data: series often did not converge, whereas the double-logistic fit for one-year data could be different from the fit for the five-year data, resulting in two different medians. Two possible solutions were proposed. First, the annual model could be modified to capture the additional autocorrelation using annual projections based on the WFD database with the possibility to adjust the trajectories so that the one-year median would match the

[10] United Nations, Department of Economic and Social Affairs, Population Division (2019). *World Fertility Data 2019*. POP/DB/Fert/Rev2019.

[11] Alkema, L., Raftery, A. E., Gerland, P., Clark, S. J., Pelletier, F., Buettner, T., & Heilig, G. K. (2011). Probabilistic projections of the total fertility rate for all countries. *Demography*, 48(3), 815-839. https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3367999/.

five-year median. Alternatively, analysts could continue using the five-year model for estimation and projection and interpolate then each trajectory to obtain the annual time series, ensuring that the one-year medians and intervals would match the five-year ones.

Ms. Ševčíková then turned to the work done on the R package *bayesLife*, which was being used to generate the projections for life expectancy at birth. This work was still under development. The current model would need to be modified including changes in the prior distribution of the two parameters maximum increment and long-term increment. There was still a need to assess whether the autocorrelation was captured correctly, whether uncertainty was underestimated, and whether the gap model should be revised. Ms. Ševčíková provided a solution similar to the one for the fertility model: instead of annual projections, each trajectory could be interpolated from the five-year model. She then considered the R package *bayesLifeHIV*, which was being developed for estimating and projecting life expectancy at birth within the context of the HIV epidemic. To continue her work, Ms. Ševčíková required annual data on past HIV prevalence, trajectories of future HIV prevalence for uncertainty assessment, and past and future anti-retroviral treatment (ART) coverage.

Ms. Ševčíková observed that the R package *MortCast*, used for estimating and projecting age-specific mortality rates, already had many functions which had been programmed to work with one-year age groups. It would be relatively easy to adjust those functions that did not yet work well with annual data, provided that additional data and information would be made available by the Division.

Ms. Ševčíková referred to the changes needed in the R package *bayesPop*, which was used for projecting the total population. Once the package *MortCast* had been updated, it would be relatively straightforward to produce "1x1" projections of total population. She underlined the need for different R packages to use similar code to compute the cohort-component method as well as for updating the method for projecting age-specific fertility rates. Work to include probabilistic projections of migration was in advanced stage.

To conclude, Ms. Ševčíková highlighted the computational challenges arising from the upgrade to "1x1" projections. In particular, computation time and the amount of data generated would increase by a factor of 25. She suggested, for the time being, to continue producing the "5x5" probabilistic projections in order to ensure upward compatibility and to allow for comparing results. The "5x5" probabilistic projections would also serve as backup.

In the ensuing discussion, it was observed that among the two solutions provided for the TFR projections, the second one, entailing the production of TFR projections for five-year periods and then interpolating the results in order to derive the one-year estimates, was preferable, due to the fact that five-year data are more reliable and suffer less from bias than the one-year data.

4. Modelling robust time trends for fertility and mortality rates

Professor Leontine Alkema, University of Massachusetts, presented some lessons learnt from developing the Bayesian B-spline Bias reduction model (B3) model and from its application in modeling time trends for various outcomes. The B3 model allows for accounting for data errors, including biases and sampling and non-sampling errors, and offers a flexible trend-fitting method.[12] A first important lesson was that 90 per cent of the time to develop the model was spent on only 10 per cent of the country-

[12] Alkema, Leontine and Jin Rou New (2014), "Global estimation of child mortality using a Bayesian B-spline Bias-reduction model", *Annals of Applied Statistics* 8(4): 2122–2149. doi:10.1214/14-AOAS768.

years, mostly addressing issues related to small countries, to the earliest years (around 1950), and to the selection of data.

Professor Alkema explained that the B3 model consisted of a process model and a data model. The process model provided a summary of underlying processes, such as the trend in mortality rates over time. The data model captured the measurement process, which was the place where biases and measurement error in the data collection process, that is sampling and non-sampling errors, were accounted for. She then presented some important components and characteristics of both models and discussed some options to reduce the duration of computing hierarchical models for all countries and areas. One option would be to produce a 'one-country' model. She concluded by acknowledging that the current B3 model would require further adaptation before it could be applied to the 2021 revision of WPP, noting that a model with both smoothing and systematic components would be useful for countries where data quality and availability had improved over the period of estimation (1950 to today). In building the data model component, it would be important to think about what data should be excluded, as well as what biases and non-sampling errors should be considered.

Questions and comments from participants focused on the use of the smoothing and structural components of the model for estimation and projection, especially in the context of accounting for fertility or mortality reversals or stalls. The use of a single model for both the estimation and projection of demographic indicators was discussed and recommended for future WPP revisions.

Ms. Fengqing Chao, King Abdullah University of Science and Technology, shared her experience in developing and applying the B3 model for time trends in mortality differentials by sex, income, or urban/rural. For example, the B3 model developed for the estimation of sex-specific infant and child mortality rates had two components: a process model and a data model. The process model for both infant and child mortality was composed of a global model and country-specific multipliers. The global model uses a spline with a penalty on the second-order differences of the coefficients. The country multipliers captured the deviation from the global trend in specific countries and were modelled hierarchically. Ms. Chao highlighted that B-splines were important for model fitting and that the lengths of intervals between splines affected the smoothness and computation time. On one hand, shorter interval lengths produced smoother estimates, but also required more parameters to estimate and longer computation time, whereas longer interval lengths had the opposite effect. The splines were set to be constant outside the lower and upper limits of the mortality rates set in the model. Ms. Chao observed that it had been useful to work on developing the model for a single country before expanding it to a global model. She also referred to the potential benefit of using alternative approaches such as Integrated Nested Laplace Approximations (INLA) to speed up computation time.

Professor Jon Wakefield, University of Washington, discussed modelling of age-specific mortality rates from summary birth histories derived from censuses and full birth histories obtained from household surveys, which provided health and demographic indicators at subnational level in low- and middle-income countries. Most of the input data was collected by household surveys and population censuses, which were available at different temporal and spatial scales, and for different age groups. Professor Wakefield covered different aspects related to data aggregation, including options for computing (including the use of Template Model Builder (TMB) language to implement INLA models that are not supported in *R* software environment) and reproducibility of results. He stressed the importance of accounting appropriately for the sampling design effects when using survey data. Many surveys used complex stratification and clustering designs. Failure to account properly for these points could lead to biased estimates. Whereas the most generally used form for spatial models was a continuous Gaussian process model, a discrete model allowed for easier adaptation and aggregation of data to higher geographic levels. He recommended using generative models using raw, collected data rather than models for log-rates or log-counts. In this way, biases and errors in data sources could be modelled appropriately and rates and counts could be derived from the results. Models should, ideally, be full probability models specifying probability distributions on all relevant parameters. Professor Wakefield highlighted the use of novel methods to ensure that the information about uncertainty was presented along with point estimates, including by using maps. For example, two-tone choropleth maps could be used to ensure that the probability of any point was correctly being classified reaches at least a threshold number to be statistically significant. This can help protect against overinterpretation of results, particularly for regions with few data points and high uncertainty. Professor Wakefield concluded his presentation with some general comments regarding the benefit of having new methods published in statistical journals first in order to have them vetted by the statistical community, and the usefulness and appropriateness of approximation when done within a wider, rigorous probabilistic framework. As many of the data used as covariates were outputs of models themselves, treating such covariates as data might not be appropriate. While acknowledging the appeal of flexible machine learning methods, he observed that accounting for uncertainty in these frameworks might not be easy.

The notion of geographic distance and its appropriate use in demography was briefly discussed. Geographic proximity of countries was not always associated with similarity on demographic parameters. For example, in TFR modelling, a common colonizing country was a stronger factor explaining similarities between countries than geographic proximity. Professor Wakefield acknowledged that distance might not always be the right metric to use in demography. At the subnational level, the focus of his work, urban-rural stratification was important to take into account.

Lastly, Mr. Oliver Stevens, Imperial College London, focused on the modelling of age-specific fertility rates from full birth histories obtained from household surveys. Mr. Stevens shared his experience in modelling district-level estimates of age-specific fertility to be used in the estimation of HIV prevalence among children. The data for his estimate were obtained from Demographic and Health Surveys (DHS), Multiple Indicator Cluster Surveys (MICS) and other household surveys that provide full and summary birth histories. Challenges related to non-sampling biases included the omission and displacement of births, and the availability of data at different spatial resolutions. Bias due to displacement of births is common when the survey instrument includes some extra set of questions that triggers a longer survey questionnaire (e.g., more in-depth interview for children less than five years old). These effects can be improved by looking at other surveys that provide information about the same parameters for the same cohorts of women. In order to account for some of these biases, Mr. Stevens reported that a statistical model was being developed to deal with these various systematic and non-systematic (smoothing) components on age and time, as well as interactions between them. Mr. Stevens agreed with previous speakers that using Template Model Builder (TMB) greatly reduced computation time.

The discussion that followed focused on the transition to an “1x1” framework for the WPP2021 and priorities for the Division. Consensus was reached on the importance of accounting for non-sampling biases in the modelling. Another point discussed concerned the best approach for countries for which data are lacking in the estimation period starting in 1950. The use of covariates was acknowledged as potentially problematic. Some participants recommended a hierarchical modelling approach.

C. Session 2

1. Adult and old-age mortality: data evaluation and modelling for countries with deficient or no vital registration systems

The adult and old-age mortality section started with the presentation of Professor Hiram Beltrán-Sánchez, University of California, Los Angeles, presented data and methods used to assemble the Latin American Mortality Database (LAMBdA). He highlighted that very few countries in Latin America had implemented both censuses and vital registration before 1930, but that in more recent years, most countries had collected both types of data. He also pointed out that national statistical offices in the region have used different upper open age group over time (e.g., from age 60 and over), a key reason for the need to correct mortality data. Prof. Beltrán-Sánchez explained the three approaches used to adjust adult mortality rates according to the availability of census and death registration data. The techniques used are based on a simulation study that combines different demographic profiles of fertility and mortality with several distortion patterns driven by coverage of population and deaths and by age misreporting. Illustrations for the decision points to construct LAMBdA life tables before 1950 and in most recent years, where more data is available, particularly information on mortality under five years old, which allows the use of more statistical techniques, were presented. The procedures used to correct the data for Latin American countries were less sensitive when all the simulated errors were present. Participants raised several technical questions regarding the number of censuses used in the assessment of the coverage, the reasons to focus on correcting for age misstatement at older ages and not adult ages, how migration was accounted for, and if similar patterns of gender differences in completeness were found throughout Latin America.

Professor Bruno Masquelier, Catholic University of Leuven, Belgium, presented his experience in estimating mortality among youth and other young people. The B3 model, which had been used extensively to estimate under-five mortality, was recently applied to estimate mortality for ages 5-15. It was also currently employed to model mortality for ages 15-25. He presented data sources used to model the mortality among adolescents and young people aged 15-24. The database storing these estimates is similar to the United Nations Inter-Agency Group for Child Mortality Estimation (UN IGME) database for modelling trends in under-five mortality rates and mortality in children aged 5-14.[13] Prof. Masquelier stressed that sibling histories from surveys rather than birth histories were used, which resulted in fewer data points. He discussed the procedure to assess the completeness of vital registration for age five and above and presented the completeness of death registration for the latest intercensal period for countries and areas with available data. The use of the B3 model helped to produce smooth estimates for 195 countries from 1990 to 2020 without the inclusion of covariates. The death probabilities were split into 5-14 and 15-24 age ranges and adjustments were introduced for conflicts and disasters, based on the WHO estimates. Prof. Masquelier acknowledged that a possible disadvantage of using the siblings' history is the underestimation of mortality, particularly in earlier retrospective periods. Besides, he illustrated that the B3 model could not be used to estimate the mortality from age 10 to 15 in some countries because of the paucity of information from vital statistics, censuses or surveys. He concluded that the B3 model could be used to estimate adult mortality from age 15 to 50 in future releases of WPP and suggested its use to estimate age-specific probabilities separately. Following a question about the absence of data for the time period around 1950, he noted that hierarchical statistical models such as the B3 would allow to produce estimates without the need to use covariates.

[13] https://childmortality.org/

Mr. Ayaga Bawah, University of Ghana, gave an overview of the Health and Demographic Surveillance System (HDSS) approach and the experience with applying the system in some African and Asian countries. Mr. Bawah indicated that the HDSS consisted of implementing a census and then following up demographic events in certain areas over time. This method allowed for enables monitoring progress of various SDGs indicators. HDSS data produced data to estimate incidence rates of diseases and to develop plans at the local level. Mr. Ayaga presented the case of the Navrongo district in Ghana, where HDSS data have allowed to estimate child mortality since 1996, making possible the identification of the leading causes of deaths in this subpopulation. The case of Navrongo demonstrated that mortality rates derived from censuses are highly correlated with the ones calculated using the HDSS information. Mr. Bawah concluded that HDSS data would help to fill some data gaps in low- and middle-income countries, providing further inputs for modelling age patterns of fertility and mortality over time. Also, HDSS data could help to analyze the causes of mortality more extensively over time.

Professor Hong Mi, Zhejiang University, Hangzhou, China, illustrated his work in estimating mortality as part of the Developing Countries Mortality Database (DCMD).[14] As deaths above age 60 in the less developed regions are currently estimated using model life tables, a more accurate estimation of old-age mortality would diminish the bias in the estimation of total deaths. Prof. Mi explained that the life tables are based on empirical estimates of child, adult, and old-age mortality using a three input parameter model life table. Prof. Mi discussed the trade-offs between the preservation of age patterns of the original abridged life tables and the smoothness of the functions of the complete life table for estimation of mortality. While the method did not incorporate the effect of the HIV/AIDS epidemics, the differences were minimal between death rates from the original life table and the ones estimated from the constructed life table for a country like Malawi. However, in the case of countries experiencing mortality crises (e.g., Rwanda genocide in 1994), the death rates calculated from the constructed life tables were less accurate, particularly at ages younger than 15.

The first part of the session concluded with a general discussion on the recommendations for the estimation of adult and old-age mortality, especially in regard to the application of the death distribution methods for countries with vital registration data. The importance of accounting for the effect of migration was acknowledged, as well the need for a recommended standard approach for the selection of the best age range on which these methods should be applied.

2. *Modelling of age patterns: abridged and complete age distributions*

Professor Samuel Clark, Ohio State University, reported on his work to design a standard modelling framework for age-specific mortality rates and for estimating complete life tables.[15] In doing so, Professor Clark highlighted the importance of incorporating the mortality impact of HIV/AIDS into the model through summary indicators, the rotation at older ages and low mortality as in the Li-Lee Carter method, and the possibility of using the Single Value Decomposition (SVD) component model for smoothing, interpolation and extrapolation. The project aims to set up a database of empirical single-year age-specific mortality rates, including information on adult HIV/AIDS prevalence and treatment coverage, and then to use these data to calibrate and validate the SVD-component model. The next steps of this project are to create a software to implement and recalibrate the SVD-component model, and then to develop an estimation method to use the model in reverse. Professor Clark briefly illustrated the SVD-component framework and described the three types of empirical datasets compiled to construct life

[14] http://www.lifetables.org/

[15] This work is carried out in collaboration with the Population Division (Mr. Patrick Gerland and Ms. Sara Hertog), Mr. Brian Houle (Australian National University), Mr. Jonathan Muir (Ohio State University) and Mr. Jason Thomas (Ohio State University).

tables. In cases of countries with high HIV prevalence, the Spectrum model produced simulated life tables for several levels of HIV prevalence and treatment coverage. He also recommended using information from the network for Analyzing Longitudinal Population-based data on HIV/AIDS in Africa (ALPHA Network). He illustrated how a DHS life table could be extended beyond age 50 and he presented examples of Spectrum simulated data.

During the discussion, it was suggested that, given the wider availability of data, the model use the probability of dying between age 15 and 50 (${}_{35}q_{15}$) rather than the probability of dying between age 15 and 60 (${}_{45}q_{15}$). In response, Professor Clark observed that work to use ${}_{35}q_{15}$ was currently under way. Another point was raised on the simulation of specific HIV/AIDS-related parameters used in the modelling process and if the extension of the life table beyond age 50 based on DHS data was affecting the results of the modelled mortality at younger ages. Professor Clark confirmed that the HIV/AIDS-related parameters were included in the model and that the extension of the life table did not affect the mortality estimation at younger ages. Finally, in answering a question related to the computation of the uncertainty of the model, he noted that the uncertainty can be dealt through the statistical modelling.

Professor Carl Schmertmann, Florida State University, presented his work on modelling fertility age patterns. The objective of his model was to find a continuous fertility schedule that matched age group data and looked similar to schedules from a large calibration database. He pointed out that there was a trade-off between those two conditions, however, and that his model was not intended to match age group data. The purpose of his model was to estimate a continuous fertility schedule using age-group fertility data and extrapolating this information outside the standard age-range. He explained the estimation of the different components of his model and presented two continuous fertility functions to illustrate the trade-off between the shape and the fit of the model. Two challenges of the model included the potential for negative values of the fertility function at the youngest and oldest ages and possible inconsistencies between the estimated age-specific fertility rates and the total fertility rates. He suggested several options for modelling in the context of the next WPP, emphasizing that the method for calibrating the shape component might be the most critical choice to estimate the continuous fertility function. Following questions from the participants, Professor Schmertmann specified that his model was using fertility rates for five-year age groups as input and that it could be used to derive single-year rates for projections once the total fertility rate and the abridged age-specific fertility rates were projected.

Professor Bruno Schoumaker, Catholic University of Leuven, presented a method to compute single-age fertility rates estimates, including under age 15, using full birth history form surveys and HDSS. The first step consisted in harmonizing the data from the various fertility surveys. He presented computations of births and exposure by age and year as well as fertility rates and standard errors. Professor Schoumaker discussed the procedure for calculating single-age fertility rates at age 20 for the ten years preceding a survey, stressing that this time frame was flexible. Distributions of sampling errors from different samples highlighted the plausibility of the confidence intervals. He illustrated the consistency of age patterns within countries, even between several survey programs and with small samples. He demonstrated the consistency between single-year age-specific fertility rates for some HDSS and DHS data. The method developed by Pantazis and Clark (2018)[16] to model age-specific fertility patterns worked well to smooth and model single-year fertility rates. This approach was based on the principal component analysis (PCA) and used the estimated components and weights to smooth the fertility rates. The approach could also be used to compute past single-age fertility patterns. He presented

[16] Pantazis, A., & Clark, S. J. (2018). A parsimonious characterization of change in global age-specific and total fertility rates. *PloS one*, *13*(1), e0190574.

the results from fitting the model with estimates of fertility patterns from surveys and observed that age 12 was the minimum age to estimate fertility rates using this method.

The second part of the presentation of Professor Schoumaker focused on the estimation of fertility for ages 10 to 14 in developing countries with limited data available for these ages. Using birth histories from several surveys, fertility rates for women aged 10 to 14 can be reconstructed for several past periods using a Lexis diagram. The reconstructed three-year fertility estimates were consistent with estimates derived from the DHS. By contrast, the three-year fertility estimates differed significantly from estimates provided by the Global Burden of Disease (GBD) which are not consistent with empirical data. Fertility rates for women under the age of 15 in Senegal, computed from HDSS data, were consistent with both the reconstructed three-year fertility estimates and DHS estimates. Professor Schoumaker concluded that his methodology produced reliable fertility trends over a longer period of time than from each DHS alone and that it allowed for the inclusion of a broader set of countries compared to the Human Fertility Collection, produced by the Max Planck Institute for Demographic Research and the Vienna Institute of Demography.[17]

During the discussion, the issue of adopting a bottom-up approach for the estimation of demographic indicators in WPP, rather than the top-down approach currently used, was raised. A bottom-up approach, which would allow for the estimation and projection of level indicators such as the total fertility rate based on their age-specific components, could be followed in the case of countries with robust data.

D. SESSION 3

1. Population reconciliation and demographic balance

The first part focused on the presentation of different experiences in reconstructing population and assuring the demographic balance. Presentations were based on a classic deterministic approach.

Ms. Helena Cruz Castanheira, United Nations Economic Commission for Latin America and the Caribbean (UN-ECLAC) presented the experience of the Latin American and Caribbean Demographic Centre (CELADE) in producing annual population estimates and projections by single age. CELADE has been collaborating with the Population Division for estimating and projecting national populations of about twenty countries since the 1960s. Ms. Cruz Castanheira shared some of the challenges faced by CELADE in producing annual single-age population estimates and projections. A first challenge was related to the fact that the disaggregation of data by single year and single age can result in more erratic variations. A second and related challenge was the difficulty to distinguish real changes in population trends and patterns from anecdotal or erratic variations in the underlying data. Data from other sources, including school enrolment and immunization campaigns, could help to validate any observed fluctuations. A third challenge was related to the issue of under-enumeration of the census population. Many countries published adjusted census results, without making available the non-adjusted data or detailed information on the type of adjustment made. Ms. Cruz Castanheira concluded her presentation with a series of recommendations to reconstruct in a consistent way the population, using the best available information and state-of-the-art demographic knowledge, keeping in mind that the true population would remain an unknown component. She reminded that the work of analyzing and evaluating data quality, conducting demographic reconciliation, and producing population estimates and projections is a complex undertaking and that it required advanced technical demographic competencies.

[17] https://www.fertilitydata.org/cgi-bin/index.php

Ms. Cruz Castanheira confirmed that the estimates produced by CELADE were similar to those of WPP, but that for some countries, the projections produced by CELADE differed from those of WPP. Further clarification on the assistance work of CELADE to National Statistical Offices in the region was also provided. The estimates and projections prepared by CELADE are first produced based on a 1x1 framework before computing 5x5 estimates and projections. In some cases, CELADE assisted countries in analyzing population data at the subnational level.

Ms. Nobuko Mizoguchi and Mr. Sean Fennel presented the experience of the Population Division of the United States Census Bureau in the field of population reconstruction and demographic balance as part of its international programme for training and statistical development. Ms. Mizoguchi introduced the Demographic Analysis and Population Projection System (DAPPS) software, a methodological tool developed to assist countries in the production and analysis of population projections. Work to implement DAPPS in R was in progress. Different features of DAPPS were presented, such as the ability to run annual single-age cohort-component population projections, options of data input and data output, as well as the capability to analyze fertility, mortality and migration data and store the results as future inputs for projections. The US Census Bureau had conducted training in over 70 countries. Some countries were using DAPPS to produce national population projections. Ms. Mizoguchi noted the many challenges that remained in the preparation of demographic estimates, especially in countries with few or deficient data as well as at sub-national level.

Mr. Tim Riffe, Max Planck Institute for Demographic Research, presented his work related to the development of the DemoTools R package—a set of demographic methods for data evaluation, transformation and adjustment. The objective of the DemoTools R package is to offer a standard set of tools to process input data at country level. The package is organized in a sequence of demographic methods that can be used programmatically for greater analytical reproducibility. An open collection of classic demographic methods was available, including common demographic operations and utilities. The evaluation methods consisted of age-related checks, such as age heaping, as well as consistency checks, including census survival ratio errors, age- and sex-ratio scores, and difference and dissimilarity indices. Data could be adjusted through graduation or smoothing and transformed through various techniques, including binning, scaling, truncation, time shift with age period, age cohort and interpolation. Additional transformations were available for specific input data, such as a life table that could be abridged, complete, extrapolated or transformed following rule and model-based criteria. DemoTools also offered the possibility to fit models to data, such as a Rogers Castro model to estimate an age pattern of migration. Further development and additions of the package were planned, such as the inclusion of the reverse survival method of fertility estimation, cohort component interpolation, other consistency adjustments, rule-based method selection, faster life table computation, as well as the development of tutorial materials and the conduct of training workshops. The set of techniques and methods included in DemoTools as well as in the method protocol covered many of the techniques and methods that have been used in past revisions of WPP. Mr. Riffe suggested, as a next step, develop a set of rules and criteria to operationalize the use of these procedures and other additional methods in a standardized sequence. Such proposition would ultimately contribute to make the production of WPP estimates more efficient, transparent and reproducible.

The second part of the session addressed probabilistic approaches to population reconstruction.

Mr. Mark Wheldon, Population Division, presented his work on Bayesian demographic estimation and population reconstruction. After offering an overview of the estimation process used for WPP, Mr. Wheldon introduced the principle of Bayesian population reconstruction, along several modelling parameters and notations. The Bayesian population reconstruction was proposed as an improved method for reconstructing populations in the recent past. The objective of the method was to quantify uncertainty probabilistically, estimate all parameters consistently, be easily replicable, and use all reliable data as well as expert opinion. Mr. Wheldon explained the four levels of the hierarchical model used to reconstruct population and demographic components to account for several types of data, variance and measurement errors. This approach was considered most useful for countries with unreliable, fragmentary data (high uncertainty), but could also be applied to countries with very good data. The cases of Laos and New Zealand were presented to illustrate the application of the model. The results for these two countries were compared to WPP estimates in order to check their consistency. The outputs of the model provided joint posterior distribution of the inputs and 95 per cent credible intervals for input parameters and the various output summary quantities. Mr. Wheldon observed that the computation speed for the Bayesian population reconstruction model to be used in WPP needed to be fast. This could be a challenge with single-year age and time. Mr. Wheldon stressed the need to expand the data collection to account for all the population censuses undertaken since 1950. Extensive testing would be required in order to use the method for WPP.

Mr. John Bryant discussed the use of Bayesian demographic estimation to infer counts from both reliable and unreliable data sources. He explained that an important advantage of Bayesian methods was the capability to model units that are comparable but not identical. These methods can combine uncertainty from different sources, including missing data or random variation in the datasets with uncertainty about future trends. Mr. Bryant provided three illustrations to demonstrate the increasing complexity of analyzing demographic data. The first framework illustrated the use of reliable data, for which measurement error is negligible and the coverage is complete (e.g. registered births or deaths in high-income countries). The methodological challenge for statistical demography in those circumstances relates to the estimation of disaggregated rates and forecasting. The second framework referred to the estimation of demographic arrays from unreliable data, that is, when data are affected by substantial measurement error, when coverage is incomplete, and when data gaps, missing variables or incorrect values are present in the dataset (e.g. migration data in high-income countries, and most fertility, mortality and migration data in low- and middle-income countries). In such cases, not only standard methodological challenges needed to be faced, but corrections for data gaps and for measurement and coverage errors needed also to be accounted for. The data model needed to predict data given true counts (e.g. predict census counts, given true population counts, or predict registered births, given true birth counts). The model is a formal representation of what a demographic analyst knows about the data, the magnitude of errors and how the errors vary with age, sex, region, time, etc. When predicting data from true counts, it is easy to deal with data gaps. To illustrate the prediction of age-specific fertility rates, Mr. Bryant used provincial census and DHS data in Cambodia. He then discussed some advantages (easy aggregation, flexibility to absorb data sources) and challenges (computations) related to this approach. The third framework referred to the estimation of demographic counts and rates from unreliable data. In this framework, the entire demographic system needed to be estimated (e.g. national population with births, deaths, and migration; employed, unemployed, or not in labour force; disease susceptibility, infection and recovery), including counts and rates. In such settings, data were affected by measurement error and coverage was incomplete. Mr. Bryant called such approach demographic accounts, the social equivalent of the national accounts, providing an example of demographic accounting for New Zealand between 1996 and 2018. The approach required data on total population, births, deaths, immigration, and emigration, by single age, sex, period and birth cohort. This approach offered unusual features, particularly in terms of flexibility about the components and dimensions, allowing translation between cohort and period. The approach also allowed the use of priors on population series and not just the initial population. Mr. Bryant discussed also the use of such approach for estimating population data for countries with limited or no data for time periods close to 1950. The Bayesian demographic account approach can also be of interest for demographic historians that rely on rough estimates of population size and growth and infer possible combinations of birth and death rates. Mr. Bryant concluded his intervention by sharing some thoughts on the demographic inference from unreliable data. Based on his experience, data models must be simple, whereas system models can be surprisingly complicated. Mr. Bryant reckoned that using estimates made by others as input data was 'bayesianly' correct and offered important practical advantages: there was no need for the original data or to repeat the analysis done by others. Treating estimates as input data could be very useful in some distinctive cases. Finally, the use of prior information when data are unreliable allowed to summarize the information about dimensions beyond the data itself (e.g. how data were generated) in a quantitative way (e.g. how much province-to-province variability to expect). Such approach offered big improvements in convergence and plausibility of the estimation.

Mr. Jeff Eaton, Imperial College London, shared his experiences in working with the UNAIDS Reference Group and with HIV/AIDS-affected countries in sub-Saharan Africa. Mr. Eaton explained that the methodology for HIV/AIDS estimates and projections for adults and children was a 1x1 multistate cohort component population projection model that was a part of the Spectrum software. Spectrum models the whole process starting from the HIV infection, the progression through stages of HIV infection, and the treatment. The model can be applied at national and provincial ("admin1") level. The demographic estimates and projections of the most recent WPP revision were incorporated as demographic inputs in Spectrum. Mr. Eaton briefly described the main steps related to the use of WPP data for the estimation of HIV/AIDS. First, WPP data needed to be interpolated into annual single-age data. Second, a life table from which the effect of HIV has been removed ("non-HIV life table") was derived through an iterative process. Finally, once the AIDS-related deaths by age and sex had been estimated, a procedure was applied to match the life expectancy at birth of WPP. Based on the experience of UNAIDS in assisting countries to produce their own HIV estimates, a frequent request was to change the default population to match national sources. Different reasons explained these requests: new data (e.g. the results of a new population census) may have become available and could not be incorporated in the WPP-based default inputs in Spectrum; countries perceived some deficiencies in WPP estimates; subnational estimates were not consistent with national estimates; political imperative to reflect the population estimates produced by the national statistical office, irrespective of methodological consideration, data inconsistencies between population components, or reluctance to acknowledge bias present in national official data. Mr. Eaton noted that some of the changes proposed for WPP2021, in particular improved visualization, transparency and reproducibility, would help countries to adopt WPP estimates as default input parameters in Spectrum. Mr. Eaton recommended also the alignment of WPP methods and tools with training and technical assistance for national statistical offices. He then reviewed some of the issues he had found in population censuses conducted in sub-Saharan Africa based on a comparison with population reconstructions available in Spectrum, WPP and the Global Burden of Disease (GBD). Using the 2014 population census of Guinea and the 2007 population census of Mozambique as examples, Mr. Eaton noted that many population censuses enumerated fewer men in working age group (25-44) than the population reconstructions.

Mr. Eaton described the main priorities of the UNAIDS Reference Group, namely harmonization of model simulation code across all current HIV/AIDS estimation models (e.g. single open-source code), harmonization of data input to Spectrum, review of natural history parameters (e.g. untreated disease progression and mortality parameters, review of evidence of HIV mortality among untreated adults), and routine review and revision of data about AIDS mortality. Mr. Eaton shared the initial steps that are currently being taken. He mentioned the use of Template Model Builder (TMB), its characteristics, advantages and current usage.[18] Mr. Eaton showed an illustration of a TMB implementation for reconstructing the female population of Burkina Faso, highlighting the speed of the computation in a 5x5 framework. Mr. Eaton concluded by sharing some considerations for WPP2021. He welcomed the harmonization of demographic inputs and calculations between HIV estimates and WPP. The migration to single-year interval would improve consistency. At the same time, he cautioned against the use of census data in Bayesian population reconstruction, especially for some key age groups (e.g. population 0-4 and working-age adult men in sub-Saharan Africa). Changes in the approach of mortality estimation in high HIV countries in WPP2021 required careful consideration. He supported the greater focus on transparency, visualization and reproducibility in order to promote the adoption of estimates and analysis by countries.

The presentation of Mr. Gabriel Mendes Borges, Brazilian Institute of Geography and Statistics, focused on the estimation of consistent population data. Using data from Brazil, Mr. Mendes Borges provided an example of a probabilistic population reconstruction. The motivation to conduct this reconstruction came from the need to quantify and communicate uncertainty of the available estimates, as well as the need for better (probabilistic) methods to estimate and reconcile inconsistent demographic parameters. To this end, Mr. Mendes Borges combined information from different data sources, while accounting for the uncertainty from random variation and measurement error. Mr. Mendes Borges reviewed the data sources and series of estimates used to derive indicators and measurement error for the total population as well as for fertility, mortality and migration. The inference was conducted in two steps using a Bayesian probabilistic approach. The first step of the modelling approach consisted in estimating the individual parts that make up the balancing equation, that is, population, mortality, fertility and migration. These estimates constituted the pre-model posterior distributions. The second step consisted in reconciling the inconsistent probability distributions using an extension of the Bayesian melding approach. The reconciled distributions served as post-model posterior distributions. Mr. Mendes Borges presented a series of results for fertility, mortality and population by age and sex at the national and provincial level, and for migration by age. Mr. Mendes Borges reviewed some of the lessons learnt from his work. First, working with observed counts, instead of rates, is very useful. Second, it is desirable to use the knowledge about the structure of demographic rates by age when conducting the demographic reconciliation. Third, it is hard to conduct the reconciliation without a direct census evaluation, such as a post-enumeration survey. In this regard, Mr. Mendes Borges noted that developing models for census coverage and quality of age patterns would be helpful. Finally, it was important to conduct sensitivity analysis of the demographic methods in order to assess and adjust for biases and calculate variance of the computed estimates. The Division reported that it had begun compiling data from post-enumeration surveys. While post-enumeration surveys were recommended to be conducted after each census, they were not implemented on a systematic basis. Sometimes, results of the post-enumeration survey were not published. Once compiled, the information would be made available.

Lastly, Ms. Dilek Yildiz, Wittgenstein Centre, Austria, focused on the reconstruction of multistate population and education specific fertility rates using a Bayesian approach. Ms. Yildiz briefly described the two approaches to rebuild past populations, that is, through back projection or reconstruction. The approach taken by Ms. Yildiz was based on earlier Bayesian modelling work by Wheldon et al. (2013),[19] but extended to reconstruct multistate populations and estimate simultaneously

[18] TMB is the software used in the Global Burden of Diseases (GBD) population reconstruction by the Institute for Health Metrics and Evaluation.

[19] Wheldon, Mark C., Adrian E. Raftery, Sam J. Clark, and P. Gerland (2013), "Reconstructing past populations with uncertainty from fragmentary data", *Journal of the American Statistical Association*, 108: 96–110.

population by age, gender and educational attainment, with education specific fertility proportions along with uncertainty around the estimates. To reconstruct multistate populations, she presented the case of Brazil. The model used has three levels: 1) modelling census counts, 2) the cohort component population projection method, and 3) modelling the initial estimates. Ms. Yildiz briefly presented results of (a) estimates of the population count by education level, age and sex, (b) reconstructed fertility estimates by age and education, and (c) survival probability at age 0-4 by sex and education. With the exception of the population reaching secondary education in specific years, the estimated population counts by age, sex and education, produced by the model, accurately reproduced the Brazilian census data. She had used the R packages rjags, dclone and snow for the computations. Ms Yildiz recommended improving the measurement error models by combining different data sources as well as conducting more detailed sensitivity analysis of the results.

During the discussion it was observed that the various statistical approaches presented during this session would take one or two days to complete for one country. Given that WPP2021 required computations for 235 countries or territories, the computation process needed to speed up. This was particularly important with the transition to a 1x1 framework that would require multiple testing and reruns. In regard of migration, further challenges could be expected when running these computations.

III. CONCLUSIONS AND WAY FORWARD

Mr. Gerland summarized some critical observations and key recommendations that had emerged from the expert presentations.

For the first session, Mr. Gerland stressed that the Division welcomed any additional comments, feedback and ideas for improving the WPP method protocol. With regard to the WPP probabilistic projections, a follow-up event would be scheduled once the upgrades of the methods and the software package had been completed. The Division would continue its work on the implementation of a 1x1 framework for estimation and projection. Building on the review of the WPP method protocol that had been conducted during the second half of 2019, a consultant would be hired to review the codes and procedures developed by the Division and its partners. Further work was required for the projections of the total fertility rate and the life expectancy at birth. In particular, further testing was needed to decide between projecting directly annual time series, accounting properly for time autocorrelation or to pursue the past practice of projecting five-year trajectories to derive annual projected indicators through interpolation at a later stage. Mr. Gerland considered that the transition to a 1x1 framework for the estimation and projection while accounting for uncertainty was feasible, but that 5x5 population estimates and projections should continue to be produced as backup and for benchmarking purposes. In terms of modelling robust time trends for fertility and mortality indicators, many useful lessons were learnt from the experiences shared during the meeting. There was need to further explore various specifications (e.g. using both structured and smoothing components) with the data model as well as within a hierarchical framework. He noted the potential benefits of using INLA or TMB and the need to follow-up on some of these substantive issues with a smaller group of experts.

For the second session, the expert presentations had revealed the need for a systematic and comprehensive assessment of the estimation methods of adult and old-age mortality. In addition to the methods, the data and the assumptions, including the age range selected and criteria used, needed to be well documented. Mr. Gerland suggested that a careful review of the literature and of the current implementation of the variants of these methods should be conducted, especially in regard of defining criteria for the selection of the optimal age range for the computation. Based on this review, existing codes, such as the DemoTools R package, would need to be modified accordingly. The experts had noted the benefits of using as many data sources and estimation methods as possible for each country. To this end, the Division would continue to collect as many data sources as possible to inform the estimation of mortality for the 2021 revision of WPP. Further testing and exploration of various model specifications of coherent time trends since 1950 for all countries would be done in follow-up meetings with a small group of experts. The Division was planning to develop statistical models to create robust fertility and mortality time series and systematically apply these models to the empirical data that it had collected. In regard of the graduation and modelling of mortality and fertility age patterns, the availability of national data would determine whether a top-down or a bottom-up approach would be applied. The proposed graduation approaches were primarily applied for estimation purposes. Participants had indicated the need for flexible modelling approaches to leverage various reference datasets, and benefits to recalibrate and validate existing models with expanded datasets for both developed and developing countries. Some smoothing of survey and HDSS data could be required prior to use. The Division would continue its work of collecting micro data from sample surveys in order to compute indicators such as the total fertility rate, age-specific fertility rates, and the average number of children ever born and surviving.

The third session had revealed that more time and resources were required to scale up existing probabilistic methods and approaches for all countries and areas. There was a need to focus on priorities for deterministic and probabilistic statistical approaches for countries with different data systems by upgrading the set of methods available for each of group of countries, based on the type and availability data as well as associated methodological and statistical challenges. This Division welcomed potential collaboration and additional support in this regard.

Given the resource constraints, progress toward a more transparent and reproducible WPP would necessarily be incremental. Mr. Gerland recalled that the short-term goals for WPP 2021 were to (a) move from a 5x5 to a 1x1 framework, (b) streamline and harmonize the steps used to prepare country data and WPP estimates, (c) provide greater access to WPP estimates and underlying empirical data for key demographic indicators, and (d) achieve greater compliance with existing standards. In the long run, for WPP 2023 and beyond, the purpose was to (a) improve access to methods and tools, underlying data and analytical steps used in WPP, (b) increase collaboration, potentially with greater country engagement, and (c) be fully compliant with international standards.

In closing, Mr. John Wilmoth complemented the organizers with holding an effective expert group meeting virtually during this international public health crisis. Upgrading WPP was one of the top priorities of the Division: it was absolutely essential to move from a quinquennial, five-year age (5x5) to an annual, single age (1x1) framework. The proposed transitions would make the production of WPP more transparent and reproducible. Mr. Wilmoth expressed his gratitude to all participants for their contributions and invited participants to continue their collaboration with the Division to address the many challenges related to the production of WPP2021.

ANNEX 1. ORGANIZATION OF WORK

6-8 April 2020

UNITED NATIONS EXPERT GROUP MEETING ON METHODS FOR WORLD POPULATION PROSPECTS 2021 AND BEYOND
Population Division
Department of Economic and Social Affairs
United Nations Secretariat
New York (GMT-5)

Organization of work

Monday, 6 April 2020

	Facilitator: Thomas Spoorenberg	Presenter
9:45	Call in/Resolve connectivity issues	
10:00	**Welcome**	John Wilmoth
10:15	**Towards a more transparent and reproducible World Population Prospects**	Patrick Gerland
10:30	**World Population Prospects: method protocol**	Peter Johnson
10:45	**World Population Prospects: probabilistic projection models and incorporating uncertainty in estimates**	
	Update for annual time series (and single age):	
	Statistical models and methods	Adrian Raftery
	R packages	Hana Ševčíková
11:15	**BREAK**	
11:30	**Modelling robust time trends for fertility and mortality**	
	Lessons learned from the B3 development and application to model time trends for various outcomes	Leontine Alkema
	Lessons learned from the B3 development and application to model time trends in differentials	Fengqing Chao
	Modelling of age-specific mortality rates from census summary birth histories and survey full histories over space and time	Jon Wakefield
	Modelling of age-specific fertility rates from survey full histories over space and time	Oliver Stevens
12:30	**Discussion**	
13:00	**ADJOURN**	

Tuesday, 7 April 2020

	Facilitator: Sara Hertog	Presenter
9:45	Call in/Resolve connectivity issue	
10:00	**Adult and old-age mortality: data evaluation and modelling for countries with deficient or no vital registration systems**	
	Evaluation and adjustments for population and mortality data in Latin America based on LAMBDA experience	Hiram Beltran
	Direct and indirect adult mortality estimates from censuses and surveys	Bruno Masquelier
	HDSS mortality	Ayaga Bawah
	Evaluation and estimates of old age mortality	Hong Mi
11:00	**Discussion**	
11:20	**BREAK**	
11:40	**Modelling of age patterns: abridged and complete age distributions**	
	Mortality age pattern	Sam Clark
	Fertility age pattern	Carl Schmertmann
	Estimation of fertility rates from survey full histories and HDSS	Bruno Schoumaker
12:40	**Discussion**	
13:00	**ADJOURN**	

Wednesday, 8 April 2020

	Facilitator: Patrick Gerland	Presenter
9:45	Call in/Resolve connectivity issue	
10:00	**Population reconciliation and demographic balance**	
	CELADE experience with 1x1 population and demographic estimates	Helena Cruz Castanheira
	US Census Bureau International Branch experience with RUP/DAPPS	Nobuko Mizoguchi & Sean Fennell
	Demographic methods for data evaluation, transformation and adjustments	Tim Riffe
	Bayesian demographic estimations and population reconstruction	Mark Wheldon
	Bayesian demographic estimation and inferring counts from (un)reliable data	John Bryant
11:15	**BREAK**	
11:30	UNAIDS Reference Group and HIV/AIDS countries in SSA	Jeff Eaton
	Consistent Population Estimates: An Application to Brazil	Gabriel Borges
	Bayesian reconstruction of populations and vital rates by educational attainment	Dilek Yildiz
12:15	**Discussion**	
12:45	**Conclusions and way forward**	

ANNEX 2. LIST OF PARTICIPANTS

List of participants

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